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GENERAL ELECTRIC REVIEW

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January, 1922—December, 1922

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GENERAL ELECTRIC REVIEW

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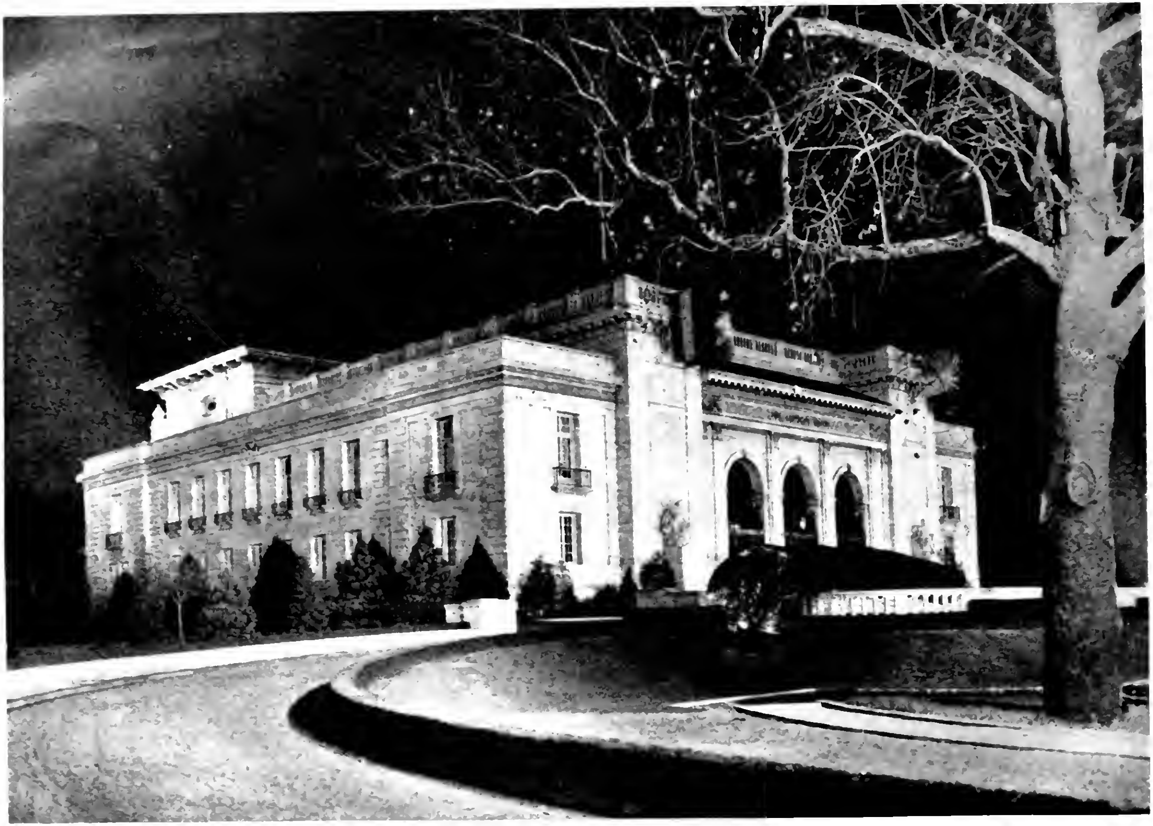

The Pan American Union Building Washington, D. C., Where the International Conference on the Limitation of Armaments is in Session, Illuminated to Celebrate the Convening of the Conference and Armistice Day

GENERAL ELECTRIC
REVIEW

"1922"

The last weeks of 1921 will, we hope, be immortalized in history as a result of the Washington Conference on the Limitation of Armaments. The constructive statemanship of Mr. Hughes' proposals on the limitation of naval armaments among the principal naval powers and the wholehearted endorsement of these proposals by the powers have sent a thrill around a war sickened world. If these proposals result in an "*understanding for peace*" in place of the old "*understandings for war*" among the Nations, we are justified in, at least, hoping for a new order of international relationships.

Since 1914 the nations have made unheard of sacrifices in war and the lessons have been the bitterest that the world has experienced. The Washington Conference is to determine whether the common sense of the *people*, because in the last analysis it is in their hands, is to demand that each nation is now to make a bloodless sacrifice for peace.

It is for the peoples now to choose whether suspicion among nations is to make secret diplomacy and secret treaties the masters of their destinies, with the inevitable burden of taxation only to pay for a bloody shambles on the field of battle, or whether open diplomacy is to show that civilization has reached a stage where no democratic state will in the future countenance the squandering of the nations' wealth to prepare for such a ghastly end. Optimism is justified.

The beginning of such a new era will make a profound difference to everyone, but will perhaps be appreciated by the engineering world to as great an, or if not to a greater, extent than elsewhere. Engineers are by nature constructive, and even those who have served their country by designing and building implements of destruction will take a keener joy in limiting such activities to the bare needs of defense, and spending their remaining energies on constructive undertakings for the benefit of mankind.

It is befitting that a large electrical corporation should have designed and carried out those brilliant illuminations in Washington which were to commemorate Armistice Day and to welcome the representatives of the nations who are taking part in the Limitation of Armaments Conference. Mr. W. D'A. Ryan, Director of the Company's Illuminating Engineering Laboratory, who made such a conspicuous success of illuminating the Panama Pacific Exposition, was responsible for this work. The frontispiece and cover of this issue of the REVIEW and some other illustrations in the magazine will give our readers some slight idea of the splendor of this display.

It is customary at Christmas time to wish our friends Good Cheer and as our January issue reaches our subscribers at this season, besides wishing them "A Merry Christmas and a Happy New Year," we want to express the wish that the great Conference that is now sitting at Washington may be, at least, the dawn of that time when Peace on Earth, Good Will Toward Men may be achieved among all peoples at all times instead of only being trotted out as a Christmas sentiment once a year. A Happy and Prosperous 1922 to all.

J. R. H.

Professional Engineering Education for the Industries

By Francis C. Pratt

Vice-President, General Electric Company

This excellent paper was one of several which were written at the request of the committee in charge of a joint convention of the American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education. Mr. Pratt as active head of the engineering organization of the General Electric Company has had unusual opportunities of judging the sufficiency of the engineering curriculum of our colleges and universities, and his comments and suggestions are based on close and intensive observation of many hundreds of engineering graduates.—Editor.

During the year 1920 the General Electric Company, with which I have the honor to be associated, took into its employ 400 college graduates, of which number

340 were graduates of electrical engineering courses,
20 were graduates of mechanical engineering courses,
30 were graduates of business or administrative courses,
10 were graduates of miscellaneous courses.

Practically all of the electrical and mechanical engineering graduates entered into the student engineering courses covering a one-year period, which have been most carefully planned at the several works of the company, while the graduates of the business or administrative courses became members of its accounting department, taking a two-year course in business administration, higher accountancy and commercial law. Fifteen graduates, including two who had specialized in physics and nine in chemistry, entered the research laboratory of the company.

The records indicate that over a term of years about one half of the young men entering the student courses remain permanently in the employ of the company in the engineering, manufacturing, commercial or administrative departments of its general and district offices, or of its works.

In entering into the daily work of a great industrial organization these young men come into contact with actual manufacturing and business conditions and acquire self-confidence and a practical experience which, in my opinion, the colleges cannot and should not seriously attempt to impart.

I regard it as an exceedingly healthy sign that there are so many inquiries being made as to our methods of technical education, but at the same time I want to say that the young men who, during the past few years, have entered the employ of the company with which I am associated have on the average been better prepared mentally, physically and morally than ever before. This is a very broad statement, but a most careful study of the conditions and the many inquiries made of our leading men who come in close contact with these young men justify this conclusion.

During the past two years we have been engaged in reorganizing one of our most important designing engineering departments, largely increasing the scope of its work and its personnel. In recently looking over a report of the organization submitted by the engineer in charge, I was struck by the reference to two young engineers, each of whom had been out of the company's student engineering course for a period of less than a full year. The report referred to one of these young men as proving to be a resourceful and inventive experimental genius along his particular line of work, and to the other as having perhaps the clearest understanding of the mathematics of this particular line of anyone in the company. The line of work is an exceedingly broad one, the engineer in charge is a particularly discerning man, and I think it a matter of great encouragement that talent of such character is being turned over to the industries by the educational institutions. It is true that the report, in referring to these two young engineers, referred likewise to four somewhat older and more experienced men who were doing particularly notable work in the department.

I have recently seen a statement that statistics show there has been a constant decrease in the number of engineers graduated from our American universities. The statistics were not cited in connection with this statement, but if, perchance, this statement holds true, the tendency would seem to be an unfortunate one, in view of the larger demand for engineering activities in our modern life, as partly reflected in the following statistics taken from the official records of Yale University:

Increase in all Yale graduates for years 1904 to 1916—

Law, medicine, ministry and teaching, combined	24 per cent
Manufacturing, finance and mercantile pursuits, combined	83 per cent
Engineering	100 per cent

I have also seen suggestions that the number of so-called cultural studies should be decreased and greater specialization made in the essential subjects of science, mathematics, the native language, and of commercial application of what is learned, and that the colleges should turn out young engineers whose services are of immediate value to the employer without several years of practical experience.

I have little sympathy with such points of view for many reasons, among which are:

While familiarity with apparatus obtained from laboratory work coincident with undergraduate studies is of great value in giving the students more appreciative knowledge of their subjects, as are also frequent visits to and summer work in industrial establishments during the undergraduate period, yet I am confident that nothing which the colleges can give can take the place of the practical experience gained in the atmosphere of an industrial organization, bringing with it an intimate knowledge of both methods and men with which and with whom one's life work is to be associated. In my opinion the time in college is so valuable that it should be primarily devoted to those things which can only be acquired later with a great deal of difficulty.

Earnest efforts are being made to combine the advantages of instruction in theory with those of practical experience by co-operative courses, carried on jointly by educational institutions and industries. A final opinion in regard to the effectiveness of these courses must, it seems to me, be held in suspense awaiting more extended experience with them.

My observations also lead me to the conclusion that the percentage of those who fail to attain a reasonable degree of success is greater in the group of men of mediocre ability but narrowly specialized education, than almost any other group coming within my knowledge. Such men, unless extraordinary vigilance is exercised by those in charge, become permanently attached to an organization doing specialized work for which they have no particular adaptability, clogging the opportunities for younger, more able and progressive men to advance. It would have been far better for such a man if the head of the department had, at the end of one or two years of employment, recognized the circumstances and frankly informed him that he was not likely to make a success in the professional work which he had undertaken, and advised him to enter into some other vocation.

If I were to make a broad criticism of our methods of engineering education as it exists today, I should base it upon too early specialization of the student, resulting in the turning out of a disproportionate number of men of the class to which I have just referred, i.e., those of mediocre ability and narrowly specialized education.

I should be disposed to strongly criticise another condition in our colleges which I recognize as an exceedingly difficult one to overcome, and that is, as the result of the high degree of standardization, induced perhaps by the numbers who have to be taught, the more brilliant men in the class are retarded in their progress by the requirement of a standard which can be met by the less capable students. If we are not only to attain, but also maintain, great eminence in the engineering professions in America, we should, and I think must, devise some means whereby the more promising students can with greater facility advance with breadth and thoroughness in their work.

It is, I think, significant that in the organization with which I am in daily contact, a noticeable number of our most accomplished theoretical engineers and research laboratorians have either pursued postgraduate studies at European universities, or else have had all of their scholastic training abroad. This may suggest an opportunity for American educational institutions which is not fully met at the present time. In this connection, I think that the colleges should sternly resist the temptation to enter into specialized fields which are adequately covered by kindred institutions, and that better results would follow if, in general, each endeavored to maintain the strongest possible staff of teachers to give most thorough instruction in the fundamentals of the sciences, engineering, economics and languages, and confine its specialization to such work as it is preeminently fitted to carry out.

The industries need administrative men well versed in the sciences and in engineering, in order that they may lend appreciative and sympathetic support to the technical developments which are, in fact, the very life blood of the industry and on which its future primarily depends. That the colleges of the country are alive to this need is evidenced by the number of courses which have in recent years been established, teaching the fundamentals of the sciences, engineering, economics and languages, and variously referred to under the names of administrative engineering, commercial engineering, or other courses.

While it seems to me probable that a much larger proportion of the graduates of such general engineering courses will be utilized by the smaller manufacturers rather than by such highly specialized organizations as pertain to the electrical industry, yet I want at this point to put in a strong plea for the more thorough appreciation and use of technical graduates by all industries, both large and small. It is, of course, apparent that a college education is not in any sense the only road to industrial accomplishment, and, in fact, some of the ablest engineers and administrators of my acquaintance have secured the fundamental knowledge upon which their life's work has been based while persistently working in practical fields and without having the foundation of a college education. One frequently finds, however, in such cases, that the individual's development had been profoundly influenced by close association in his work with a master mind, who, in reality, became a great teacher to him.

The industries need strong designing engineers thoroughly versed in the theory and practice of the art who have such knowledge of material values and of men as to render their work effective. In general, the industries must look to the colleges for young men who have the knowledge, the enthusiasm for constructive work and the patient tenacity, which alone go to make up a successful designing engineer. In many respects the loss of a good designing engineer to an industry leaves a vacancy which is harder to fill than almost any other, as pre-eminence in design can only be attained through a happy combination of natural ability and of knowledge and experience gained by years of intelligent and exacting work. Owing to the highly developed state of the art there is undoubtedly a great deal of routine work to be done in designing engineering which is not inspiring to young men, and experience indicates that a diminishing proportion of technical graduates is drawn towards this most important branch of work. While this must, I think, necessarily be one of the problems of the colleges, it is also one of very immediate concern to the industries, demanding their most resourceful consideration. In general, the goal of success in design work seems more remote to the young graduate than in other branches, and also the character of the work more exacting and confining. On the other hand, this fascinating field of investigation, research and constructive accomplishment should appeal most strongly to one who has the imagination and courage to look well into the future, and the stamina necessary to accomplish a difficult task. I feel certain that far too many capable young graduates sacrifice their greatest ultimate development by yielding to the temptations of early rapid advancement along the easier lines.

I wish only to add one thing more, and that is to point out the wonderful opportunities which modern industry offers in its research laboratories to specially talented and most highly educated technical graduates. The colleges must, I am sure, be most liberal in providing instruction and laboratory facilities for the growth of such picked students, and in inspiring them by the work and example of a few really great teachers.

SUMMARY

I. A careful study of a large number of college graduates employed at the several works of the General Electric Company indicates that our educational institutions are developing young men of real ability for the industry.

II. The suggestion that is sometimes made to reduce the amount of cultural studies, in order to more intensively specialize on technical subjects, is not viewed with favor.

III. The time in college is of such value that it should be primarily devoted to those things which can only be acquired later with great difficulty. At best, the student cannot hope to attain in college the well rounded knowledge and practical experience that are to be gained in an industrial organization.

IV. A broad criticism of methods of engineering education is that it undertakes too early specialization of the student.

Another is the lack of facility offered to the more capable students to rapidly advance.

V. Suggestions for modification and improvement of American educational methods may be gleaned from the fact that a noticeably large number of accomplished theoretical engineers and research laboratorians have either received all their education or pursued post-graduate courses at European universities.

Best results may be expected if each educational institution will strive to maintain a highly capable staff of teachers in the fundamentals of the sciences, engineering, economics and languages, and restrict specialization to only that work for which it may be pre-eminently qualified.

VI. The teacher in engineering courses should constantly emphasize to those students who show special aptitude the great need among the industries for able designing engineers.

VII. Through its research laboratories modern industry offers to specially talented and highly educated technical graduates wonderful opportunities for development.

Some Developments in the Electrical Industry During 1921

By John Liston

Publication Bureau, General Electric Company

Mr. Liston's annual review of the progress that has been made in the manufacturing branch of the electrical industry during the preceding twelve months has become a prominent feature of the General Electric Review, and its customary publication in our January issue is eagerly awaited. In view of the radical adjustment and retrenchment that has occurred everywhere in industry, we are agreeably surprised to find that there is such a number and diversity of new things to be told about.—Editor.

Despite the business depression which naturally hampered development work in commercial fields, there were a considerable number of improvements made in existing types of apparatus and results achieved in research work which may in the future have far reaching effects.

The most spectacular development of the year was the successful generation, insulation, transmission and measurement of current at commercial frequencies with potentials exceeding one million volts. The practical results to be obtained from this achievement are, at present, problematical, but the data secured make it possible for the electrical engineer to calculate with certainty transmission lines utilizing potentials greatly in excess of those used at present.

Perhaps the most important feature from a practical engineering standpoint was the great increase in the use of automatic generating stations and substations, the development of which appeared to be hastened by the necessity for more economical operation of generating and distribution systems.

The equipment for the first Diesel engine electrically propelled merchant ship in the United States was completed; and the economies to be secured with this method of propulsion may radically influence the future of our merchant marine.

Some of the smaller developments have a potential importance out of proportion to the unit size of the apparatus considered. Among these may be included special relays, push button control, safety features, and new types of contactors which make possible more reliable and economical forms of control in various industries combined with long life and a greatly decreased demand for renewal parts.

The progress made in radio communication included the production of new tubes of increased capacity, the development of complete standardized lines of both transmitting

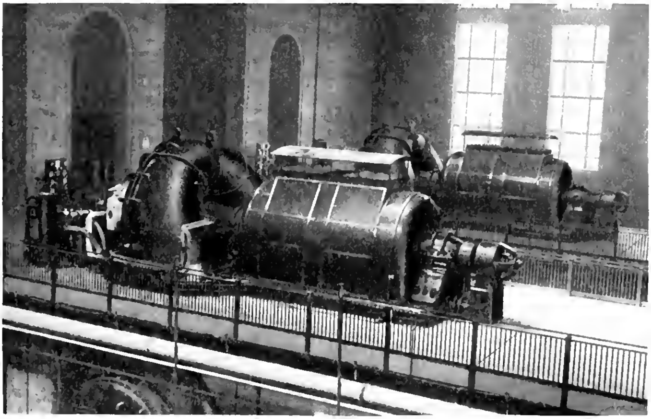

Fig. 1. Two 30,000-kw. Turbines Installed in Delaware Station of the Philadelphia Electric Company

and receiving apparatus, embodying the latest features of demonstrated value suitable for both amateur and commercial work, and the formal opening of the world's largest radio central station.

While the results of the research work accomplished during the year cannot be definitely appraised, some of the new materials and devices have already found practical application on an extensive scale.

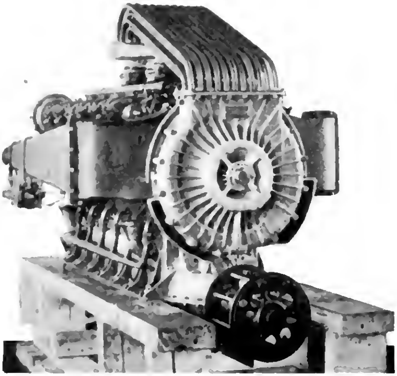

Fig. 2. G-E Turbine Supercharger with Automatic Control Installed on Liberty 12-cylinder Engine

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.

Turbines

Several new central stations equipped with large Curtis turbine-generator units were put in successful operation. Typical of these is the Delaware station of the Philadelphia Electric Company (Fig. 1).

Engineering and research work resulted in establishing more rational design constants and formulas which have replaced the empirical rules in common use.

The tendency toward higher steam pressures and temperatures is illustrated by the fact that in two central stations 30,000-kw. turbines were placed in operation with a pressure of 300 lb. gauge at the turbine throttle.

Supercharger

On September 28th a new altitude record of 40,800 ft. was made at McCook field, Dayton, Ohio, in a LePere biplane equipped with a G-E supercharger.

As a result of the numerous experimental flights made, the design of the supercharger has been standardized (Fig. 2) for certain engine ratings so that they can now, for the first time, be produced in quantity on a commercial basis.

Turbine-electric Ship Propulsion

The S. S. *Eclipse*, the first turbine-electric cargo ship, went into service in November 1920, and sailed from New York to the Dutch East Indies, returning to New York in May, 1921, after a voyage of 26,500 miles.

During this voyage, no difficulties were experienced in the operation of the main propulsion equipment and no major repairs had to be made, the entire distance being covered in one week less than that required for ships of similar rating. On the trip from New York to Gibraltar, the *Eclipse* reduced the previous running time by two days.

During the year four additional 12,000-d. wt. ton merchant ships, *Invincible* (Fig. 3), *Archer*, *Independence*, *Victorious*, of the U. S. Shipping Board fleet, were each equipped with a 3000-h.p., 3000-r.p.m. Curtis steam turbine direct-connected to a 3-phase, 2300-volt alternating-current generator supplying energy to a 3000-h.p., 100-r.p.m. induction motor direct-connected to the propeller shaft. The speed of these ships is about 11 knots, and in addition to the five which have already been completed, seven sets of similar propelling equipment are under construction and will probably be completed early in 1922.

The propelling equipment for four U. S. coast guard cutters was completed and two of these ships have already been launched, one of them, the *Tampa*, having completed her trial trips and been accepted. These ships have a displacement tonnage of 1600 with a speed of 16 knots. The propelling machinery consists of a 2600-h.p., 3000-r.p.m. turbine-generator (Fig. 5) and a 130-r.p.m., 2300-volt synchronous motor (Fig. 5). Spring thrust bearings are used on the propeller shafts.

Naval Ships

The extent to which electric drive has been adopted for the ships of the U. S. Navy is indicated by the fact that, at the close of the year, there had been completed or were under

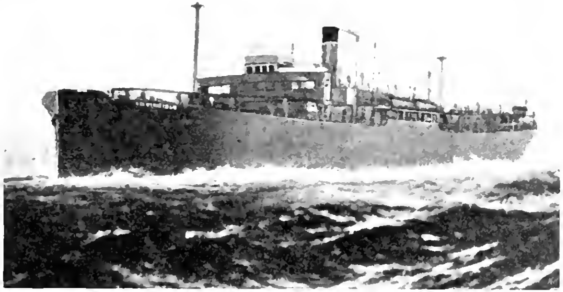

Fig. 3. S.S. *Invincible* Equipped with 3000-h.p. Electric Ship Propulsion Machinery

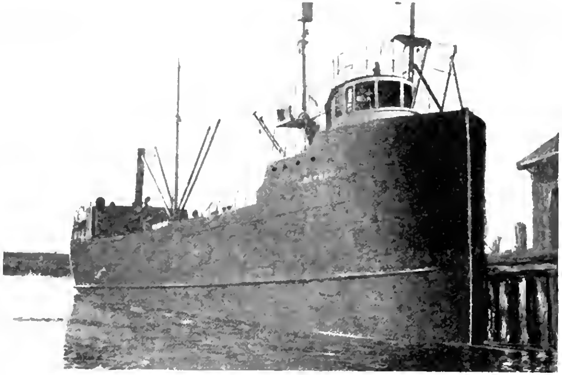

Fig. 4. M.S. *Fordonian*, First Diesel Engine Electrically Operated General Cargo Ship in the United States

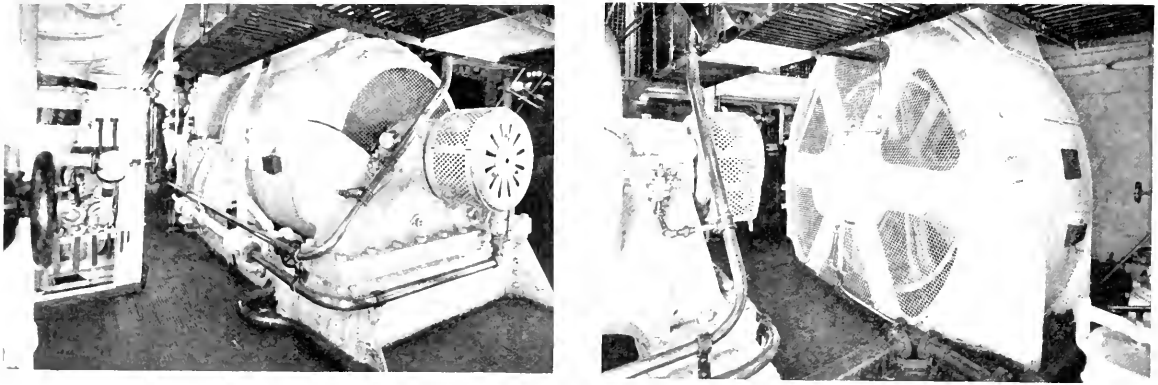

Fig. 5. Engine Room U. S. Coast Guard Cutter *Tampa* Showing Main Turbine-generator (left) and Synchronous Propulsion Motor (right)

construction twenty ships designed for electric propulsion with a total displacement of 769,000 tons and an aggregate of 1,657,000 h.p. in propelling motors.

These figures are doubly impressive when we remember that the first electrically propelled ship constructed for the Navy was put in commission in 1913. Considerably more than 50 per cent of these equipments consist of G-E apparatus.

Following the lead of the U. S. Navy, Japan has closed a contract for a 14,000-ton electrically propelled fuel ship. The main equipment for this ship will consist of an 8000-h.p. turbine-generator supplying current to two 4000-h.p., 120-r.p.m. synchronous propeller motors. There will also be two 400-kw. direct-current turbine-generator sets for supplying excitation current for the main generating units as well as energy for the operation of the electrical auxiliaries.

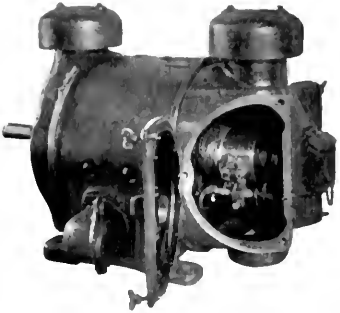

Fig. 6. 10-h.p., 1700-r.p.m. Enclosed Self-ventilated Marine Motor

In addition there will be a 650-kw. alternating-current generator which can be connected to one of the 400-kw. direct-current sets so that in case of failure of the main generator, this small generator will give sufficient power to propel the ship at about 7 knots. This generator will be normally held in reserve.

Diesel Electric Ship Propulsion

The 2200-d.wt. ton freighter *Fordonian*, (Fig. 4) which is now nearing completion, will be the first U. S. cargo ship to be equipped with Diesel engine electric drive.

The propelling machinery comprises two 500-b.h.p., 2-cycle, 4-cylinder Diesel engines, direct-connected to two 350-kw., 250-volt, 200-r.p.m., compound-wound, d-c. generators, and a double armature, 850-h.p., 120-r.p.m., shunt-wound motor direct-connected to the propeller shaft. The speed obtainable is estimated at about 9 knots.

In general arrangement the electrical equipment of the *Fordonian* is similar to that supplied for the 500-ton trawler *Mariner*, which went into commission during the latter part of 1919 and has since maintained a satisfactory operating record, except that in the case of the *Fordonian* bridge control is not utilized. A dual system of control is installed in the engine room, one being electrically operated and the other manually, the latter control being intended only for emergency use.

It is interesting to review the rapid developments which have occurred in marine propelling equipment during the last decade. Within this brief period we have seen the first ships in the United States using high-speed marine geared turbines with double reduction gears, turbine electric propulsion in naval and merchant service, and Diesel electric drive in fishing and merchant service; all these pioneer installations utilized G-E apparatus.

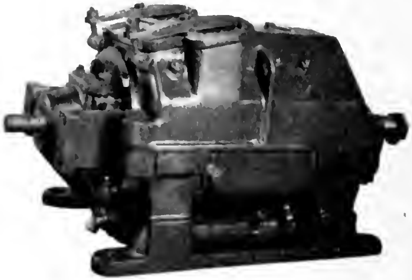

Fig. 7. 25-h.p., 550-r.p.m. Water-tight Marine Motor

Electric Drive for Auxiliaries Aboard Ships

There was developed during the year a complete new line of direct-current motors (Figs. 6, 7 and 8) especially designed to meet the severe operating conditions normally encountered in marine service, and designed for the efficient operation of all classes of deck and engine room auxiliaries.

Except for specially designed motors which had been provided for the navy, most of the previous electrical equipment installed on ships has utilized land motors which, in many cases, have not proved satisfactory.

Electrical apparatus mounted on the open deck is subject to temporary submersion in rough weather and has to withstand the impact of heavy seas. The crew, when washing down decks, will often play the hose on the machinery. In tropical climates the deck machinery is subject to excessive heat, and on northern routes to very low temperatures. Apparatus installed in the engine room is exposed to drippings from condensation and from leaky pipes, to water and oil spray, to damage by rodents, loose tools, etc. In Diesel engine propelled ships and in tankers, protection must be given from oil fumes, vapors, and gases. All apparatus, if not correctly built, is liable to deteriorate and corrode owing to the action of the moist and salt-laden atmosphere.

Other motors on shipboard are frequently operated at various angles to the horizontal, due to pitching or rolling of the ship at sea, or listing due to loading and unloading or shifting of cargo or to accident. Motors used on tankers are also a potential source of danger unless they are suitably enclosed and ventilated.

In designing this new line of motors, the conditions outlined above were kept in mind and, while the line has no unusual electrical characteristics, the motors intended for deck service have great mechanical strength and are waterproof. All windings are especially insulated and all fittings subject to corrosion are made of non-corrodible material or have non-corrodible surfaces.

The motors designed for engine room service are enclosed and self-ventilated and immune to dripping water, oil or spray. The mechanical parts are not so heavy as those for deck service but are ample to withstand the usage which experience shows they will be subjected to under operating conditions.

The motors for deck service range in size from 3 h.p. to 100 h.p. and for engine room service from 2 h.p. to 200 h.p. and may be either series, shunt or compound wound.

Two types of waterproof magnetic brakes have been provided for these motors, one being a disk type and the other a shoe type, the former being supplied on motors operating capstans, windlasses, etc., and the shoe type being utilized for severe duty cycles such as are involved in operating cargo winches.

To complete the auxiliary electrical equipment, controls of different types have been standardized for marine service and are provided with different degrees of protection, depending on whether they are to be placed in exposed or protected locations. A very desirable arrangement is to provide decentralized control instead of one main control board for the engine room auxiliaries, with small control panels placed near the groups or individual motors which they are to control. The starting and stopping of the motors is accomplished by means of master switches located directly on or near the motors.

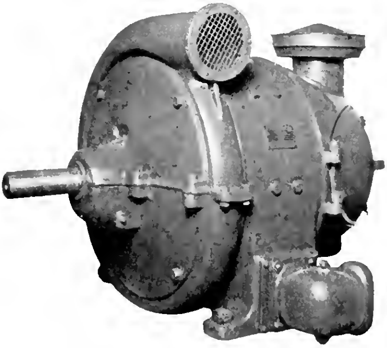

Fig. 8. 50-h.p., 1075-r.p.m. Enclosed Ventilated Marine Motor

Electric Railways

The activities of electric railway operators during 1921 were in the main confined to efforts to reduce operating costs and thus effect economies to enable them to meet running expenses. These efforts were extended in three directions, viz., the reduction in the weight of existing rolling stock by purchase of lighter cars, the replacement of existing obsolete motors with new and improved types, and the use of automatic substations.

The number of sales of safety cars continued to be large and several railroad companies are now operating their lines entirely with this new type of car. The city of Detroit is a notable example of the development of the one-man safety car idea, orders having been placed by the railway management for 250 safety cars designed for one-man operation. Also, 50 double truck cars are each to be equipped with four GE-265-35-h.p. motors, control and air brakes and arranged for one-man operation.

A number of other roads are also equipping double truck cars for one-man operation.

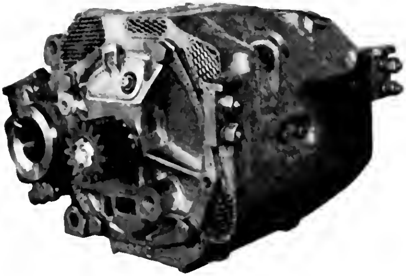

Fig. 9. 55-h.p. Railway Motor for the Los Angeles Railway Company

A notable example is the Pittsburg County Railway (Oklahoma) with three light weight double truck cars equipped with GE-264 motors, K-35 control and air brakes weighing, completely equipped, 14 tons and replacing older types weighing 30 tons; and the Bangor Railway & Light Company (Maine) with seven equipments for double truck cars of similar construction equipped for one-man operation.

Perhaps the most striking example of this trend is furnished by the Kentucky Traction & Terminal Company which placed in service ten double truck cars each equipped with four GE-264-25-h.p. motors, K-35 control, and G-E air brakes, headlights and compressors. These cars completely equipped weigh 25,000 lb. and are operated in interurban service at maximum speeds up to 37 miles per hour. The seating capacity is 45 passengers with liberal spacing, which compares favorably with 54,000-lb. cars which they replaced. The saving in power, due to the reduction of equipment weight, has enabled the customer to improve voltage conditions by redistribution of existing substation apparatus.

Two conspicuous examples of the replacement of obsolete equipment are furnished by the Denver City Tramway Company and the Los Angeles Railway Company. In the first case 144 GE-249-40-h.p. motors were furnished. These are being used for replacing motors of the older types on present equipment. The same practice is being followed by the Los Angeles Railway Company which has placed orders for 200 GE-269-55-h.p. motors (Fig. 9).

One of the interesting developments of the year was the adaptation of electric drive to motor buses (Fig. 10), and the production of collecting equipment for supplying 600-volt current. A number of these trackless trolley buses have been placed in operation and there seems to be no difficulty in collecting the necessary current from wires supported along the highway. The collecting device is so arranged that considerable latitude is allowed for passing other vehicles along the road.

For heavy subway and elevated operation the city of Philadelphia will utilize 108 GE-259-120-h.p. motors which will be installed on new cars for operating the Frankford elevated lines now being completed by the city. Two 2000-kw. synchronous converters, transformers and switchboards will be provided for the new Fairmont substation.

Fig. 10. Trackless Trolley Equipped with Railway Motors, Foot Control and Special Form of Collector

Steam Road Electrification

Practically all active electrification work during the past year occurred in foreign countries where the fuel situation is much more acute than in the United States. The largest equipment is for the Spanish Northern

Railway for the Pajares Grade electrification. This is a heavy mountain line near the French border and 3000-volt d-c. equipment will be installed. The apparatus under construction includes six 86-ton, 3000-volt locomotives, two complete 3000-kw. substations and overhead line material for 39 miles of track.

Progress in the electrification of the French railways is apparently along the lines indicated in the report of the Railway Commission (General Electric Review, April, 1920). This commission recommended 1500 volts direct current as the standard potential for overhead distribution. While the major portion of the equipment will be built in France some equipment will be supplied by the General Electric Company. This includes seven high-speed circuit breakers which will be used by the Midi Railway for the protection of synchronous converters of 750-kw. capacity operating two in series for 1500 volts, and 21 PC controllers for the State railways to be used on the Paris-Versailles line which will also operate eventually at 1500 volts.

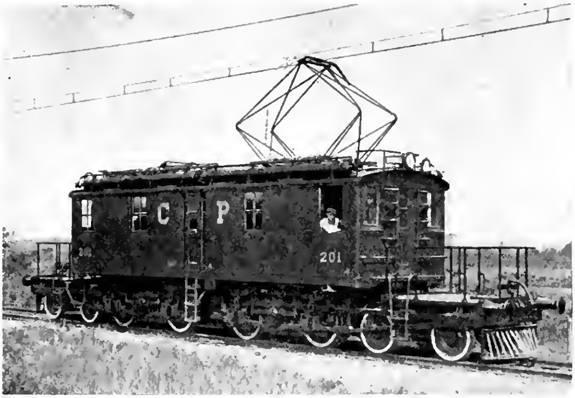

Fig. 11. 3000-volt Passenger Locomotive for the Paulista Railway

The Japanese Government is making active preparations for the further electrification of the Imperial Government Railways and the initial equipment will include two 66-ton, 750/1500-volt locomotives which will be tried out on the Tokio-Yokohama line. This division was electrified in 1914 with 1200 volts direct current, and indications point to the adoption of 1500 volts for new projects now under consideration. The rolling stock on this line consists of motor cars for high speed interurban service. A new line, known as the Tokaido Electric Railway, is also under construction between the cities of Nogoya and Okazaki, a distance of 22.4 miles. Each of the fourteen 45-ton motor cars will be equipped with four GE-244-750-1500-volt motors and type PC control.

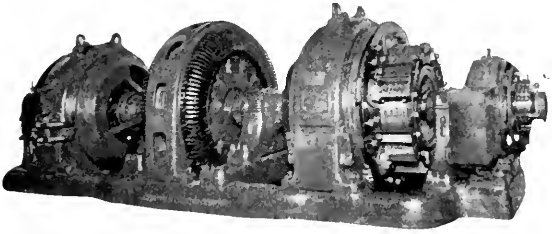

Fig. 12. 1500-kw. Synchronous Motor Generator Set for Paulista Railway

An unusual feature of the equipment for the Paulista locomotives, which have just been placed in service, is a 4-unit set (Fig. 13) consisting of combination air compressor and exhauster and a d-c. generator direct driven by a double commutator, 3000-volt motor.

In the United States compressed air is, as a rule, used for operating brakes on trains, but in Europe, and to a considerable extent in South America, the vacuum system is still used, and on the Paulista Railway the train brakes are operated by means of the vacuum system. The locomotive itself, however, is equipped in every way with up-to-date equipment including standard American compressed air braking.

The combined unit occupies a space 9 ft. long by 4½ ft. wide and is about 3 ft. 3 in.

high. The shaft, which is common to the motor and compressors, has only two bearings but is direct connected to a 3-kw., 60-volt generator by means of a flexible coupling. The entire set normally operates at 915 r.p.m., the speed varying with the voltage and load.

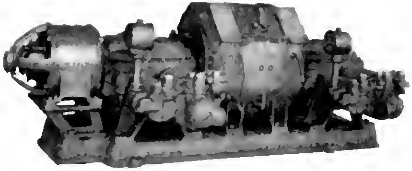

Fig. 13. Combination Air Exhauster-compressor Generator Set for Paulista Railway

Each of the compressor units is utilized both as a compressor and exhauster, the large cylinder being used for the vacuum service, maintaining 22 inches of vacuum, and the small cylinder delivering compressed air at 90-lb. pressure. The set is intended to operate continuously, the compressor lines being provided with the usual unloader and the exhaust lines with relief valves, and both discharge lines being provided with oil separators.

Under normal operating conditions the voltage on the driving motor will vary from 1200 to 3800 volts, causing considerable variation in the speed of the set, so that in order to insure the necessary constant voltage output from the d-c. generator, the current from which is utilized for the lighting system and the operation of the control contactors, the generator is provided with a voltage regulator.

During the year the New York Central Railroad installed a new 20,000-kw. steam turbine in its Glenwood Station and dismantled one of the old 5000-kw. vertical units installed in 1904. The remarkable improvements in turbine efficiency during this period have more than justified the expenditure required.

Automatic Stations

There was a very notable increase in the use of the automatic principle for central station and substation operation. This was due to the marked success which had been secured with the automatic stations which were in operation prior to 1921, combined with the necessity for increased economy in the operation of power systems. It had also been demonstrated that considerable saving in operating costs could be effected where existing generator and feeder stations could be changed over from hand control to automatic control.

As an indication of the growth referred to above, the number of automatic stations and substations installed or under construction during the year exceeded the total of all similar equipments of all preceding years.

Prior to 1921, most of the automatic stations were designed for railway use, but numerous equipments were provided during the year for central stations and for the power systems of a variety of industries.

The following definition may be of assistance in clearing up any misunderstanding as to what constitutes an automatic station:

An automatic station or 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. The master element may be a contact-making voltmeter, contact-making ammeter, remote control switch, float switch, time switch, etc.

Owing to financial and operating conditions the electric railways of the country confined their purchases, with few exceptions, to urgently needed equipment. One of these exceptions was the automatic railway substation (Fig. 14) which had demonstrated such notable economies as to warrant expenditures even under the existing conditions. A number of automatic control equipments which were sold to electric railways during the year included control apparatus for both synchronous converters and motor-generators and a number of complete station equipments ranging in capacity from 300 kw. to 1000 kw.

Control equipments were also adopted for changing over a number of manually operated stations to automatic control. Records to date show that the General Electric Company has installed 96 railway type synchronous converter automatic control equipments and nine similar equipments for synchronous motor-generator sets. The service conditions under which these substations are operating include heavy steam road electrification, such as Detroit River Tunnel and Melbourne Suburban Railway, high speed interurban, suburban and city service. There have been no material alterations in the design of this equipment and new developments have been mainly confined to improvement of existing designs to secure practically standard apparatus.

Automatic stations in the province of central stations made notable strides. The first shipments of the equipment for the automatic operation of the 3-wire Edison system of Kansas City were made. This system will be fed by two 2600-kw. and eight 1500-kw., 250-volt, 3-wire, 60-cycle synchronous converters (Fig. 15). One of the large machines is regulated by a synchronous booster, the other machines obtaining their voltage regulation by field control and high reactance transformers. The units will be installed in pairs in the basements of buildings, but each unit will feed separate busses.

The converters will start and stop by load demand; they are designed to insure maximum continuity of service and are carefully protected against damage. The control is such that if one cable fails the machine that is fed by that cable is automatically transferred to another cable entering that station.

Automatic control for six hydroelectric units was installed and is giving very satisfactory service. One 11,750-kv-a. vertical water-wheel driven generator with remote control was completed for the Washington Water Power Company, at Spokane, Wash. This generator is installed in a non-attendant station 600 ft. from the substation from which it will be controlled. It is the largest generator that has been completed for this system of control.

A 5000-kv-a. water-wheel generator and complete automatic control for the New England Power Company will be located on the Deerfield River, at Searsburg, in an inaccessible part of the Berkshires. This unit will feed into the 66,000-volt transmission line of the company, starting and stopping by a time switch. It will be the largest fully automatic hydroelectric station.

Equipments for the automatic operation of six transformer and alternating-current distribution stations were installed. The largest of these stations is at Kansas City. This station is laid out for three 3-phase, 6000-kv-a. transformers and a suitable number of feeders. Three incoming lines will be provided, one of which will be a spare. In case of failure of one transformer or feeder the load will automatically be transferred to the spare transformer or feeder. When service has been restored on the normal source the load will be transferred back to it. At present two banks of transformers and two cables are being installed.

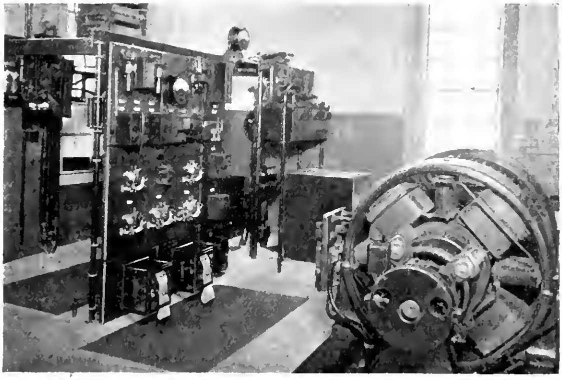

Fig. 14. Automatic Switchboard and Motor-generator Set, St. Joseph Railway, Light, Heat and Power Company, Savannah, Mo.

A combined self-cooled and water-cooled 3-phase, 6000-kv-a. transformer was installed in an automatic substation of the Union Electric Light and Power Company, at St. Louis. The low tension feeder voltage is controlled by induction regulators having water cooling coils, and the control of the water supply to transformer and regulator is automatic.

In automatic distributing stations the feeder breakers are designed to reclose after a definite time when tripped out by an overload or short circuit (Fig. 16). If the breaker is opened three times successively, it is locked open until reset by hand. The service given by the reclosing equipments is so satisfactory that some companies are installing reclosing devices in stations in which attendants are required for other reasons.

There were completed or under construction at the close of the year twelve automatic substation equipments for mining and industries, particularly for coal mining (Fig. 18), which will utilize altogether nineteen converters or motor-generator sets. These equipments are of widely different character, covering the following conditions:

Single synchronous motor-generator sets.
Two synchronous motor-generator sets in parallel in the same substation.
Single synchronous converters.
Two and three synchronous converters in parallel in the same substation.
Three balancer sets in parallel in the same substation.

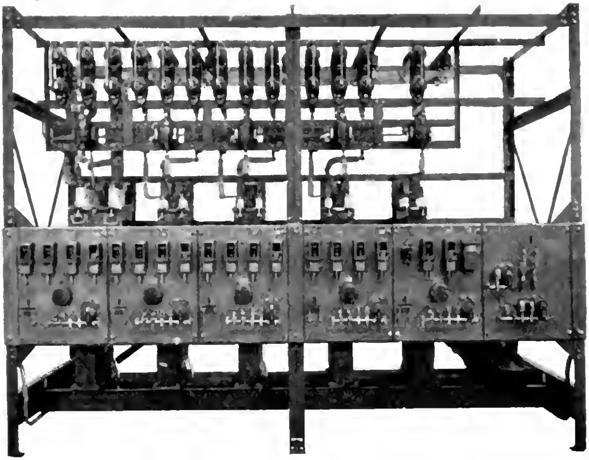
Fig. 16. 4000-volt, 60-cycle Automatic Reclosing Feeder Station

Synchronous Motors

The growing tendency on the part of central stations to impose penalties for low power-factor on industrial circuits resulted in a demand for a type of synchronous motor which could be utilized to replace squirrel-cage induction motors for various classes of industrial machine drive.

A new line of unity power-factor synchronous motors for belt drive was designed for this particular class of service. They range in capacity from 75 h.p. at 1200 r.p.m. to 400 h.p. at 600 r.p.m. for standard frequencies and voltages. These motors are all provided with direct-connected exciters and the field is adjusted for full load operation so that no rheostat or other adjustments need be made by the operator. With 70 per cent voltage, a 50 per cent starting and pull-in torque is developed.

Another new line of synchronous motors was designed especially for the operation of ammonia compressors and is a logical development from a previous line intended for the operation of air compressors.

The important characteristic in these new motors is the high torque provided to meet severe starting conditions. They have a pull-in torque of about 40 per cent of full load and the line ranges from 100 h.p. at 164 r.p.m. to 1500 h.p. at 100 r.p.m.

Exciters

The operation of exciters through a wide range in voltage has always been desirable where the exciter controls a single generator, in order to avoid losses in the alternator field rheostat. This could not be done with the usual design of exciters used in the past because of low stability at low voltage which might cause loss of voltage during disturbances. This is true only when the exciter volt-

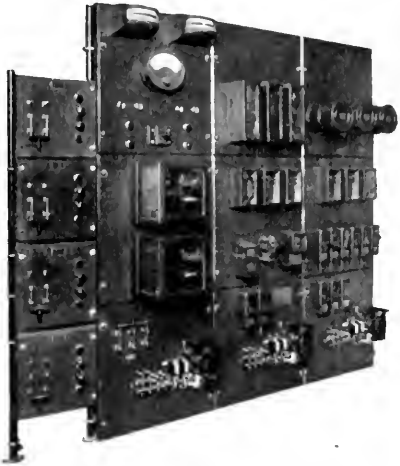
Fig. 15. Automatic Switching Equipment for Control of 1500-kw., 250-volt Synchronous Converter

age is controlled by hand. If controlled by a voltage regulator, the regulator would, of course, correct for the unstable action and no difficulties would be experienced.

With ordinary exciters the saturation curve is practically a straight line at the lower voltages, so that only a slight change in rheostat setting would give a very large change in voltage. To avoid this condition, there was designed a new form of pole construction which gives a bend in the saturation curve at low voltage and thus requires a greater change in excitation of the exciter to produce a given change in voltage, thus permitting operation at the lower voltages with much greater stability than could be obtained from older designs.

Oil Wells

During the year the development of suitable motor drive for rotary rigs for oil well drilling (Fig. 17) was successfully concluded in the California oil fields. Trials of various layouts had been carried on for about two years and the electrical equipment originally selected was found to be suitable from the start.

The chief difficulty was that of a suitable mechanical drive between the motor and the drilling rig. The successful arrangement (Fig. 19) makes use of a cut spur gear drive from a 600-r.p.m. or 720-r.p.m. induction motor to a short countershaft, and chain drive from the latter to the draw-works spindle of the rotary rig, using standard "rotary" chain. The bearings supporting the gear and pinion are mounted on a structural steel foundation, on the bottom of which is riveted a heavy steel plate web on which the motor is mounted. The latter is connected to the pinion shaft by a flexible coupling.

The extension of the I beams on each side of the motor is for the purpose of stiffening the steel plate on which the motor is mounted. The entire structure is supported on heavy timbers buried in the ground, as it has been found by experience that concrete foundations are too rigid and will usually shatter under the heavy whipping action of the drilling stem when striking or passing boulders.

Generally 75 h.p. is ample in capacity, but if the driller plans to operate the drilling bit at a higher speed than the normal average speed, a capacity of 100 h.p. may be necessary.

A shaft extension is provided on the end of the countershaft for a pulley, for belt drive to the bandwheel if cable tool drilling is considered advisable for completion of the well after the oil sand has been reached. The combined use of rotary and standard cable tool drilling is quite general practice in many fields in California. There are seven of these rigs now working, which have handled rotary drilling work to a depth of 3000 ft. and finished wells with standard cable tools to a depth of 4200 ft., without any trouble whatever and without any occasion for change in any portion of the design.

Fig. 17. Motor Driven Rotary Drilling Rig at Montebello, Calif.

Steel Mills

An important event in steel mill electrification was the replacement of the twin tandem reversing engine, which drove the first finishing stand of the Lackawanna rail mill, by a reversing motor equipment. This equipment was the first main roll electric reversing drive produced in this country to replace an engine. While it was completed in 1918, conditions at the Lackawanna plant were such as to make it inexpedient to install the equipment until 1921.

The motor unit (Fig. 20) has the highest continuous horse power capacity (8000 h.p., 50 deg. C.) of any electric reversing drive in the world. It was designed to roll the first four of the last five passes on a 105-lb. rail section at the rate of 240 gross tons per hour,

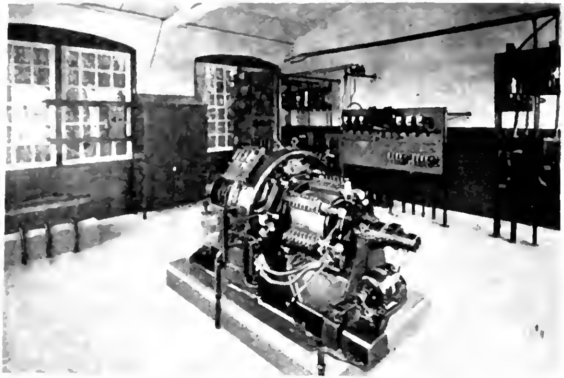

Fig. 18. 200-kw. Synchronous Converter with Automatic Control in Drifton Colliery of Lehigh Valley Coal Company

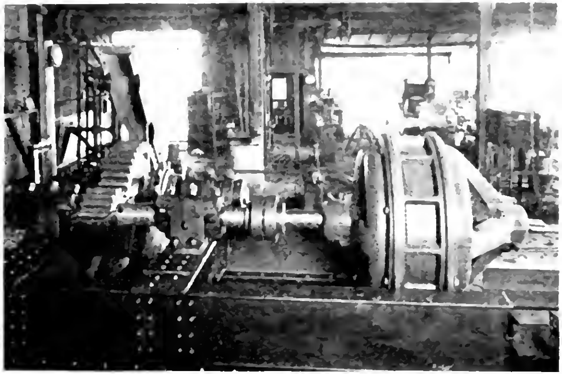

Fig. 19. 75-h.p., 440-volt Induction Motor Mounted for Oil Well Rotary Drilling Rig

Fig. 20. 8000 h.p. Double Unit Motor for Reversing Rail Mill

Fig. 21. 40-ton Furnace Showing Control Panels on Right and Electrode Motors on Platform Above

the last pass being made in an adjacent mill driven by a separate engine. The maximum production so far has been at the rate of 198 gross tons per hour of 105-lb. rail which exceeds all previous tonnage records of this mill. A particularly interesting feature is that this rate of rolling was made with the last finishing stand disconnected from its engine and connected to the first finishing stand so that the motor was driving both stands and rolling five instead of four passes.

Installation of the induction motors with double range Scherbius speed regulating set for driving the 12-in. and 20-in. hot strip mills at the Gary Works of the Illinois Steel Company was practically completed.

This equipment includes a 5500-h.p. constant torque induction motor with double range Scherbius equipment for obtaining adjustable speed control between 170 r.p.m. and 105 r.p.m., which is the largest adjustable speed mill type motor yet built.

Arc Furnaces

The two largest electric furnaces in the world, for the melting and refining of steel, were put in operation at the U. S. Naval Ordnance Plant, South Charleston, W. Va., on February 2, 1921.

Each furnace is normally rated at 40 tons (Fig. 21) holding capacity, each charge being handled separately so as to keep the metal as clean as possible, and large ingots will be formed from two ladles through two runners. One of the 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 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 1⅓ 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 (Fig. 22) for each furnace consists of one transformer, one switch and instrument panel, one electrode regulator panel, one operator's panel, three electrode motors, and a tilting motor.

Each transformer (Fig. 23) 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.

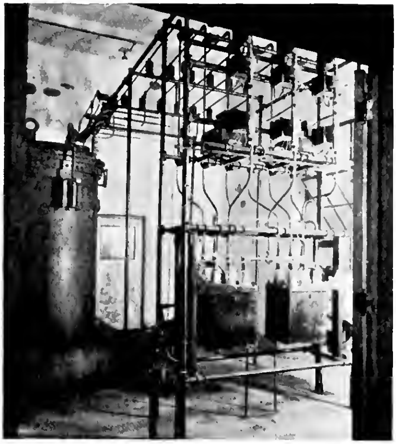

Fig. 22. Arrangement of High Tension Switching Equipment for 40-ton Steel Furnace

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.

Induction Furnaces

Despite the fact that only a few steel concerns in this country had attempted to use the induction furnace and that these had not met with real commercial success, there appeared to be no fundamental reason why furnaces of the induction type could not be made extremely useful in the arts of metal making, including steel. The problem of evolving an improved and thoroughly commercial furnace of this type was seriously undertaken a few years ago and the results have been very successful.

Not only have important improvements been made in the design but, more important perhaps, a superior grade of refractory material for the lining has been developed, without which the furnace would be of far less value commercially.

A 250-kw., 4000-lb. furnace (Fig. 24) was placed in operation nearly two years ago and it has since then been in continuous operation for the reclamation of steel scrap, over 2500 tons of high grade steel ingots having so far been produced. Although the process is exceptionally hard on the lining, it has a remarkably long life as compared with other types of furnaces. A life of 300 heats per lining is considered normal, and in 1921 one lining gave over 600 heats during a run extending over three months.

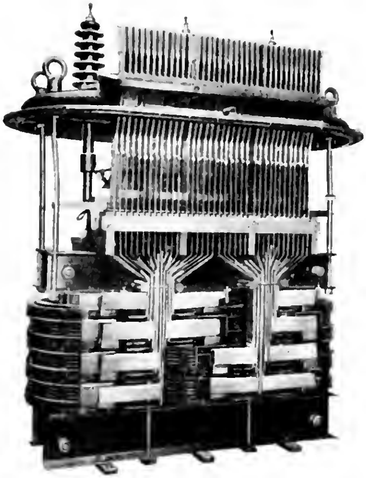

Fig. 23. High Capacity Transformer of the Type Supplied for 40-ton Steel Furnace

These furnaces have always offered attractive possibilities on account of the elimination of electrodes, roof upkeep, complication of leads, etc., and are now available in reasonable capacities for the melting of steels and alloys whose constituents are easily lost by oxidation in other types of melting furnaces.

Electric Welding

A new semi-automatic arc welding lead, when used in conjunction with an automatic arc welding head, retains the continuous feed features of the automatic apparatus yet allows the operator to direct the arc as required by the conditions of the work; thereby extending the benefits of the automatic electrode feed to work of unsymmetrical shape.

The field of application of the semi-automatic outfit is the welding of products where the seams to be welded are of very irregular contour, or on very large work where the travel mechanism and clamping necessary for the full automatic welder would be complicated and costly.

Industrial Heating

Considerable advance was made in the application of different types of heating units. Exhaustive experiments have shown that without any deterioration in equipment, a wider range of temperatures than was formerly considered possible can be reached with present types of heating units, and heating problems which previously were thought to be beyond the scope of electric heat are now being successfully solved.

There was an increased demand for electric furnaces to operate up to 2000 deg. F. (Fig. 25), to be used for a great variety of heat treating operations. A semi-cylindrical heat treating furnace was standardized with inside dimensions of 10½ in. wide, 21 in. long and 7 in. from the floor to the center of the arch; and a box type furnace with inside dimensions of 18 in. wide, 36 in. long and 24 in. high. There were also two vertical cylindrical type furnaces produced, one being 10 in. in diameter by 21 in. high and the other 17 in. in diameter by 36 in. high.

Fig. 24. 4000-lb. Induction Furnace Showing Rammed Lining in Place

These furnaces are completely built up and equipped with an automatic panel and temperature control instrument.

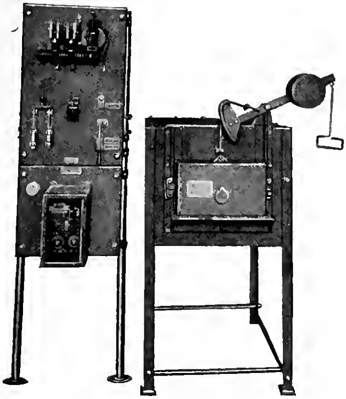

Fig. 25. Electric Resistance Furnace with Panel for Automatic Temperature Control

The advantages secured in electric heat treating furnaces are:

Maximum rate of heating the charge
Automatic control of temperature
Minimum temperature variation in the furnace
Uniform heating throughout the charge
Maximum efficiency in heat treating
Duplicate results day after day
Elimination of combustion methods with their attendant uncertainty of results and general fuel problems.

The uniformity of heating and accuracy of temperature control give results much superior to those obtained with fuel furnaces. As an example, it was found that in machining steel blanks, annealed in an electric furnace of the type described, the speed of cutting was increased about 20 per cent over that possible on steel annealed in the oil furnace.

In the hardening of ring gears in an electric furnace, it was found that after quenching it was not necessary to straighten the gears. General practice in fuel fired furnaces showed that 40 per cent of the gears have to be straightened, indicating distortion in heating.

In addition to these standard furnaces, heating equipment for furnaces of greater size and capacity was designed and built. Marked success was secured in furnaces for baking vitreous enamel and annealing glass.

A new type of heater of low temperature gradient (Fig. 26) was designed for use in japan baking, drying and tempering ovens. The development of this heater was due in part to the desire by certain manufacturers for a heater in which the heating ribbon is continuous or in as long lengths as possible, in order to reduce as far as possible the number of bolted or clamped connections which carry current.

Fig. 26. Continuous Ribbon Heating Unit for Floor Mounting

In some localities it is not only practicable but economical to utilize electric energy for generating steam. A heating unit (Fig. 27) with control was therefore developed for application to standard fire tube boilers. Wherever there is an excess of hydroelectric power and a scarcity of fuel, or where a manufacturer whose processes require steam desires to do away with the bother and expense of firing boilers, the electrically heated boiler is desirable, since it requires no brick setting, no stack, no attendance except occasional observation, and can be located at the most advantageous point, thus affect-

Fig. 27. Ribbon Resistor Forming Electric Heating Unit for Insertion in Tubes of a Fire Tube Steam Boiler

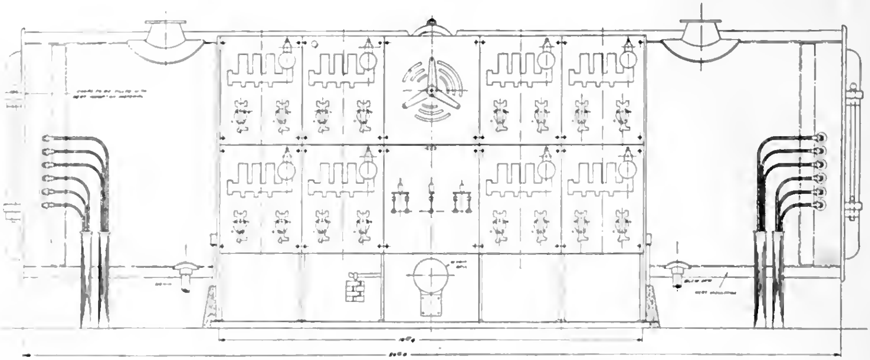

Fig. 28. Outline of Electrically Heated Steam Boiler and Control Board for Automatic Pressure Control

ing in many cases considerable economy in pipe lines and heat losses.

The efficiency of the electric steam boiler of fire tube type (Fig. 28) is practically 100 per cent, as all the energy is expended inside the boiler, and if properly heat insulated the losses from radiation are negligible. These boilers will appeal to engineers for the reason that standard boilers, transformers, governors and auxiliary devices are used.

To meet a widespread demand for compact melting pots for solder, tin, lead and babbitt, there was produced a small self-regulating solder melting pot (Fig. 29) having a capacity of 30 lb. The self-regulating feature on this pot allows for quick initial heating, and as the temperature rises the resistance of the heating units increases and thus the amount of current is reduced, making for economical operation and preventing the contents from burning.

Many manufacturers require larger quantities of tin, lead or babbitt and to take care of this demand a heating pot of greater capacity was produced (Fig. 30) which can be used for temperatures up to 1100 deg. F. This pot has a capacity of 1000 lb. of lead, the equipment including the pot, supporting plate, heating units, insulators, automatic control panel and temperature control instrument.

The advantages of the application of electric heat for purely local purposes are being widely recognized. Where formerly gas, steam, kerosene or gasolene flames were used, requiring considerable piping and attended by many other disadvantages, the cartridge unit and the helical core unit have met with marked success, as they concentrate the heat where desired and do away with piping, are easy to install, improve working conditions, operate efficiently, and maintain

Fig. 29. 30 lb. Self Regulating Melting Pot

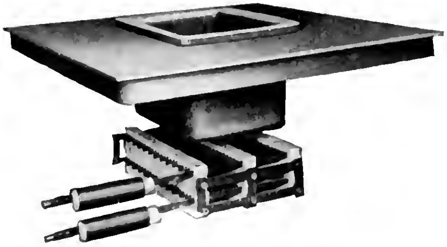

Fig. 30. Details of 1000-lb. High Temperature Melting Pot Not Bricked Up

the same even temperature without adjustment. The helical core unit (Fig. 31) can be made up into a very compact and long lived immersion unit.

TRANSFORMERS

There were three very noticeable advances in transformer construction. The first of these was the marked increase in the use of permanently grounded terminal transformers on grounded neutral systems; another was the increase in the use of large capacity, high voltage transformers; and the last was the great increase in the use of the oil conservator and its adoption for lower capacities than had been used prior to 1921.

High Voltage Transformers

The four 8333-kv-a., 220,000-volt single-phase water-cooled transformers for the Southern California Edison Company (Figs. 32 and 33) were completed, shipped and installed.

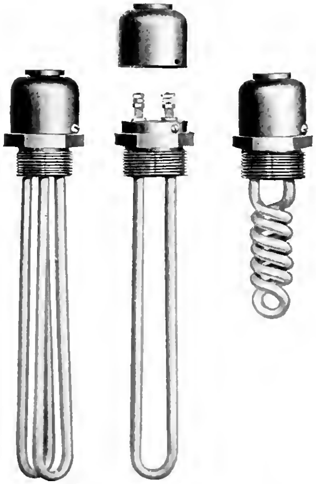

Fig. 31. Helical Core Standard Type Heating Units

These transformers were 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 a grounded neutral. The high voltage winding was composed of two sections in multiple, the line lead being located at the center of the coil stacks, and the grounded lead at the ends of the stacks. These transformers were the first built for 220,000-volt commercial service, but at the present time are operating at 150,000 volts, pending the change-over of this system to the higher voltage.

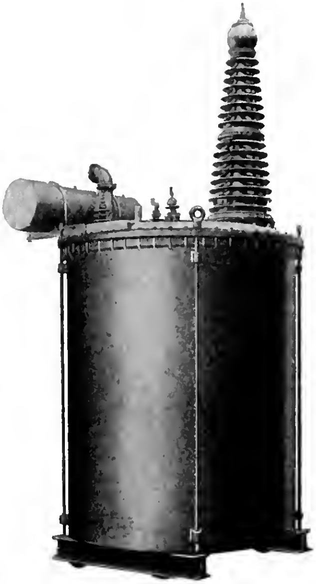

Fig. 32. High Voltage Side of 220,000-volt Transformer

It has been found that the concentric arrangement of circular high and low voltage coils is the only one which is satisfactory for transformers designed for very high potentials. Not only is the space factor greatly improved by this construction, but the major insulation between windings is very simply obtained by a group of several insulating cylinders of high mechanical and dielectric strength.

There were under construction seven 7500-kv-a., 220,000/100,000/110,000-volt, 60-cycle single-phase water-cooled transformers for the Pacific Gas & Electric Company, having an output capacity of 16,666 kv-a. and provided with three windings; the tertiary winding giving 13,333 kv-a. for the operation of 11,000-volt synchronous condensers.

Transformers of Large Capacity

The development of a satisfactory means of dissipating the losses in large self-cooled transformers, namely, separable steel radiators, resulted in a demand for larger self-cooled units. Three transformers rated 10,000 kv-a. 27,600Y/13,800Y volts (Fig. 34) were built for the Milwaukee Electric Railway & Light Company. In kilovolt-amperes capacity they are the largest transformers of this type.

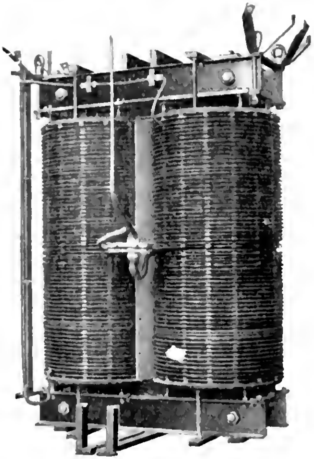

Fig. 33. Arrangement of Coils and Leads of 220,000-volt Transformer

Four combination self-cooled water-cooled units rated 7500/15,000 kv-a., 22,000Y-33,000Y-12,600 volts were constructed for the Commonwealth Edison Company of Chicago. These have a self-cooled rating of 7500 kv-a., and by circulating water through the cooling coils the rating may be increased to 15,000 kv-a.

Two three-phase water-cooled units were built which were rated 10,000/20,000 kv-a., 62,000Y-11,000 volts. These were designed for either 25-cycle or 60-cycle operation, the higher capacity rating corresponding to the higher frequency.

There were also a considerable number of large capacity units completed or under construction for foreign countries. These include both water-cooled and self-cooled types and are mostly for 50-cycle service. They range in capacity from 7500 to 14,000 kv-a. with high potential windings up to 132,000 volts. They will be placed in service in South America, Europe, Asia and Australia.

Among these foreign units are seven single-phase water-cooled transformers rated 3333-kv-a., 105,000-volt, 50 cycles for service in France. These units are all provided with ratio adjusters and are the first high voltage transformers built for Europe which are so equipped.

The use of the ratio adjuster (Fig. 35) in the United States was greatly extended during the year and it was applied to larger sizes than in previous years, being now available for capacities up to 115,000 volts at 200 amperes. When ratio adjusters are used on transformers with conservators, it is necessary to bring the operating handle and position indicator outside the tank, and at the same time to maintain an oil-tight joint. A design has been developed for this purpose and is now regularly supplied.

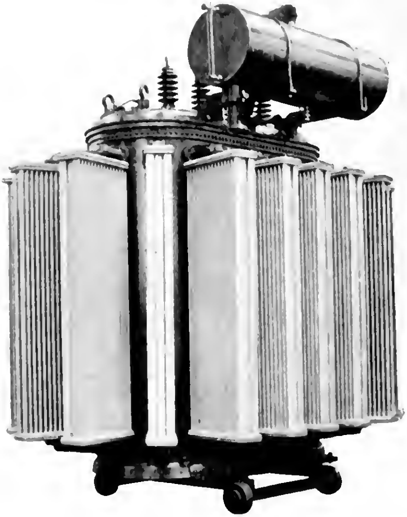

Fig. 34. Arrangement of Radiators on 10,000-kv-a. Self-cooled Transformer

The previous low limits for transformers equipped with conservators were 7500 kv-a. at all voltages and 80,000 volts at all kilovoltampere capacities, but during the year numerous units with ratings ranging down to 2500 kv-a. were so equipped and the economy and reliability secured in actual service with these units indicate the entire feasibility of applying the conservator to transformers of lower capacity.

The advantages resulting from the use of the conservator have been known for some time; namely, the protection from condensation of moisture in the oil, the elimination of possible explosion of mixtures of gas and air at the top of the tank, and the practical elimination of sludging of the oil due to its oxidation when in contact with air at fairly high temperatures. During the year it was further found that the life of fibrous insulating materials is considerably increased by the use of the conservator. The decrease in aging due to the use of the conservator offers an advantage of about 10 deg. C. in temperature; that is, the deterioration at 105 deg. C. with a conservator is no greater than the deterioration at 95 deg. C. without a conservator.

Another self-apparent feature is the immediate detection of leaky cover or bushing joints, and the impossibility of moisture entering the transformer at these points.

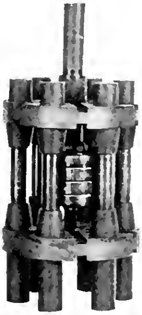

Fig. 35. 110-kv-a., 200-ampere Ratio Adjuster

In the January, 1920, issue of the GENERAL ELECTRIC REVIEW mention was made of the use of the four-part distributed core (Form K) for larger transformers. This construction has since been used on some transformers rated 1500 kv-a., 72,600/13,200 volts. It is probable that in the near future it will be used for moderate voltage transformers up to 2500 kv-a.

TRANSMISSION LINE CHARACTERISTICS AT ONE MILLION VOLTS

Twenty-three hundred volts from a 60-cycle generator were stepped up by a transformer to a million volts and higher in the high voltage engineering laboratory at the Pittsfield Works, and this was transmitted over a short section of transmission line (Fig. 36). This line was insulated with ordinary porcelain insulators and the conductors were free from corona. As far as is known this is the first time that a million volts has been produced at commercial frequencies.

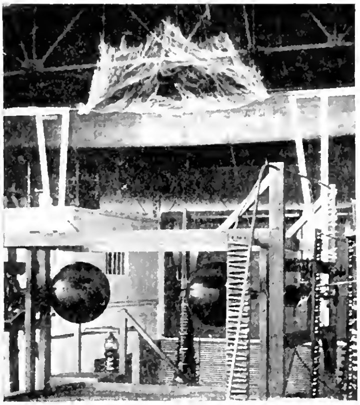

Fig. 36. 1,000,000 Volts Arcing Across a 9-ft. Spark Gap

The importance of these tests from the transmission line standpoint is that apparatus has been built and a short line insulated far above immediate requirements.

For some time engineers have been able to predict with certainty corona and sparkover characteristics of high voltage transmission lines. These predictions were based on laws of corona established by careful tests made up to about 250 kv. and on sparkover curves established on needle and sphere gaps and line insulators at somewhat over double this voltage. As is mentioned elsewhere, commercial apparatus has already been built for 220-kv. operation.

It was of great present theoretical and probably future practical interest to determine experimentally if there was a discontinuity in the established laws and curves at a million volts or over. While no deviation was expected, assurance was not possible until actual tests had been made.

Tests up to about 1100 kv. were made on the various elements entering a transmission line as follows:

(a) The spark-over curve between points showed no discontinuity. The spark-over at 1000 kv. was found to be about 105 inches.

Fig. 37. Shield for Equalization of Voltage on Insulators Showing Dry 60-cycle Arc-over on a Shielded String

(b) The spark-over curve between 75 cm. spheres showed no great deviation from calculated values.

(c) Tests were made on strings of line insulators and the spark-over voltages were as expected. For instance, a string of eighteen standard suspension insulators arced over at about 900 kv., while a string of twenty-two insulators did not arc over at over 1000 kv.

(d) Visual corona tests were made on 3½-in. diameter brass tube lines, single-phase. The corona starting voltage, about 900 kv., checked with the calculated value.

As a result of these tests, a million volts are now available for laboratory work, and transmission systems with potentials greatly in excess of those used commercially at the present time can be accurately calculated. The future effect of this investigation on superpower zones is, of course, problematical at present, but it is interesting to recall that 220,000 volts were produced in a similar manner about twenty years before being applied commercially.

The production of a million volts could not have been accomplished without suitable insulation, and experiments during the year have proved that this feature will not limit the development of higher voltage transmission lines.

When a number of suspension insulator units are placed in series the voltage does not divide evenly over the string. In fact, when over five units are used 20 to 30 per cent of the voltage appears across the line unit. As can be readily seen, this becomes serious at the higher voltages when the stresses across the units near the line become very high.

The uneven distribution is caused by the capacity and resulting dielectric stress to ground. It was found that the uneven voltage distribution can be readily corrected by means of an electrostatic flux distributing shield (Fig. 37) placed at the line end. The shield in effect eliminates the disturbing flux to ground and causes each unit to take its share of the voltage. By using this shield it is possible to have lower unit stresses on the insulators of a 220-kv. line than those existing on present 110-kv. lines. Fig. 37 shows an arc-over on a shielded string of insulators.

Shielding has other important uses, and its advantages may be summarized as follows:

(a) Causes even distribution of voltage on the string.

(b) Prevents corona on the units.

(c) Directs arcs away from the string.

(d) Reduces surface voltage stresses, and this increases arc-over on a string where part of the units have become conducting because of dirt.

(e) Does not require special insulators.

Current Limiting Reactors

Since reactors are intended to function under abnormal conditions only, such as short circuits, it is necessary that they be designed very generously so as to have an ample factor of safety for both the currents and voltages developed under these abnormal conditions. In order to demonstrate that the cast-in concrete type of reactor will protect under abnormal conditions, tests were made during the year on a large operating company's system, under the most severe conditions of short circuit obtainable. These tests fully proved both the reliability and the mechanical strength of this type of reactor. The normal capacity of the system used in these tests was 150,000 kw.

For several years there has been a demand for reactors suitable for outdoor installation, and this demand increased notably during the year. To be suitable for this service, the reactor must be able to function under the most adverse conditions. Similar tests were therefore made on the same system with outdoor reactors under conditions representing the heaviest precipitation of rain. These tests were unqualifiedly successful, thereby demonstrating that outdoor reactors of substantially standard construction can be safely used where this seems necessary from an operating standpoint.

Under certain conditions it is desirable and economical to install reactors in high voltage lines, and several reactors were built for service in 66,000-volt circuits. The windings were constructed and insulated in the same manner as in a transformer of the same voltage, and because of the high voltage they were oil immersed and were contained in a corrugated steel tank when self cooled, or in steel plate or corrugated tank (Fig. 38) when water cooled.

Since they were current-limiting reactors, it was necessary that they have a straight line volt-ampere characteristic. For this reason they had no iron cores and unless properly confined the flux would pass into the containing tanks, causing excessive losses. This condition was avoided by placing a short circuited winding outside the reactor and adjacent to the walls of the tank, effectually preventing the flux from flowing into the tank and minimizing the losses. On water-cooled reactors the cooling coil was utilized for the flux shielding winding.

Research Laboratory

The work of the Research Laboratory during the year resulted in a number of important developments, some of which have already been turned to practical commercial use. Space limitations prohibit more than a brief reference to some of the more important achievements.

A highly efficient photo-electric cell was produced which comprises a sealed tube having a central anode and a cathode consisting of a coating of silver formed upon the wall of the tube and upon which metallic potassium has been deposited. An opening in the cathode is left to provide a window for the passage of light which falls on the interior surface of the cathode. The cell is highly sensitive and permanent in its characteristics.

In operation, this cell is placed in series with a suitable supply of potential, such as a pliotron tube, and the current values of the circuit vary with the amount of light entering the cell. A great variety of applications are possible with this cell; among them the transmission of pictures by radio is probably made feasible.

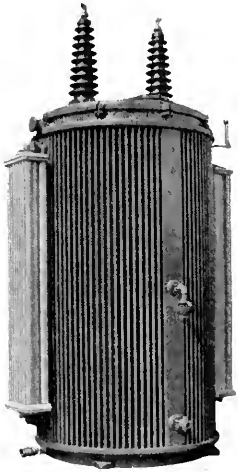

Fig. 38. Oil Insulated Disc Coil, Water-cooled Reactor

A kenotron rectifier was constructed for use in smoke precipitation, with a rating of 0.25 ampere, 100,000 volts.

In connection with turbine research work a condenser was constructed for spark discharge photography, which of course is available for any high speed work of similar character. The camera takes a film of 100 pictures at the rate of 1000 per second. This means that for a 25-cycle phenomenon there will be 40 pictures per cycle and 2½ complete cycles per film, and on 60 cycles there will be 16⅔ pictures per cycle and six complete cycles per film. This camera has been applied to the photography of transformer coil distortion on instantaneous short circuit.

An interesting form of automatic motor starter consists of a unit resembling a large sized sheath wire unit but insulated with copper oxide, which has a high resistance when cold and low resistance when hot. The unit is placed in series with the armature and a relay provided to short circuit it when the motor is up to speed.

Carrier Current

A demonstration of the application of "carrier current" communication from a moving car was made in November, 1921, and represents an important advance in electric train operation. The system was developed to provide better means of communication between the locomotive and caboose of long trains and between trains and substations or waiting rooms of electric railroads.

The operation of the system is as follows: The trolley wire, carrying current to the electric locomotive or trolley car, is used as a carrier of telephone communication by means of another current of different frequency, which is superimposed on the wire and travels along it. This "carrier current," properly modulated by speech, is drawn off by special apparatus (Fig. 39) to a telephone instrument. At any point along the line, however, the message speeding along the trolley wire may be transmitted short distances through the air and made to energize an instrument in a substation or waiting room, becoming audible through a receiver. In effect the system transmits messages electrically partly over a wire and partly through space

Fig. 39. Operation of Carrier Current Communication on Test Car

In tests engineers have not only been able to telephone but to operate relays, light lamps and start and stop one car from another car at a distance of a mile and a half. Communication by this means has been effected successfully over distances of from 40 to 60 miles.

Oil Immersed X-ray Apparatus

An important advance in the development of X-ray apparatus successfully eliminates the danger of electric shock to patient and operator by complete isolation of the high tension sources within a grounded, oil-filled metallic container. This receptacle contains the X-ray tube, high tension transformer, and the stabilizer, the whole weighing only 20 lb.

Fig. 40. Dental Oil Immersed X-ray Outfit in Use

The metal container is mounted in a rotating forked steel bracket (Fig. 40) giving thorough freedom of motion both vertically and horizontally through a considerable space and with just sufficient friction to hold it wherever put. The bracket may be supported from the wall, or when used for dental radiography, which is believed to be one of its most useful applications, from some existing dental fixture. The X-rays pass through the top of the sealed container and are focused by a bakelite tube attached to the container which also serves as a mechanical contact between the outfit and the patient.

The outfits operate on 40,000 volts, 10 milliamperes in the small size apparatus suitable for dental purposes, and 60,000 volts, 50 milliamperes in a larger outfit intended for more general work. The tube is of the self-rectifying type and is materially smaller than any yet developed, being only 5¾ in. long. Except for its small transparent window of lime glass through which the X-rays pass it is made of glass containing 55 per cent by weight of lead. This affords protection equal to $\frac{1}{32}$ in. of sheet lead.

The small stabilizer serves to hold the milliamperage constant at the predetermined value. This is hermetically sealed in a small bakelite box supported by insulators from the cover of the oil-filled container. The oil in the tank expands as its temperature rises and flows through a small capillary tube into an air chamber which is so designed that the air cannot escape into the main tank.

200,000-volt D-C. Generating Apparatus

In order to satisfy a demand for some effective method of generating high tension direct current, an outfit was developed capable of producing direct current at 2 kw., 200 kv., by rectifying high tension alternating current. Aside from X-ray therapy, this outfit will be found useful for laboratory applications, such as research work on X-ray spectra, study of corona and sparkover as a function of potential, and insulation tests.

The generating equipment consists of a small, 2000-cycle, 2-kw., 110-volt generator driven by a 125-volt direct-current motor, a transformer, four kenotrons, and a series of condensers and choke coils. By means of this apparatus the X-ray tube, for example, is supplied with 10 milliamperes at 200 kv., with a "ripple" varying from 1 per cent to 0.1 per cent, depending on how many refinements in the way of choke coils, condensers, etc., are used.

In operation, the motor-driven generator supplies 110-volt, 2000-cycle current to the transformer. The generator is excited from a direct-current source, and by means of a rheostat in its field can be controlled so as to give from 50 to 200 kv. at the terminals of the X-ray tube. The transformer is wound to give 75 kv. on the high tension side and has an air gap in the magnetic circuit. When untuned it requires 75 amperes magnetizing current. One end of the high side is grounded, the other goes to the rectifying circuit.

To understand the operation of the outfit it is necessary to have some idea of how a kenotron functions in rectifying the current. A kenotron consists of a hot filament cathode and a metal anode in a vacuum, the conductivity being entirely due to the passage of the electrons emitted by the hot filament. For this reason the conductivity is entirely uni-directional in character. In other words, the resistance to a wave of alternating current is very low in one direction, but when the current starts to reverse, it encounters infinite resistance and cannot pass over. The result, from a single kenotron, is a series of half waves, giving what amounts to a pulsating continuous current, of the same value as the original alternating current.

In this equipment the half waves are made to charge a condenser, which discharges in the same direction when the transformer potential falls below that of the condenser; or, when no current is flowing from the kenotron, the condenser supplies the current by discharging, thus rendering the pulsations of continuous current smaller. The condenser cannot discharge back through the kenotron on account of the latter's resistance to the flow of current in the reverse direction.

By connecting in two pairs of kenotrons, with the anodes and cathodes reversed, and two pairs of condensers, both halves of the alternating-current waves are used, with the result that the direct-current voltage produced is twice the maximum voltage given by the transformer, or 2.8 times the effective voltage of the transformer.

Radio

Notable progress was made in the development and design of apparatus and devices for radio telephony and telegraphy, and during the year many of the new devices were produced in quantity on a commercial basis.

The improved equipments for transoceanic receiving systems permits practically continuous reception even under the most adverse operating conditions. This new type of equipment was installed in several stations on the Atlantic Coast and three complete sets are under construction for installation in Poland.

For high power transmission, 21 200-kw. Alexanderson high frequency alternator equipments were completed. Some of these machines are now in operation on the Atlantic and Pacific Coasts of the United States, and in Hawaii and England. The most conspicuous installation is that near Port Jefferson, Long Island, in the great radio central station which, when completed, will be the largest and most powerful in existence, insuring a transmission range that is practically world wide.

Low power commercial sets (Fig. 41) suitable for either marine or land service were developed for both telephone and telegraph transmission. The vacuum tubes used in these sets are rated at 0.2 and 1 kw. In addition there were produced a 2-kw. and 4-kw. vacuum tube transmitter, a duplex telephone equipment and an accessory unit, for use with the present spark set ship installations, providing continuous wave telegraphy.

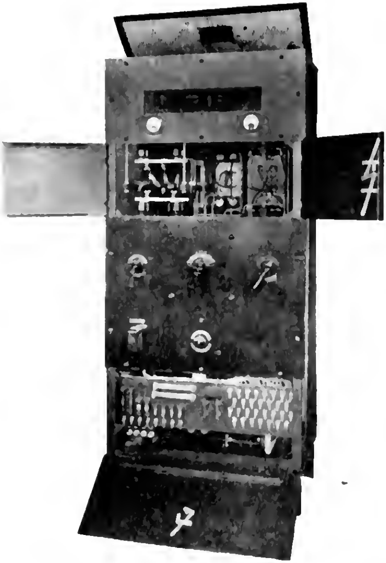
Fig. 41. 1-kw Commercial Radio Transmitter

The first installation of a 2-kw. set (Fig. 42) was made at Almirante, Republic of Panama, for the United Fruit Company, and gives a 66 per cent greater signal strength at a distance of 1550 miles than a 25-kw. spark transmitter at a distance of 960 miles. For use with these transmitting sets there was standardized and produced in quantities a complete receiving equipment. The vacuum tube detector and amplifying units of this equipment (Fig. 43) utilize a special form of metal case which provides a maximum amount of shielding and accessibility.

In the manufacture of the commercial sets, there was standardized a full line of component parts which are available to the radio experimenter. This enables the experimenter to assemble these parts as complete equipments and permits the selection of various combinations and capacities at a minimum expense. Included among these component parts are such signal developments as the magnetic modulator and the radio frequency intervalve transformer.

A complete line of three element tubes for radio purposes was produced in quantities. For receiving purposes, there is an unusually sensitive gas content detector and also an amplifier, both of these being long life tubes. For transmission, there are now available tubes giving an output of 5, 50, 250 and 1000 watts, and also a line of kenotrons to provide high plate voltage for the different pliotrons as an alternative to high voltage generators.

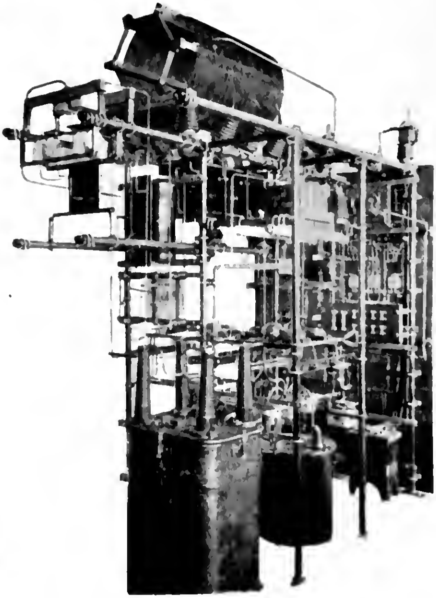
Fig. 42. 2-kw. Radio Telegraph Transmitter for "Almirante"

Industrial Control

The vast forces employed in the electrical operation of steel mills and various industrial applications where large motors are operated under severe service conditions must be controlled with absolute reliability in order that the operation of the machinery may be both safe and efficient.

It is therefore evident that the design of the controlling apparatus is as important as that of the machinery which is controlled and the degree to which success is attained in the numerous industrial installations is directly dependent on the efficiency and reliability of the detail elements which are used for their control.

The industrial control developments included radical improvements in previous designs and methods of manufacture which resulted in greatly increased life and reliability for many of the basic control elements. Among the more important of the new products are "bent-frame" direct-current shunt contactors, voltage-drop relays, plunger type series contactors and open-phase and phase-failure relays.

The "bent-frame" type of direct-current shunt contactors (Fig. 44) utilizes pressed steel and punchings for many parts which were made up of castings in previous designs. The rupturing capacity has been increased by means of arcing horns on the tips, large pear-shaped pole pieces and restricted arc chute openings, so that when the arc is formed it is instantaneously extended, cooled and broken; thereby lengthening the life of the contact tips and minimizing the burning effect on the chute adjacent to the tips.

On the "bent-frame" type, the total elapsed time from energizing the coil until the armature is closed is a little less than for earlier designs; but the time from beginning of the movement of the armature until it is closed is considerably less. The smaller inertia of the armature gives a higher speed to the tips and decreases the possibility of "freezing" especially when "jogging."

The new voltage-drop relays are used to electrically interlock shunt contactors in such a manner as to govern the time and sequence of their closing when short circuiting steps of a resistor, a function which current-limit interlocks have performed in the past. Each current-limit interlock has been mechanically connected to a contactor and has been operated by a current coil connected in series with the controlled motor. This system imposed a mechanical burden on the contactor and exposed the interlock, which was of necessity more or less delicately adjusted, to the jars of the contactor; distributed the interlocks over the panel so that they could not be adequately protected against the excessive accumulation of dust and the action of corrosive gases; and necessitated a series coil that was designed according to the value of full-load current of the motor for each interlock.

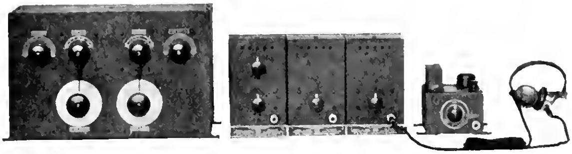

Fig. 43. Commercial Short Wave Radio Receiving Equipment

The operation of the relays (Fig. 45) is mechanically independent of all other units. They can therefore be grouped on the base of some panel (Fig. 46) and enclosed. Each relay has two shunt-wound coils, one of which functions in a way which corresponds to the action of the mechanical connection between a current limit interlock and a contactor and another which has the same

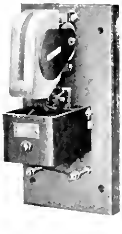

Fig. 44. 150-amp. Bent-frame Type, Direct-current Shunt Contactor

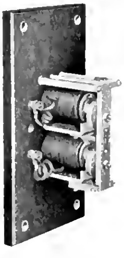

Fig. 45. Voltage Drop Relay

function as that of the series coil of the interlock.

The relay functions on the drop in voltage across a step of the armature resistor so as to give true current limit acceleration similar to that of a current-limit interlock, but in addition it has a definite time element. This time element is obtained by the inductance in the relay and is adjustable, but after adjustment it is not subject to change as are the time adjustments that are obtained by dashpots and other mechanical appliances.

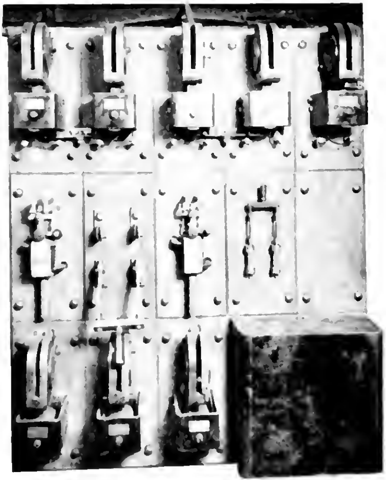

Fig. 46. Arrangement of Panel with Voltage Drop Relays Enclosed in Protecting Case

The combination of current limit and time element is particularly desirable in the control of motors that are occasionally required to accelerate loads much greater than normal. When accelerating a heavy load the current-limit characteristic governs the operation and allows current inrushes sufficient for the torque required, but when accelerating a light load the time element governs the operation and limits the current peaks to much lower values.

The development of the gap-adjusted plunger type series contactor (Fig. 47) has logically resulted from the simple type of control possible with series contactors and its consequent widespread application. It is made in three forms, viz., with a series coil, with a series coil and a shunt coil, and with a series coil, a shunt coil, and a magnetic blowout.

The principal application of these contactors is to short circuit steps of an accelerating resistor. They provide current-limit by means of the series coil, which is ordinarily connected in series with the accelerating resistor or motor armature or both. For applications in which it is sometimes required to accelerate a motor with such a light load that insufficient current to close the contactor would be encountered, and also for applications where the load of the motor might become small enough to let the contactor open, a shunt coil which furnishes sufficient flux to close the contactor is also supplied.

It was found that a good many polyphase motor burnouts are due to attempting to operate single-phase and this caused a demand for a reliable and inexpensive open-phase protective relay. Most relays designed for this purpose depend for their operation on an unbalancing of the line voltage at the motor terminals, caused by the single-phase condition. Obviously, a single-phase condition does not always cause voltage unbalancing, as for example, a lightly loaded motor operating from a supply whose voltage is well maintained.

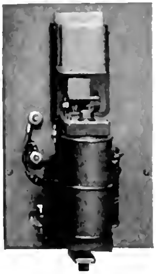

Fig. 47. 300-amp. Gap Adjusted Plunger Type Series Contactor

The open-phase and phase-reversal relay (Fig. 48) equipped with series coils provides protection against phase failure when the motor is running and also operates upon attempting to start the motor single-phase. It also provides reverse phase protection.

Printing Press Control

A line of predetermined speed, push button operated printing press controllers of the totally enclosed type was produced (Fig. 49). By means of an externally operated handle the speed can be set at any predetermined value. Enclosed push button stations mounted upon the press enable the operator to jog, start the press and run it up to the predetermined speed, slow it down to a minimum speed, or stop the press quickly through a dynamic brake. There is no possibility of coming in contact with any live parts and fire risk is absolutely removed.

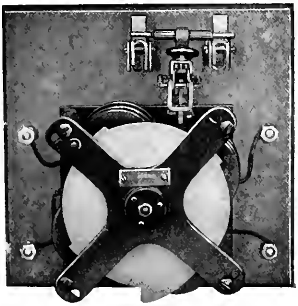

Fig. 48. Open-phase and Phase Reversal Relay

The controller provides for acceleration both by a current limit lock-out contactor and a counter e.m.f. contactor according to the individual requirements. It is built in sizes from ¼ to 20 h.p. and is adapted for all types of printing and allied machinery involving variable speed and starting under load. As the controller is totally enclosed it is protected against dust and dirt and tends to keep in perfect condition.

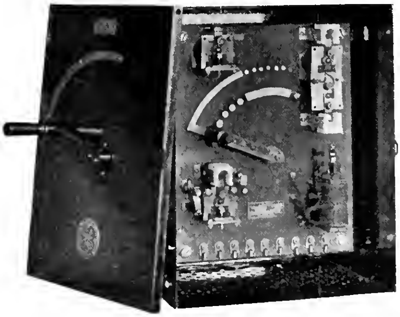

Fig. 49. Safety Type Predetermined Speed Controller

Blower and Fan Control

In the control of electric motors for operating blowers and fans in public buildings, office buildings, schools, theaters, etc., there has gradually been reached a standardization on enclosed designs of the safety type. Such controllers must be protected against accidental personal contact with live parts, and they should be locked against starting or changing of the speed by tenants of the building or other unauthorized persons.

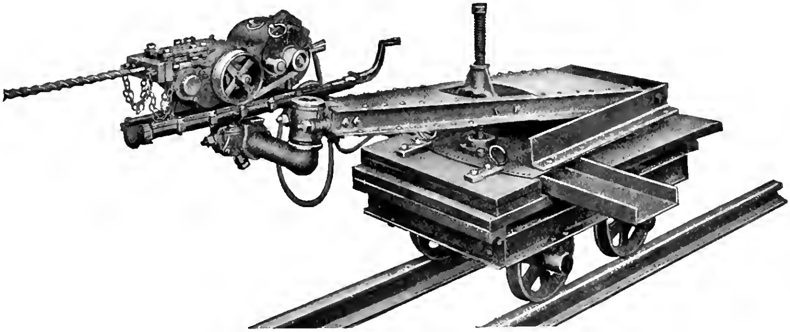

Fig. 50. Boom Mounting for Rock Drill Installed on Mine Car

The new controller is contained in a separate cabinet provided with hinged lock. The switch and fuses are contained in a separate box of safety-first construction, so arranged that the cover cannot be opened to remove the fuses without opening the switch. The fuse compartment is on the dead side of the switch, making all contact with live parts impossible.

Fig. 51. 100-amp. Safety Enclosed Overload Air Circuit Breaker

The enclosed controller and the enclosed switch are both mounted upon pipe frame work suitable for floor mounting, the whole equipment being wired up in rigid pipe with no exposed parts of any kind. It may be of the manually operated type or of the remote predetermined push button operated type, the same method of mounting and enclosing being employed in either case.

Fig. 52. 2400-amp., 250-volt Direct-current Circuit Breakers Mounted on Feeder Bars

Boom Mounting for Rock Drill

To meet the demand for a more nearly universal mounting to support the Fort Wayne electric rock drill, a boom mounting for installation on a mine car was developed to take the place of the tripod and column mountings previously used. With a drill so mounted on a mine car (Fig. 50) all the work of moving the drill and of set-ups is eliminated. The drill can be quickly and easily adjusted to any desired drilling position as the lifting and shifting of the drill is done by the boom.

This mounting is adaptable to any character of work; for instance, drilling top and bottom in coal mines, driving tunnel, etc. It will handle a tunnel 7 ft. high by 12 ft. wide and will pass under a headroom of 3 ft. measured from the top of the track rail.

The device consists of a steel bed which supports the boom, and rests on two channel irons bolted to the bed of a mine car. The boom is a V shaped steel structure, one end being held in position by a through stud about which it can revolve, the outer end being raised or lowered as desired by means of a jack screw passing through a nut in swivel bearing supports. An adjustable arm to support the drill saddle and drill is mounted on the outer end of the boom. A mine car of at least 42 in. wheel base should be used for the outfit.

Fig 53. 15,000-volt, 400-amp. Triple Pole Solenoid Operated Oil Circuit Breaker

Switching Apparatus

The latest type of small safety enclosed air circuit breaker is mounted in a metal box (Fig. 51) and is tripped from the outside of the box by a button attached to a tripping shaft connected to the breaker tripping device.

The closing is accomplished by a pivoted arm rotated in one direction to close one pole and in the opposite direction to close the other pole, thus leaving the pole first closed free to trip if the other pole is being closed on a short circuit. The handle returns to the mid-position when released by the operator. There are slots in the front of the box through which an indicator shows green or red, depending upon whether the respective poles are open or closed.

As safety features, there are means for locking the cover on the box and for locking the operating handle so that only an authorized person can reclose the breaker after it has been tripped, either automatically or manually. If the lock is not used the breaker can be closed by any person at any time.

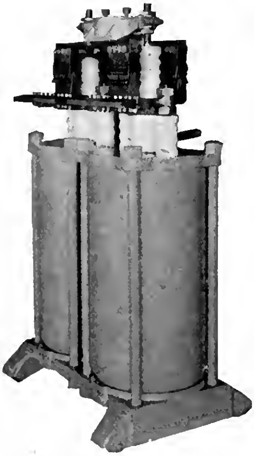

Fig. 54. Removable Single Pole Unit for Isolated Phase Arrangement

The breaker can be tripped manually or automatically at any time regardless of the locking features.

A new type of solenoid operated air circuit breaker was produced for use in bus bars where space is limited. These circuit breakers are non-automatic and are used on 250-volt, 2400-ampere circuits. They are made up as entirely separate units and may be secured into place on the feeder bars (Fig. 52) from the front by tightening the nuts on three studs at each side of the breaker. The upper contact block is insulated from the other parts of the breaker, and the bus bars to which the breakers are connected are run horizontally back of and are supported by a suitable iron framework. The framework or feeder bar on which the breakers are mounted is supported by insulated studs at the top and bottom.

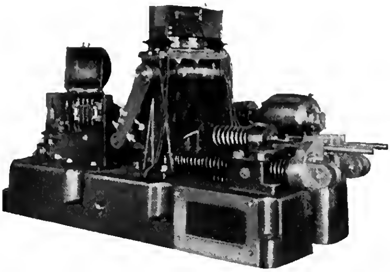

Fig. 55. Motor Operated Mechanism for Oil Circuit Breaker for Isolated Phase Arrangement

Standard push button control switches are used to operate the breakers, and control circuits are arranged simultaneously to close or trip the positive and negative breakers.

An oil circuit breaker originally designed for outdoor service and pole mounting was developed for ground or floor mounting. The pole-mounted breaker is manually operated only, but the ground-mounted breaker (Fig. 53) can be operated manually or by solenoid; the solenoid being located on the ground or floor in a weatherproof case. The solenoid can be tripped from the outside of the weatherproof case, which has removable doors. Relays can be mounted inside the weatherproof housing if required.

A very important line of large central station cell-mounted oil circuit breakers embody several new ideas. The oil tanks are oil tight, gas tight, and electrically dead. Each pole is mounted on a truck (Fig. 54) and can be quickly removed from the cell for inspection or repair and a spare unit inserted. The contacts and other current carrying parts can be removed from or replaced in the oil tanks as a unit. In each oil tank there is a gas vent which can be connected to a pipe for leading away any gas generated when the breaker has interrupted the circuit under load.

The cells containing the oil tanks can be arranged in the ordinary manner for motor operated oil circuit breakers, or they can be arranged according to the separated-phase system in which all breaker poles, disconnecting switches and bus work for any particular phase are installed in a cell structure isolated from the other phases.

Fig. 56. 200,000-volt Oil Circuit Breaker Showing Arrangement of Triple Solenoid for Operating Mechanism

In a recent installation of these breakers arranged for operation as a separated-phase system, the switching equipment is mounted in three stages or tiers, one above the other. The lowest comprises the oil circuit breakers, the second the disconnecting switches, and the top the main operating mechanism and the unit mechanisms.

The breakers are motor operated (Fig. 55) through three paralleling mechanisms, one per pole, which are actuated by a heavy main operating mechanism so constructed that the motor which operates it compresses a number of strong spiral springs. The springs when compressed have sufficient energy for both the opening and closing strokes. As a safety feature the motor follows the spring action in the opening stroke to assure an absolute opening operation.

Disconnecting switches of special design and of the same capacities as the breakers are also included in the equipment and are operated from the breaker mechanisms to close before the breaker closes. The disconnecting switches are also adapted to manual operation and when so operated can be thrown to a third position so as to ground the oil circuit breaker. The disconnecting switches are double-throw and there are six to each triple-pole breaker.

In the opening stroke the opening of the breakers is followed shortly after by the opening of the disconnecting switches; the circuit then being opened cannot again be closed until the springs are again compressed for the operation of the opening and closing stroke. Interlocks between the oil circuit breakers and the disconnecting switches

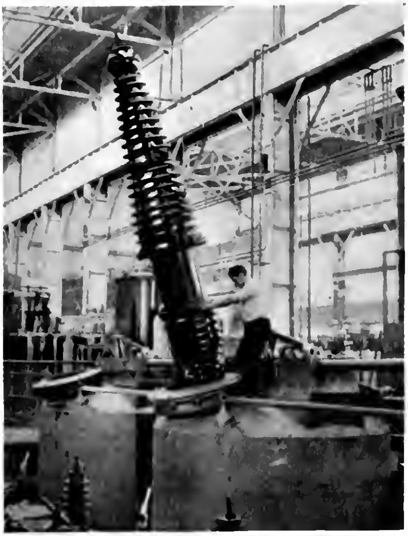

Fig. 57. One of Top Bushings of 200,000-volt Circuit Breaker Being Installed

prevent the disconnecting switches from either being opened or closed when the breaker is closed.

The main operating mechanism is controlled by a three-button control switch with visual indicating signals. A white light indicates that the breaker and disconnecting switches are open and that the springs in the main operating mechanism are relaxed with all energy expended. When the first control switch is closed the motor compresses the springs, closes the disconnecting switches, and the indication that all is in readiness for the closing of the oil circuit breaker is given by a green light. The second control switch is then closed and the mechanism functions and closes the oil circuit breaker, indicating by a red light that the circuit has been completed. Then when it is desired to open the breaker the third control switch is closed and the breaker trips out, the disconnecting switches follow, and the white light gives this indication.

These breakers have been made up to 3000 amperes, 15,000 volts, but can be built for higher current capacities.

The line of outdoor high voltage high capacity oil circuit breakers was extended during the year from 165,000 to 220,000 volts by the production of the largest units ever built. Three solenoids, one on top of the other (Fig. 56), are used to operate the breaker. The tanks are equipped with three-ply pressboard linings, and with oil filling and oil draining valves. A manhole in the dome cover allows entrance to an empty oil tank for examination of the explosion chambers and the operating contacts. Each breaker is equipped with an indicator which tells whether the contacts are in the closed or open position.

Fig. 58. Direct-current Underload and Reverse Power Relay

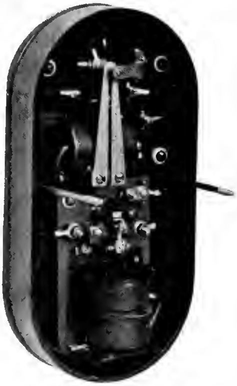

Fig. 59. Temperature Relay for Automatic Switching Equipment

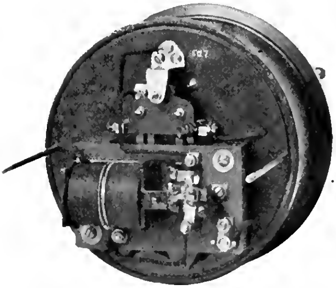

Fig. 60. Temperature Relay for Protection of Waterwheel Generators

The breaker with mechanism weighs approximately 25 tons, is 22½ ft. from the top of the bushing (Fig. 57) to the bottom of the tank, and has an overall length of 34 ft. Each oil tank requires approximately 5000 gallons of oil.

Relays*

A direct-current reverse power and underload relay (Fig. 58) was developed to combine these two protective features in a single device. It has two pairs of contacts and a single pivoted armature actuated by one potential and two current coils. This relay is used principally in automatic stations. Under normal operating conditions one pair of contacts is open and the other closed. If the current on the line drops below the underload setting of the relay the underload contact opens and starts to shut down the machine in the normal stopping sequence. If the power reverses, the reverse power contact will close to cause the opening of the direct-current interrupting device.

Fig. 61. 7500-volt, Alternating-current Safety Enclosed Unit Removable Truck Switchboard Panel

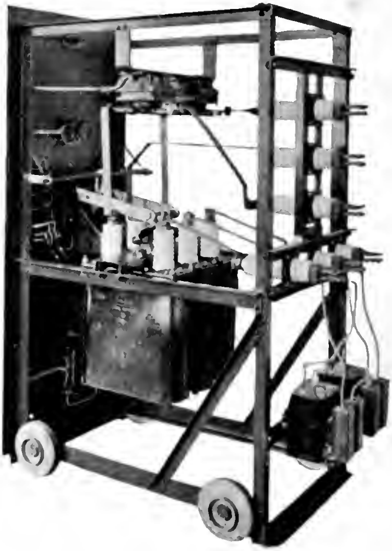

Fig. 62. Interior View of Removable Truck Switchboard Panel

Two new thermal relays, applicable especially to automatic stations, were used extensively. The first relay (Fig. 59) used for the protection of synchronous generators consists of a heating element to which is attached a thermo-couple which operates the primary contacts of the relay. The heating element and thermo-couple are supplied with current proportional to the load in the generator and operate the contacts of the relay to open the circuit-interrupting device before excessive heating occurs in the windings of the machine. An auxiliary relay is provided to operate the circuit-interrupting device and is arranged so that upon the cooling of the relay the circuit is not broken at the primary contacts.

The other relay (Fig. 60) is used for the protection of waterwheel generators. Its principle of operation is similar to that of the first one, but in addition it is provided with a high speed thermo-couple connected in parallel with the heating element and this thermo-couple is used for protection against sustained overload. This high speed element provides additional protection against damage due to destructive commutation.

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* Description of other extensive relay developments by the Switchboard Department has been withheld for publication as a separate article in an early issue of the Review.—Editor.

Truck Type Panels

The safety enclosed removable truck type panel (Figs. 61 and 62), while not a development of the year, was considerably extended in its application and was also improved in several important details. The voltage limit is now 15,000 instead of 7500. The panels have been built for currents up to 1200 amperes and the standard line now includes panels for incoming line, generator, transformer, lighting feeder, power feeder, synchronous motor, induction motor, lightning arrester and bus sectionalizing. The oil circuit breakers can be manually or solenoid controlled.

The dimensions of all these panels are such that a fixed depth, or distance from front to rear of the stationary housing, is suitable for all. The direct consequence is that a single basic design of truck and housing serves for the entire line. The trucks vary only in the dimensions of the transverse members and width of the panels and the housings have in all cases the same side frames, or walls, with transverse members to suit the requirements of the width of the truck panels.

The panels with 7500-volt breakers may be readily lined up with buses run through the entire installation. The wider spacing re-

Fig. 63. Secondary Disconnecting Device for Safety Enclosed Unit

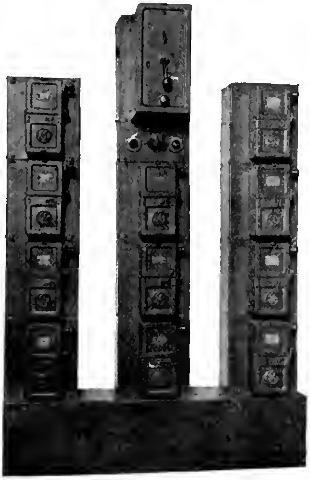


Fig. 64. Switchboard Built Up of Safety Enclosed Lever Switches

Fig. 65. Enclosed Sectional Switchboard with Front Plates Removed Showing Arrangement of Bus Bars

quired by buses of 15,000-volt truck panels is provided by mounting them in a superstructure attached to the standardized 7500-volt housing. Connection bars are used to join the stationary disconnector contacts of the housing to the buses above.

Fig. 66. Post Type Heavy Duty Bus Bar Insulator

This construction allows 15,000-volt truck panels to be lined up exactly with those for 600 to 7500 volts, the same depth being maintained, with the principal difference in total height. The moderate height of the panel, which is the same for all these voltages, does not necessitate an unwieldy truck even for the 15,000-volt breaker and equipment.

Another important matter is provided for in the design of these standardized housings, that is, there is a choice of front-connected or rear-connected bus arrangements. The conventional design, of which there are many truck panel switchboards in service, has the buses supported on the rear ends of the studs of the stationary disconnector contacts. With this location of buses it is necessary to have a passageway of at least 1½ ft. between the rear of the housing and the station wall. If the buses are supported on the front of the stationary disconnector insulators, directly back of the contacts, there is no need of accessibility from the rear (in order to tighten nuts, etc.), and the housing can be set directly against the wall, eliminating the 1½ ft. floor space in rear.

The usual requirement for the incoming and outgoing conductors is that they be carried through the floor, but in cases where it is desired to carry them above, the standardized housing permits the use of overhead conductors just as readily. This applies to installations with front-connected or rear-connected buses.

An automatic shutter of extremely simple construction, and having no small or delicate parts, was developed to completely cover the openings to the live contacts of the stationary housing when the truck is withdrawn.

Other improvements consist of riveted steel angle and sheet construction for the panel and housing, pressed steel wheels with

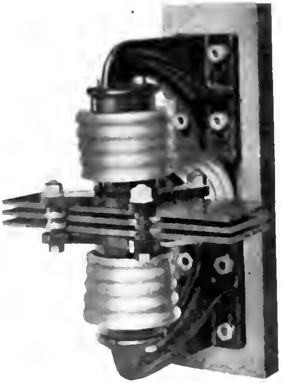


Fig. 67. Bracket Type Bus Bar Insulator

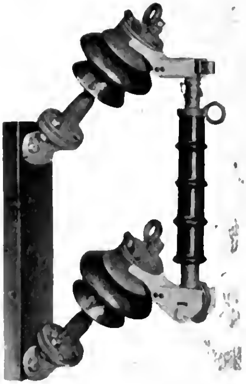


Fig. 68. Fuse Cutout, 15,000-volt 50-ampere

roller bearings and a new design (Fig. 63) of self-adjusting secondary disconnecting device.

Stationary panels, where required, are readily installed alongside or interspersed between truck panels, and serve particularly for exciter switching equipment necessary for generator truck panels. There is but slight modification of the standard housing required where a stationary panel is installed.

The enclosed sectional switchboard represents a very important development for low voltage switchboard work. The main features are flexibility of arrangement and ease of installation. These boards are built up of enclosed lever switches, mounted on suitable boxes (Fig. 64) to form wiring troughs and bus raceways. The busbars, connections to bus, and necessary supports are part of the equipment. As many horizontal boxes as are required can be placed end to end, and a tier of vertical boxes built up on each horizontal box. End plates are removable and thus allow for a bus trough the length of the switchboard.

Removable front plates (Fig. 65) upon which the switches are mounted can be secured into place after all connections have been installed. Holes in this plate correspond to the knockout holes in back of the switch box and the wires can be fed through the back of the switch box when the front plate and switch are mounted.

The units can be mounted on any flat surface or simple framework. Requirements for future additions can be met simply by the addition of units (switch and corresponding wiring trough) and this is an important consideration because the initial expense need be no greater than immediate switching requirements demand.

All switches and wiring are totally enclosed and are thus made safe from an operating standpoint.

Two new types of heavy duty bus supports were produced, the post type and the bracket type. The strength of the post type insulator (Fig. 66) is in the order of 2000 lb. cantilever and 4000 lb. tensile strength. The bracket type insulator (Fig. 67) can be adjusted to support enormous strains. The insulators are subjected to compression strains only. Both supports are rated at 15,000 volts.

A superseding line of fusible cutouts was produced for outdoor service from 15,000 to 75,000 volts and 5 to 50 amperes. The main features of the improved cutout (Fig. 68) consist of asphalt impregnated paper surrounding the fiber fuse tube, a trunnion, and bayonet lock hinge.

The fuse used in the cutout is of the strip type with a contact disk on the upper end for locking under the fuse cap, which, to prevent loss, is attached to the tube by a small chain. Fuses can be removed or replaced without tools.

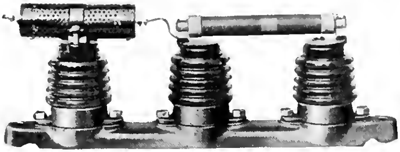


Fig. 69. Combined Potential Transformer Fuse and Resistor for 15,000 Volts

Current limiting resistors (Fig. 69) were developed for use with potential transformer fuses, having voltage ratings ranging from 2500 to 22,000 volts. The object of the resistors is to cut down the amount of current which a potential transformer fuse must interrupt under short circuit conditions.

The resistors are used only with enclosed fuses (not expulsion type) and are particularly recommended on large capacity systems. They so limit the current that in case of a short circuit in the transformer primary windings the amount to be interrupted by the fuse is independent of connected generator capacity.

The ohmic resistance of the resistors for various voltages is such that the error introduced in instrument readings caused by the IR drop across the resistors, with full rated secondary load on the potential transformer, is within the allowable accuracy limits set for instrument transformers.

ULTRA-VIOLET RADIATION

Apparatus

To differentiate the quartz mercury arc from the glass enclosed mercury arc, known for years as the Cooper Hewitt lamp, the trade name of Uviarc was adopted to designate quartz mercury arcs designed primarily as sources of ultra-violet radiation.

For phototherapy with greater ultra-violet radiation intensities than those practical with the familiar air cooled quartz mercury arc, or the Finsen methods, a new high intensity arc was developed for use with a water cooling system by which the radiant heat is very largely removed from the area under treatment. The outfit normally operates at 400 watts, 300 watts in the arc itself. By means of the quartz water cell, which is a part of the cooling system (Fig. 70), it is possible to direct the visible and ultraviolet radiation on surfaces to be treated while at the same time removing the thermal radiation. The intensity and length of ultraviolet treatments thus possible make available physiological effects of great therapeutic value. The concentrated nature of the arc and its high intrinsic ultra-violet radiation make it of special value in connection with the use of quartz lenses and applicators since they only transmit the radiation from a portion of the arc approximately equal to their own relatively small areas.

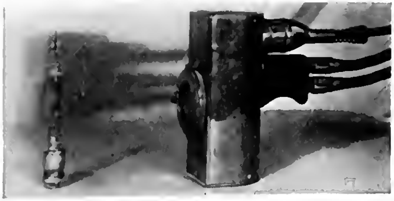


Fig. 70. Water-cooled Quartz Arc Outfit and Burner

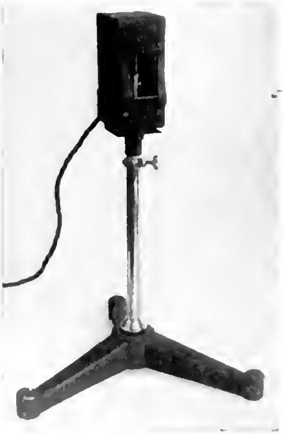


Fig. 72. Quartz Lamp for Use in the Physical Laboratory

A 450-watt quartz mercury arc (Fig. 71) for operation on a-c. was produced to meet the demand for such an arc in places where d-c. is not available. The a-c. Uviarc operates on the familiar Cooper Hewitt rectifier principle with an auxiliary apparatus consisting of auto-transformer and the usual inductance and resistance. This arc has the same radiation characteristics as the standard 110-volt d-c. Uviarc lamp, but may be operated on any standard a-c. voltage by the proper choice of transformer. On a-c. the power factor is 80 per cent. Although not primarily intended for the purpose this burner may also be operated on 110 volts d-c.

Fig. 71. Alternating-current Quartz Mercury Arc Burner

A 100-watt, one-ampere, quartz mercury arc (Fig. 72) was developed for use in the Physical Laboratory. It has an effective light source area of ¼×2 in.; is enclosed in a metal casing to protect the operator and to provide a holder for light filters; emits so little radiant heat relatively that it can be used close up to the accessory optical apparatus; operates indefinitely and without attention; and is made as a single standard unit for operation on 110 or 220 volts, within 10 per cent, and on either a-c. or

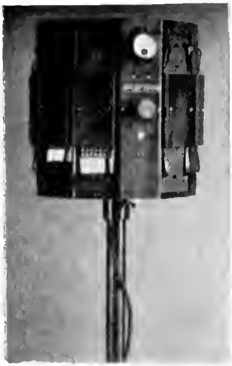


Fig. 73. Ultra-violet Material Testing Cabinet

d-c. The Labarc has the same intrinsic brilliancy as the larger quartz lamps sold for industrial purposes and gives the same well known radiation, a 10,140 Å line in the infra red; yellow, green, blue and violet lines in the visible for the isolation of which Wratten monochromatic filters have been developed; and a very characteristic series of ultra-violet lines extending out to the limits of transmission of clear fused quartz. This light source is of special value to the polariscopist since the Bureau of Standards has recommended the mercury green line, 5461 Å, as the standard source for all accurate polariscopic work. It will also add to the usefulness of the spectroscopic or monochromatic illuminometer, the spectrophotometer, the interferometer, and will be of special value in ultra-violet photomicrography.

The quartz mercury arc has been used for years as a fast method in the routine testing of materials for their resistance to the destructive action of sunlight. It is well known that this is largely due to the photochemical action of the ultra-violet component of the sun's radiation. This component is relatively much greater in the light of the carbon arc and the quartz mercury arc, while the latter has the additional advantage of high ultra-violet intensity with a relatively low thermal intensity. To standardize the technique in this use of the quartz mercury arc a Uviarc material testing cabinet was constructed (Fig. 73) with holders providing for from 20 to 60 samples of thin fabrics, yarn, or paint samples on wood, which are so mounted that various exposures on each sample are easily obtained, and the sample holder itself may be entirely removed without exposing the operator in the slightest to the direct light of the Uviarc. The apparatus is equipped to operate on 110 volts, or on 220 volts, either a-c. or d-c.

Lighting

According to estimates the total sale (Fig. 74) of large tungsten filament lamps (excluding miniature) in the United States during 1921 amounted to 161,000,000 lamps. This is about 20 per cent less than the sales for 1920, and indicates that the demand for lamps has held up comparatively well as contrasted with many other commodities. A similar estimate for the demand for carbon lamps indicates a sale of about 7,000,000 for the year, but since most of the carbon lamps are used for certain special applications they can be considered to have practically disappeared from general lighting service.

The most important of the lamp developments was the improvement of the so-called mill type lamp, which is especially designed to stand rough usage, such as is received by low hung lamps and those used more or less as portables and temporary lamps for construction work. These lamps are more expensive and less efficient than the regular Mazda lamps, and therefore are desirable only for unusually severe conditions. The mill type lamps are made with tipless bulbs having the same diameter as the corresponding regular lamps, but are $1\frac{3}{8}$ in. shorter over all. An important feature of strength is the short stem and coil arrangement of the filament.

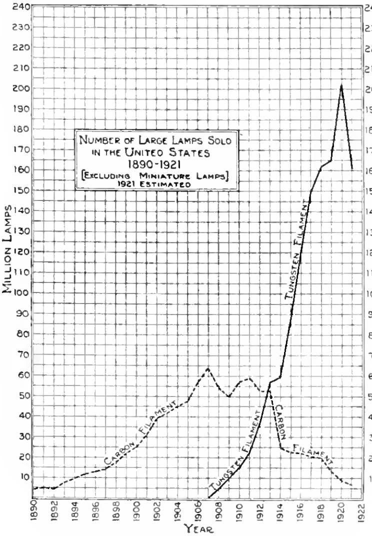


Fig. 74. Number of Incandescent Lamps Sold in the United States—Excluding Miniature Lamps

A new lamp for sign lighting has the same dimensions and type of construction as the mill type lamp, except that it has a bluish colored bulb, giving a whiter appearance when lighted. This lamp is made in the 25- and 50-watt sizes, with vacuum construction for operation on 110, 115 and 120 volts. Both the color of the light and the high end-on candle-power make it particularly distinctive and effective, so that there was a heavy initial demand.

In the miniature lamp field a new process of manufacture was inaugurated which bids fair to have a far-reaching effect on automobile headlighting practice. Automatic machinery was utilized for the manufacture of a precision headlight lamp, and this process is being applied to the 6-8-volt, 21-candlepower tipless lamp. With this construction lamps can be produced with a much smaller variation in light center length and axial alignment. With such a lamp in universal production and using accurately constructed sockets, it should be possible to eliminate the necessity of a focusing adjustment; the headlight being so constructed as to insure proper focus.

Fig. 75. Rigid and Flexible Types of Wall Bracket "Elexit" Connections

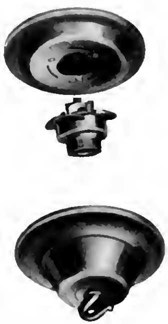


Fig. 76. "Elexit" Ceiling Outfit

Another improvement in the automobile headlight lamp is the parallel coil arrangement of filaments which gives greater concentration of light source than the V form. This produces a more uniform headlight beam and better control thereof by various glare reducing lenses.

The lumen was adopted as a standard for the rating of series Mazda lamps in place of the mean horizontal candle-power unit formerly employed. While the latter proved quite satisfactory for vacuum lamps, it failed to provide a fair measure of output for Mazda C lamps, as it did not take into account variations of distribution. For several years these lamps have been tested with reference to the total output in lumens, but rated in nominal candle-power based on the performance of vacuum lamps. This seemed necessary on account of the large number of street lighting contracts in which candlepower was specified. Since the practice of street lighting with Mazda C lamps is now fairly well established, it seems likely to prove more satisfactory in the long run to use the actual rather than the nominal rating.

The United States Bureau of Standards revised the standard specifications for incandescent lamps, so as to conform better to the characteristics of tungsten filament lamps, especially with regard to life. Since Mazda lamps are not subject to the extreme depreciation of carbon lamps, and are invariably operated until they burn out, it was found desirable to drop the old 80 per cent basis and express lamp quality in terms of total life at specified average lumens per watt, as a measure of efficiency. A separation of these specifications from the schedule of ratings should facilitate the adoption of this method by other countries where ratings may be different, and thus permit an equitable comparison of all tungsten lamps on a common basis.

The standardization of lamp voltages in the 100 to 130-volt range has progressed so that over 85 per cent of the lamps now manufactured are for 110, 115 and 120 volts, leaving but a small minority for the intermediate voltages. The adjustment of circuit voltages through which this was brought about not only reduces the confusion in lamp distribution but improves the service derived from heating and motor appliances. A corresponding standardization is being undertaken to

Fig. 77. Semi-indirect, Completely Enclosed Lighting Unit

concentrate circuits in the 200 and 260-volt lamp at 220, 230 and 250 volts, while similarly for street railway circuits progress is being made on 525, 550, 575, 600, 625 and 650 volts. An attempt is also being made to standardize circuits at 6.6 amperes, which has for several years been strongly predominant.

Substantial progress was made in factory production, utilizing the principles of correct illumination. More thought is apparently being given to the questions of low brightness and diffusion than heretofore. In the field of residence lighting an all-glass decorative dining room dome designed along simple but attractive lines, is a notable addition. Decorative glassware, harmonizing with the room decoration, is receiving more extensive application and better arrangements are being made for distributing such equipment to the public.

Fig. 78. Relay Operated Flashing Danger Signal at Railway Crossing

One of the most useful equipments produced is the automatic disconnecting plug, by which fixtures can readily be hung or removed without expert attention. A number of manufacturers are marketing such devices under the trade name of "Elexit" (Figs. 75 and 76). This seems likely to render the term "fixture" obsolete with its anomaly "removable fixture." To meet this situation, the Illuminating Engineering Society has proposed the substitution of the French word "luminaire" as being more appropriate.

A new type of semi-indirect unit (Fig. 77) for stores, offices and similar interiors is completely enclosed so as to prevent the accumulation of dust on the lamp and interior surfaces of the fixture. Such units are less susceptible to depreciation from dirt and are more easily cleaned.

Surgical and dental devices in which the incandescent lamps are used for illuminating interior cavities of the body are playing a much more important part in the welfare of humanity than is ordinarily realized, and have made possible almost miraculous advances in surgery. While these lamps are not required in large numbers, their importance is of the highest order, and every effort has been made to improve them as much as possible. Some of them are now being manufactured in blue bulbs in order to give more nearly daylight quality of illumination and thus assist in the recognition of the color of tissues.

Fig. 79. Battery Operated Highway Guide Post

The activitiy in sign lighting increased with a marked tendency toward the use of high-power lamps and whiter light. The Mazda C lamp, up to the 150-watt size, was used extensively in outline effects on large roof signs. In the low hung signs and in small communities the 25 and 50-watt sign lamps, already referred to, are being used where formerly the 10-watt size was almost exclusively employed. The use of higher wattage lamps has raised some problems in existing signs, as it is necessary to avoid excessive voltage drop and the resultant decrease in effectiveness.

The Mazda C lamp, when used in sign lighting, has been subject to a certain amount of cracking when rain or snow falls at the hot point on the upper side of the bulb. A metal protective cap which is ordinarily invisible has been developed to reduce this weather cracking.

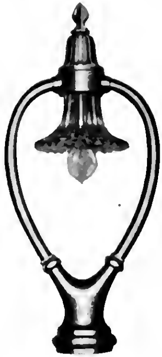


Fig. 80. Globeless Lighting Unit for Rochester, N. Y.

In the application of flashing red signals at railroad crossings (Fig. 78) low voltage Mazda lamps are operated through track relays so as to light up for approaching trains and go out again, thus conserving the battery. This makes a conspicuous warning, both by day and night. Incandescent lamps operated from batteries (Fig. 79) are also being supplied with the flashing signals at the intersection of heavily travelled highways.

Contrary to the general trend of business, the volume of sales in street lighting equipments was greater in 1921 than in any preceding year.

While there were no important new installations of arc lamps in street lighting, there were a considerable number of extensions of previous installations, thereby indicating that the magnetite arc lamp installed in previous years is giving satisfactory service. The largest installations of this character occurred in Salt Lake City and Detroit where more than a thousand arc lamps were added to the existing street lighting systems.

A globeless lighting unit (Fig. 80) of very ample construction was designed for illuminating the residential section of the City of Rochester, N. Y. The fixture consists of a heart-shaped pipe support from the top of which is suspended an all-porcelain unit which is a combined insulator, reflector and globe holder. The white enamel radial reflecting surface restores to the street the upward light which is dissipated with the globe type which has heretofore been used for this class of lighting.

The reduction in maintenance expense made possible by this simple and efficient lighting unit is obvious. With a bowl-frosted or bowl-enameled lamp, 100 per cent more light is directed to the street surface than with the superseded diffusing ball globe type. Eight hundred of these units (Fig. 81) were provided for the City of Rochester.

The largest street lighting installation of the year utilized 7200 600-candle-power, 20-ampere series lamps for a complete new lighting system for Kansas City, Mo.

This installation is unusual for several reasons. The previously existing lighting systems were completely discarded and the entirely new up-to-date illumination provided has practically the same intensity throughout the entire municipal area; a uniform ornamental single light standard being used with approximately uniform spacing.

Fig. 81. Globeless Lighting Units Installed in Residential District of Rochester, N. Y.

The engineering practice adopted is of unusual interest as each lighting standard is equipped with a two-coil transformer mounted in the base of the post, so that for this series system all high voltage lines are below the street surface with the low voltage leads from the transformer running through the post to the lamps.

For purposes of control, the installation is divided into groups of 50 lamps, each group being served by a constant current transformer which, instead of being located in the central station, is mounted on a pole in the center of the group controlled. Individual switches are provided for all transformers and the entire system is tied together by one 2200-volt feeder line from the central station, so that, if necessary, the throwing of a single switch can cut in or out of service the entire city lighting system, while the switching arrangements on the groups and individual lighting standards permit the control of segregated sections or units without affecting the general system.

Statistics were gathered concerning the relation of illumination to traffic accidents in over 30 cities. An ingenious comparison of accidents in the summer and winter months shows that the accident rate increases considerably after dark, thus indicating that the present practice of artificial street lighting falls far short of daylight as an adequate accident preventive. Another comparison, based on the records of the City of Cleveland before and after the installation of the whiteway lighting, seems to indicate that the higher standard of lighting is effective in reducing both accidents and crime.

The success of the highway lighting unit (Fig. 82) with its double nested, triple reflectors which direct the light lengthwise of the road, and which was brought out commercially last year, resulted in a number of installations of varying size in practically every section of the country.

The largest installation is located on the roads leading out of the City of Detroit, a distance of approximately 22 miles being illuminated in this way.

In addition to the purpose for which it was originally designed, this unit can be utilized to advantage for the illumination of train yards, narrow roads, alleys in industrial plants, and in any location where a long, narrow area must be lighted.

Fig. 82. A Typical Installation of Highway Lighting Units

The remarkable record of engineering progress in the motion picture industry for many years produced very little improvement in the light source used for the projection of the completed picture; the only notable change in the arc used for projection being a gradual increase in current to accomplish the longer throws. Arc amperes increased from 35 to even 150 with no compensating development along the lines of greater efficiency in light utilization or in light production.

An adaption of the high intensity arc lamp, however, previously used in searchlight projectors, rendered possible the production of a motion picture projection outfit which, for the same current that had previously been used, gave from three and a half to four times the amount of light.

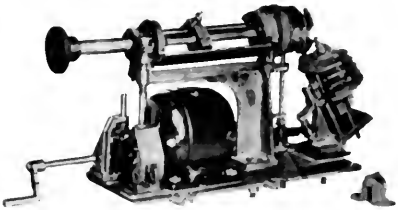


Fig. 83. Motion Picture Projection Lamp Showing Arrangement of Motor and Hand Control

The lamp employs uncommonly small electrodes, the positive having a highly mineralized core. In the operation of this lamp (Fig. 83) the positive electrode is rotated about its axis and the negative electrode is placed at an angle to the positive in such relation that the negative flame drills a deep crater into the face of the positive electrode. This crater is filled with the vapor of the minerals of the core and emits a very high light flux (Beck system).

The control of the lamp is semi-automatic, the carbons being fed, after the arc is struck by hand, by means of a motor connected across the arc. Through a system of gears, the positive carbon is slowly revolved as well as fed forward by the motor. This insures an even crater which is held permanently at the proper focal distance from the lens. The regulation is due to the arc voltage. When the distance between the carbons is too great, the voltage on the motor rises, increasing the motor speed and feeding the carbons faster; when the distance is too short, the motor slows down.

The lamp beam has a spectrum analysis closely approximating daylight, resulting in better definition on the screen and full color value in colored pictures.

The results attained in commercial operation have verified the laboratory calculations. The screen intensity is almost exactly twice as great as an old-fashioned arc at the same current. The color more nearly approximates the characteristics of daylight and there is a better color relation in color films and a better definition in black and white prints. From an operating standpoint, the adjustments have been simplified to a point where it is practically automatic.

The movement for the installation of permanent educational demonstrations of industrial lighting (Fig. 84) under the auspices of the National Electric Light Association has progressed so that there are approximately twelve demonstrations in the various large cities. Some of the larger lamp manufacturers have provided similar equipments on a smaller scale, arranged to facilitate shipment from point to point. These portable demonstrations have been exhibited in over 150 cities and towns, reaching a large number of people to whom the permanent demonstrations have not been accessible. Some of the portable demonstrations have been arranged to teach commercial lighting as well as industrial.

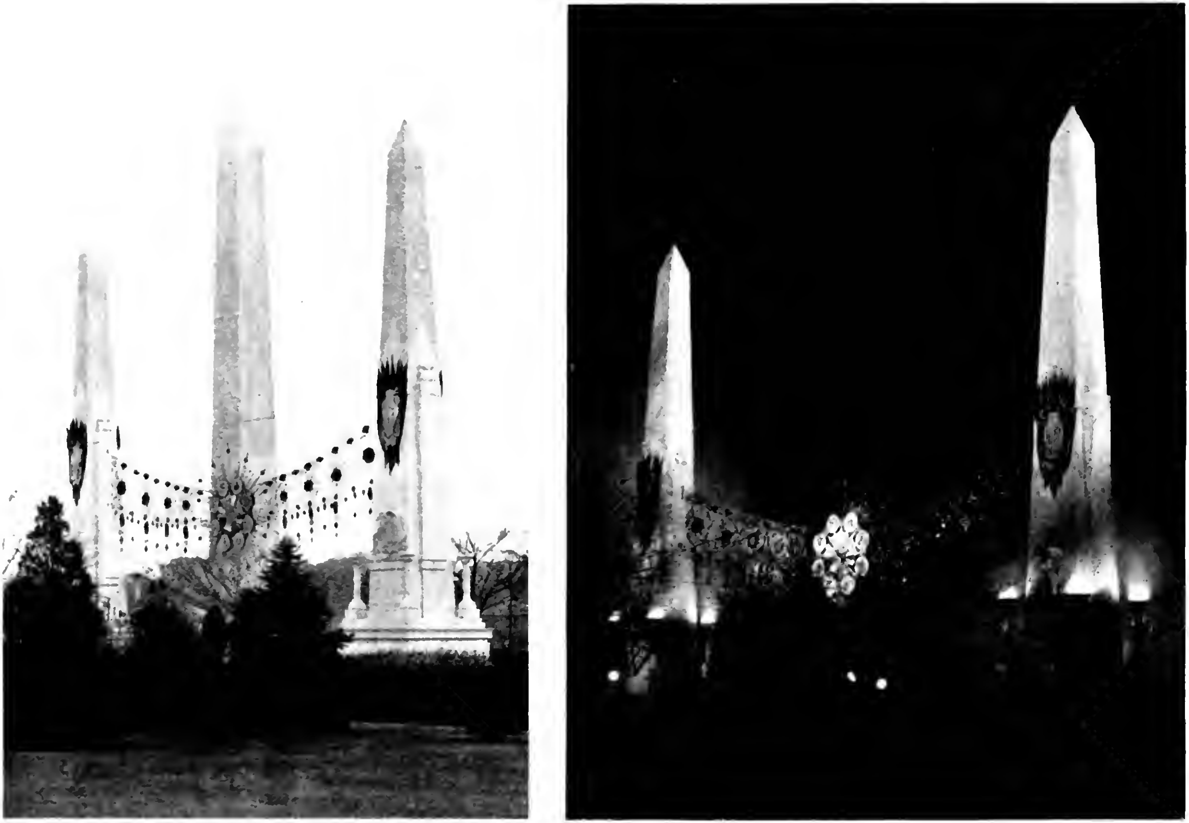
Another type of demonstration was provided for the presentation of good lighting principles and the possibility of artistic effects, as well as the application of other electrical devices. This is in the form of a rotary stage, which can be arranged to simulate the section of a room. The construction permits the setting up of one display (Fig. 85) while another is being shown. By providing for the separate rotation of the upper portion, the lighting equipment can be changed expeditiously without disturbing the room setting, thus facilitating comparisons. The demonstration is applicable for either large or small groups of people. In the so-called Merchandising Conference this exhibit was applied during the year for the education of those responsible for the distribution of lamps and other electrical equipment, demonstrations being held in the principal cities of the United States, starting at Newark, N. J., in January and ending in Los Angeles, Cal., in May.

Seven states now have the industrial codes and a beneficient effect is being felt with regard to industrial accidents. Experience in applying these codes is suggesting minor changes to make the codes clearer and more definite.

The Illuminating Engineering Society's code, which has been the pattern for those adopted by the various states, was revised and republished during the year. It is now proposed as an American Engineering Standard. A new glare rule was proposed for consideration, which classifies the degrees of permissible glare in the terms of operations to be illuminated, while the illuminants acceptable are classified with respect to brilliancy, power and location. The proposal seems to have considerable possibility of

Fig. 84. Industrial Lighting Exhibit, Massachusetts Institute of Technology

Fig. 85. Rotary Stage Lighting Demonstration Showing an Industrial Setting



Day and Night Views of the Jeweled Portal Erected at the Intersection of Seventeenth and "B" Streets, Washington, D. C., in Commemoration of Armistice Day and in Honor of the Conference on the Limitation of Armaments. The Obelisks were 85 ft. high and 86 ft. apart. On the Curtain and Obelisks were mounted 37,200 Novagem Jewels of various colors. The center Sunburst contains the Flags and Coats of Arms of the eight nations participating in the Conference. In the day view the distant Washington Monument appears in the center providing a practicable glare specification, which will be more definite than the present ones and leave less to the individual judgment.

Wisconsin was the first state to adopt a school lighting code. This is essentially the same as that proposed by the Illuminating Engineering Society and quite similar to the industrial lighting code.

Automobile headlighting regulations, based on those of the Illuminating Engineering Society, are now in force in twelve states. The Massachusetts regulation, which became effective in August, requires more illumination at certain points than any of its predecessors. It specified the 21-candle-power size of gas-filled incandescent lamp with definite voltage limitation.

The International Commission of Illumination reorganized and met in Paris for the first time since the war. From reports it is apparent that the European countries are looking to the United States as the leader in lighting practice for the immediate future. An American was elected president of the organization and the next meeting is to be held in the United States.

Genelite and Water Japan Exhibit at the New York Automobile Show

During the New York Automobile Show, January 7 to 13, 1922, the exhibit of the General Electric Company will occupy spaces D 222 and 223. The features of the exhibit will be two new developments of the Company, namely, a new bearing material known as Genelite[1], and water japan[2], a baking japan with water as a solvent.

Genelite is a synthetic bronze, containing approximately 40 per cent by volume of graphite, distributed evenly throughout its mass. It has the general appearance of bronze, but the characteristics are quite different, and the exhibit has been planned with a view to bringing out this fact, as well as to show its superior performance under various service conditions.

One of its salient features is its porosity, which makes it capable of absorbing 2½ per cent by weight of oil. To demonstrate this feature, three small stands have been prepared, each carrying a beaker of oil on top, with a rod of genelite, babbitt, and bronze, respectively, set in the beaker. Below is another beaker, and a wick connecting it to the top of the rod in the upper one. In the case of the genelite, oil from the upper beaker is siphoned into the lower one by capillary attraction in the metal and the wick. The bronze and babbitt have no siphoning effect.

To show the action of genelite with various degrees of lubrication, a three-bearing stand has been made, each bearing being of genelite. A small motor drives a shaft carrying two flywheels and running in the bearings which are cut away. One of them runs flooded in oil, to show that the graphite will not wash out; the second has oil saturated waste in contact with the outside of the genelite, to demonstrate its properties when properly lubricated; and the third is genelite without any oil whatever, to demonstrate it as a self-lubricated bearing.

Another exhibit consists of a small flywheel driven by a motor and running in genelite bearings. One of the pedestals is supplied with an electric heating unit, and contains two wells on each side of the genelite bearing filled with babbitt. The pedestal is heated by the coil to a degree sufficient to keep the babbitt molten without affecting the genelite, which shows that the latter will operate without trouble at a much higher temperature than babbitt, and that it has no tendency to "freeze," or weld to the shaft when running hot.

The other feature, water japan, is an emulsion of high grade japan base with water. It gives the same finish as any other japan, and the process is absolutely devoid of any fire or explosion risk. In connection with the water japan exhibit there will be eight tests to show its resistance to corrosion, and two to show its flexibility. Strips of metal coated with japan will be continually twisted and bent, to show how the coating stands such treatment.

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[1] General Electric Review, Nov., 1921.

[2] General Electric Review, Aug., 1919, Nov., 1921.

Opening of New Long Island Station of the Radio Corporation of America

PRESIDENT HARDING'S OPENING MESSAGE AND ADDRESS BY OWEN D. YOUNG

On the afternoon of November 5th the new Radio Central located at Rocky Point, Long Island, was formally opened for business by President Harding, from his desk in the White House at Washington. Stations in all of the principal countries of the world were invited to listen in, and a few seconds after President Harding's signature was transmitted acknowledgment was received from Nauen, Germany, and then in order from Norway, England, France and the other nations of the world having stations sufficiently powerful to communicate with Radio Central.

The ceremony was witnessed by 300 guests, among whom were many distinguished government officials and scientists. The President's message was made audible by amplifiers located about the station so that it might be read by those who understood the code, while those who did not had only a moment to wait before copies printed on radiogram blanks and bearing a reproduction of the President's signature were distributed.

President Harding's Wireless Greeting to the Nations of the Earth

"To be able to transmit a message by radio in expectation that it may reach every radio station in the world is so marvelous a scientific and technical achievement as to justify special recognition. It affords peculiar gratification that such a message from the Chief Executive of the United States of America may be received in every land, from every sky, by peoples with whom our nation is at peace and amity. That this happy situation may ever continue, and that the peace which blesses our own land may presently become the fortune of all lands and peoples, is the earnest hope of the American nation."

After the opening ceremonies and an inspection of the power plant and other equipment the party assembled in the community house, where David Sarnoff, General Manager of the Radio Corporation, made a brief address and read radiograms of congratulation from the following men who have attained prominence in the development of radio communication: Edward J. Nally, President of the Radio Corporation, who had sailed that very day from England; Guglielmo Marconi, Godfrey Isaacs, and Mr. Steadman, Director of the British Marconi Company; Mr. Girardeau, Managing Director of the French Radio Company; E. F. W. Alexanderson, Chief Engineer of the Radio Corporation, who had been called to England to attend a worldwide radio conference; Mr. Yoneda, Director-General, Department of Communications, Tokyo, Japan; Mr. Solari, Managing Director Italian Radio Company; and the Management of the Trans-Radio and Telefunken Company of Germany.

Mr. Owen D. Young, Chairman of the Board of the Radio Corporation and Vice-president of the General Electric Company, then addressed the guests, outlining the circumstances that brought about the organization of the Radio Corporation of America, and reviewing the great advantages, geographical and commercial, which will make the United States of America the radio central of the world. His address follows:

"I am glad to welcome you in the name of the Radio Corporation of America, and to express our appreciation of the trouble you have taken to come here to see us open the new station.

"If there be any thrill, and there is a very great thrill in this occasion to me, it is not because of the great technical achievements which have made this station possible. It is not because of the work done, great as it is, by these constructors of the station, but it is that today America is able to lay down in her name, in twenty-eight countries of the world, this message from the President of the United States.

"Just a word about the Radio Corporation of America: Some two years ago when it became evident that this new art of communication might become influential in the world's communications, an attempt was made to mobilize the resources, especially the technical resources, of America. This attempt has been successful to the extent that the American Telephone and Telegraph Company, the Western Electric Company, the Westinghouse Electric and Manufacturing Company, the United Fruit Company and the General Electric Company joined not only all the inventions which they then had, but undertook for twenty years to come, in the radio field, to turn their inventions in to the Radio Corporation of America, in order that America might quickly develop the best radio communication in the world.

"Our new art heretofore has been suspended in its development by patent litigation, by energetic claims of engineers, by the great clash of large concerns, and America could not wait for the duplication of the history of the Telephone Company, or the duplication of the electrical industry. She could not wait ten years while her people were fighting, because the communications of the world were at stake, and America's position in those communications was at stake.

"Now just a minute as to the position of America:

"England, because of her geographical position, was the natural landing place of the cables of the world. Realizing the importance of communications of the world, she took advantage, as she properly should, of that geographical location, until if you look at the maps of the communication systems of the world, you will see the great lines running to and radiating from London.

"In this new art of radio communications, America is the center of the world. Why? Because every country in the world desires to get direct communications with America and not to relay through a country on the coast where a cable may be landed.

"It is hardly worth while to develop radio merely for communication within Europe alone. The distances are relatively short, the means of communication—land communication—already developed. Radio is designed to reach out afar.

"Norway has already come, and we are in communication with her. England has already come, and we are in communication with her. France has already come, and we are in communication with her. Germany, with her cables cut, is yet in direct communication with America. Poland, whose Minister is here today, has already come in, and contracted for a high power station to reach out directly to America.

"Every country in Europe, seeking to build a radio station, makes one inquiry: 'Will this station communicate with the United States?' and the answer must be yes, or the station is not built.

"Now the question is, has America the courage, the farsightedness, the skill to take advantage of her geographical position in this great new art, as England took advantage of her position with reference to the cable? Is America ready to take advantage of this, not because she is grasping for something she is not entitled to, but because nature has given her a position on which she ought to realize? Is she ready in this great art to take her place in the communication of the world? That means two things: It means that we must mobilize our technical resources in America in a single unit. It means that we must mobilize back of that unit our financial resources, and back of that we must have at least the moral support of the Government of the United States. Will America do it?

"Already there has been a charge that the Radio Corporation of America is a monopoly. It is not a monopoly, but if it were it would be a fighting unit of America against the world in the development of communications.

"I have just returned from Europe and I have come to an agreement with the Germans, the English and the French regarding a co-operative development of wireless in South America; because Germany was starting to build a station in the Argentine, the French were starting to build a station, the English were, and the Americans were—four stations to do the work of one. Great waste of capital, and that is not all. We know that the wave lengths in the world are limited and must therefore be conserved.

"And now even if these private companies could afford to waste capital for four stations where only one could adequately do the job, we certainly could not afford to waste wave lengths on stations operating at only twenty-five per cent of their capacity.

"Therefore, it became necessary, and I am glad our friends abroad recognized it, for us to co-operate, and instead of having four stations in Argentina, we will have one, an International Station, carrying messages from the Argentine to all parts of the world.

"We expect a similar station in Brazil, and such other countries of South America as may show need of these communications.

"The reason for Mr. Alexanderson's absence is that he is in London now in consultation with the technical people of the other nations, laying out plans for these great new stations.

"I am very keen about this communication business. We have in Washington, just about to convene, a Disarmament Conference. When you can no longer appeal to the armies of the world, you must appeal to the public opinion of the world, and there can be no public opinion of the world unless there be cheap and adequate communication in the world. I venture this assertion; that underlying the success of any program of disarmament is inevitably the development of adequate communications, and this new art promises to be effective in making these communications available everywhere.

"We are greatly pleased that the President of the United States should so far favor us by sending this message from this station.

"The Radio Corporation of America has had, heretofore, by nomination of the President, a member of the Government sitting with its Board of Directors. I sincerely hope that policy may be continued in order that America may still go forward in developing these communications with the united support of the technicians, of the capitalists, and of the Government."

Fig. 1. Bird's Eye View of Proposed Ultimate Station

Description of New Station

In the pioneer days of high power radio telegraphy a station functioned alternately as a transmitter, a receiver and a telegraph office. This involved much loss of time and greatly reduced traffic facilities, for a station had to stop sending while it received and vice versa. It therefore became apparent that the ideal radio station should comprise three separate but closely connected units operating through remote control and employing a transmitting unit, a receiving unit and a central traffic office, the latter preferably in the heart of the business district of large cities.

The Radio Corporation has had this system in operation for some time and having found it most effective has adopted it at Radio Central and other trans-Atlantic stations. The new radio station therefore comprises these three units:

Radio Central. A high power multiplex transmitting station located on Long Island, some distance from New York City, ultimately having several separate antenna systems each intended to communicate with a given country. Telegraphic operations are controlled from the central traffic office conveniently located in New York City.

Riverhead, L. I. A multiplex receiving station located on Long Island sixteen miles from the transmitting station and so planned and arranged as to simultaneously receive all radiograms destined to the United States from as many foreign countries as take part in the world wide wireless system.

Central Traffic Office, New York City. The traffic center of the Radio Corporation system where all radio telegraph operation is performed. Here radiograms are gathered from various sources and despatched to foreign points through Radio Central and other high power stations. Direct transmission from 64 Broad Street, New York City, is accomplished through the use of a special system of remote control.

Direct reception is effected in like manner, the incoming signals being intercepted at

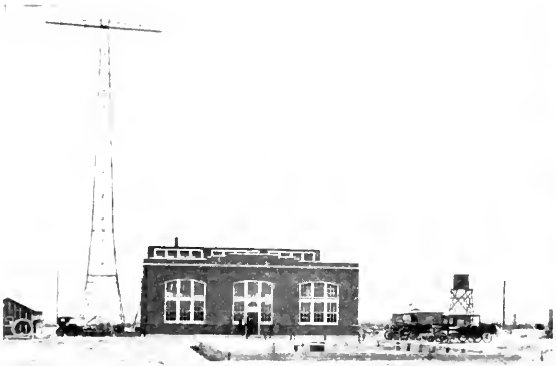

Fig. 2. Power House and Towers at Radio Central

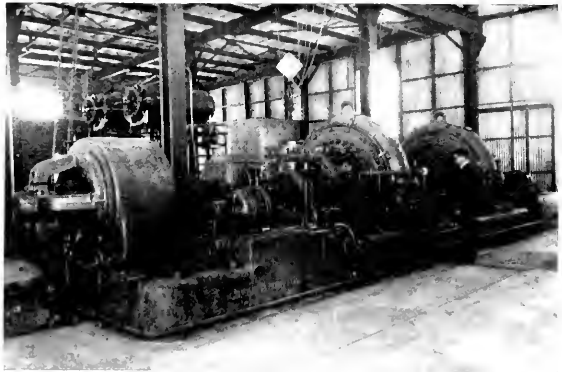

Fig. 3. Two 200-kw. High Frequency Alternators at Radio Central

Fig. 4. Receiving Station Radio Corporation, Riverhead, Long Island

Fig. 5. Main Traffic Office Radio Corporation, 64 Broad Street, New York

Riverhead, L. I., and automatically transferred over land lines to the central traffic office. These signals are interpreted and recorded on typewriters by skilled telegraph operators at high speed or are automatically received by ink recorders. Final delivery is then effected through a special messenger service from the central traffic office or its supplementary branch traffic offices located at 233 Broadway, 933 Broadway and 500 Fifth Avenue, or dispatched by telegraph when the point of destination is other than New York City.

The plans of Radio Central call for an ultimate construction of 12 antennae arranged in the form of spokes of a giant wheel with the power plant at the hub. Each antenna will consist of 16 silicon bronze cables $\frac{3}{8}$ in. in diameter stretched in a horizontal plane on six towers spaced 1250 ft. apart. Each tower is 410 ft. high and the cross arm or bridge which supports the antennae is 150 ft. long. Nine hundred tons of structural steel are required for each spoke of six towers and 4100 tons of concrete are used for the tower foundations. The ground system for the two antennae now in service consists of 450 miles of buried copper wire. The other ten spokes of the antenna system will be erected as business requires.

Construction on Radio Central was started in July, 1920, and the first test signals were sent out in October, 1921, or a little more than a year later. The first section of the power house covers a space 130 by 60 ft., and the present power equipment consists of two 200-kw. Alexanderson high frequency alternators with the necessary switching apparatus, high frequency transformers, etc. Ultimately there will be installed ten of these alternators having a total output of 2000 kw.

What the Manufacturer Has to Sell and What the Railway Company Requires

By J. C. Thirlwall

Railway and Traction Engineering Department, General Electric Company

Discussions of this nature should prove both timely and useful, as the closest co-operation is necessary between the Operator and Manufacturer if such economies are to be effected as will permit the Railways to operate at a profit.—Editor.

This subject, which was discussed before the New England Street Railway Club on October 13, 1921, is of particular interest to the manufacturers, who know that for some time past there have been comparatively few things that the electric railways have felt that they were compelled to purchase, and who are, for that reason, anxious to find out what the railways really require.

It is unnecessary in a discussion of this nature to draw up a list of materials or a description of apparatus; the operators are just as well posted on most of our products as are the manufacturers. And after all, what we have to sell is not only materials of various kinds. It is not merely an assembly of brick, concrete and machinery that makes a power station, nor of steel and equipment that constitutes a car. It is the application in concrete form of the thoughts, ideas and experiences of many minds, co-ordinated by the manufacturer into a useful, efficient product.

And what every successful manufacturer has to sell is not only the fabricated product of his tools, but the ideas of his designers, of his engineers and of his salesmen, and their ability to save money or to make money for his customers; in other words, service. And in the long run, it is the ability of a manufacturer to give service to his customers that governs the volume of his sales. This service may lie in the design of an unusually efficient or reliable piece of machinery, car, or apparatus; it may be in the instruction that is given on how to obtain especially good results from his product; it may be the extension of credit during the periods of financial stress, or assistance in financing necessary purchases; it may consist of bringing new and efficient methods of operation or of maintenance to the notice of a busy executive; it may be and often is the combination of all these things, and of more.

The long period of stationary receipts and of mounting wages and material costs, through which the electric roads have been passing for the past five years, has emphasized the need of *service* from the manufacturers to their hard pressed customers, and, in general, we need not be ashamed of the response. This period has seen many economies and methods of increasing earnings introduced and worked out by the operators; it has also seen many valuable results in the same direction worked out by the manufacturers. For instance, the Birney safety car, to the development of which many different manufacturing interests contributed, is directly adding some $12,000,000 or $13,000,000 to this year's net earnings of the 275 companies using them. The introduction of the Birney safety car is effecting other indirect economies through the rapid extension of one-man operation of other cars, made possible by its success; this saving probably amounts to another $2,000,000. The development of other types of low wheel light weight cars and of their equipment, and of automatic control for substations are simply a few of the many contributions the manufacturers have made to the concerted effort to help the traction companies in their struggle for existence.

But it did not need the war, and the crisis in the railway industry that resulted, to start improvements in design and to improve efficiency, and to lengthen the economical life and increase the reliability of railway apparatus. In this connection it is interesting to point out a few of the more important developments of the past twenty years.

Power Stations

Two decades ago each railway had its own power station, equipped with small 25-cycle generators, driven by reciprocating engines. The largest units were not over 5000-kilowatt capacity; the majority were much smaller. The minimum fuel consumption of these plants was from 5 to 6 pounds of coal per kilowatt-hour; the average probably 7 or 8 pounds.

The development of the turbine practically cut the fuel bill in two; changes in the design and capacity of the generator itself carried the economies of power production still further. The small capacity plant with turbine drive requires about 3 pounds of coal per kilowatt-hour; the modern central station with individual units running from 20,000 to 45,000-kilowatt capacity takes two pounds or less.

In addition to this material fuel economy, the modern large capacity plant will show reductions in all of the other elements entering into power costs. The high speed apparatus is lighter and occupies less space for a given capacity, and so requires a lower investment in machines, in buildings and in land; the labor cost is materially less and the maintenance is greatly reduced. These facts are so self evident that, to a greater and greater extent, the smaller railways are shutting down their own generating plants and turning to the purchase of power from some adjacent central station. In very many cases it has been found that a railway by purchasing power can not only save itself the initial power plant investment, but can actually obtain a lower rate from the central station than its own operating cost for producing a similar amount.

Substations

A somewhat similar development has occurred in railway substations. Twenty years ago, they universally used 25-cycle converters, heavy low speed machines which had a high first cost and which took up a great deal of valuable floor space. Because they were 25 cycles, they could not be tied into the larger central stations, which were putting out 60-cycle power for their lighting load, and this compelled the railways to build and operate their own smaller and less efficient generating plants.

Then the 60-cycle converter was developed and gradually improved by adding commutating poles using non-magnetic cores, flash barriers, radial type brush rigging and other improvements that decreased its weight and cost, while greatly increasing its continuous and overload capacity and its reliability. The high speed circuit breaker helped decrease flashovers resulting from line surges or short circuits. And finally the General Electric engineers perfected and turned over to the industry the automatic substation.

Automatic control in connection with reliable and efficient converting apparatus today shows a lower percentage of failures or interruptions than the ordinary station with manual operation. Its use not only saves the wages of the station attendants, which amount to about $3000 per year, but also reduces light load losses, and by reason of its load limiting equipment, which throws resistance in the path of an overload (instead of opening a circuit breaker), prevents interruptions and increases the load factor, which makes it possible to secure a better contract with a power company. It also permits the railway company to distribute a given number of converters to better advantage. Since the cost of station attendance is not the limiting factor, a greater number of substations can be installed; they can be located closer together and with a better regard to the center of gravity of the load and with a large saving in overhead copper. In this way trolley disturbances can be restricted to a comparatively short section of track, and the failure of a complete substation feed no longer cripples service as was the case where a bank of machines fed a network through a single artery or duct. Furthermore, the improvement in voltage that results, particularly in outlying districts, makes possible higher speed schedules, with resultant economies in platform wages.

Car Equipment

Motors

The writer's first electric railway experience was in the car shops of the Brooklyn Rapid Transit System about 18 years ago. The railway motors used then were non-ventilated and without commutating fields; the frames were split; the lubrication system crude; the bearings were iron shells with a thick lining of soft lead base babbitt; the gearing was made from untreated castings; and the insulation of armature coils, fields, and brush-holders was far below present standards. These motors were brought in for overhauling three or four times a year, because the armature bearings would not last longer than three or four months, and a motor that did not come in once or twice for repairs between overhauling periods was a rarity.

These or similar motors are still in service on many roads. They have been given the advantage of many developments that have materially helped their performance. That is, they have been provided with heat treated gears and pinions; bronze bearings with tin base babbitt liners; slotted commutators and higher grade brushes; a better system of oil waste lubrication, etc. But even so, recent records show that their average maintenance cost is $3.50 to $4 per 1000 motor miles, or from $120 to $150 per motor annually. Without the improvements in parts, at present rates for labor and material, they would cost at least twice as much.

The modern box frame ventilated motor with commutating fields, better insulation, improved brush-holders, bearings and gearing, weighs 30 to 40 per cent less for a given working capacity or for a given car weight to be handled, and so saves in first cost. Moreover, its average cost of maintenance, as shown by records in every part of the country, is only 50 to 60 cents per 1000 motor miles, or from $18 to $22 per motor annually, directly saving the railway company several hundred dollars on each car they operate. Indirectly, they save additional amounts because of their greater reliability. Fewer cars must be pulled in for motor failures, less cars held from service for motor repairs.

A comparison was recently worked out to illustrate the reduction in investment costs made possible by modern motor design. The following table is based on the sales of railway motors in this country by the two large electrical manufacturers for the year 1919. The upper figures represent the approximate number, weight and selling price of the motors actually sold; the lower figures are what a similar number of the heavier non-ventilated type of equal working capacity would have weighed and cost had our designers remained idle for the previous ten years.

RAILWAY MOTOR SALES

SIZE Horse Power	Number Sold	Approximate Weight in Lb.	Approximate Prices
25	3,000	3,000,000	$2,250,000
35–45	3,000	5,250,000	3,300,000
50	1,500	3,400,000	2,000,000
60–70	500	1,450,000	750,000
Total	8,000	13,100,000	8,300,000

SAME VOLUME OF SALES WITH NON-VENTILATED MOTORS

35	3,000	6,000,000	3,600,000
50	3,000	8,500,000	4,500,000
60–70	1,500	5,200,000	2,600,000
75–90	500	2,200,000	1,100,000
Total	8,000	22,900,000	11,800,000
Saving to operators.		9,800,000	3,500,000

These figures indicate the economies obtained by the railway industry in one year directly due to motor development; 10,000,000 lb. less weight to be carried on the rails and $3,500,000 less in investment. The annual saving would be about $500,000 in fixed charges and at least as much more in operating costs.

Moreover, the development of the low wheel motor permitted the car builders to make changes in their designs that reduced weights and initial costs in bodies and trucks to a material extent, and which went a long way toward absorbing the tremendous increases in labor and material costs brought about by the war. In other words, the 15,000-lb. Birney car today does not cost very much more than the 24,000-lb. single truck car of equal capacity did ten years ago; and a 25,000-lb. 44-passenger double-truck car can be bought for about the same price as its 44,000-lb. predecessor could at that period.

Controllers

Multiple unit control, for train operation, has undergone radical changes. The original designs were power-driven drums, followed by groups of contactors actuated by solenoids or by electrically controlled air cylinders. The interlocking arrangements were complicated and delicate, blowout coils weak and ineffective; failures were numerous and costly. This control, today, is a relatively simple affair; interlocking has been simplified and made more positive in action, and great improvements have been made in the blowout coils and in the speed of opening line contactors. The whole group is lighter, cheaper and far more reliable.

Air Brakes

Much that has been said of the older designs of motors applies to the air compressor, and similar improvements have been made in its design until today it is one of the most reliable pieces of apparatus on a street car. Chief among these improvements are better insulation on the armature, fields and brushholders, better lubrication for the moving parts and better protection for the motor against the admission of oil. The whole design is lighter and more compact.

In the automatic air brake, the trend has been toward quicker and more uniform action on the long trains used in rapid transit service, and toward the use of electro-pneumatic valves to obtain simultaneous and immediate application on every car.

One of the really striking developments in the use of air has been in the safety devices which contributed so materially to the success of the Birney one-man car, and to one-man car operation of other types of cars. The working out of this apparatus which automatically opens the power circuit, applies the brakes, sands the rail and unlocks the doors, in case of the operator becoming incapacitated, proved to be a most effective argument with Public Service Commissions and legislative bodies in the introduction of the safety car. These cars have certainly been one of the most effective means of reducing costs and increasing receipts for the railway companies.

Shop Equipment

Tremendous economies have been effected in many shops by the use of labor saving tools and machines, but too large a proportion of railways have not yet taken full advantage of the developments in this direction, and are neglecting the savings in cost of repairs, or in the effectiveness of repair work, that they might obtain with better shop equipment. Only a few of the devices that should be in every properly equipped general overhauling and repair shop will be mentioned.

All of the following devices, and many more, have been worked out and perfected for the railway's use. They save many times their cost, and they illustrate what the manufacturers have done and what they wish to do for the railway industry.

Electric hoists on jib cranes and monorail cranes; banding lathes; armature slotting machines attached to the bed plate of the lathe; air blowing and paint spraying machines for armatures, fields and controllers; baking ovens; testing outfits for short circuits and open circuits in armature or fields; 2500-volt test set for newly rewound armatures; 1000-volt set for testing old motors; screw or jack type pinion pullers; hot water heaters for mounting pinions; acetylene or electric welders, etc.

In mentioning what improvements have been effected in electric equipment and apparatus design, which is a part of the service which the manufacturers sell and which it is hoped the railways require, the writer is indicating what others have also done with their machines or materials. The manufacturers have developed a force of engineers and salesmen who are thoroughly conversant with the operators' problems and who are ready and anxious to serve the railways in any manner, whether it be in the selection of suitable equipment, the way to most efficiently use such equipment, or how to most economically maintain it. It is this service, in the continued improvement of design, and in reducing the railway's costs of operation, that the manufacturer has to sell and which the railway pays for when it buys the finished product.

Manufacturers and operators alike have trimmed their sails during the storm that has swept the business world; the operators have, of necessity, reduced their purchases to the absolute minimum; the manufacturers have cut their expenses of production to bed rock. Prices have receded with the wave of post-war inflation, and are back to what is believed to be a fairly stable basis; the manufacturers are anxious for orders, they are, therefore, most eager to hear from the railways as to what they require.

Final Report on the Electrification of Railways

By The Advisory Committee, British Ministry of Transport

This report presents the conclusions arrived at by a capable national committee after thoroughly studying the operation of various systems of railway electrification and the extent and character of engineering regulations that are desirable to facilitate continuous travel over connecting railway lines. The principal recommendations of the investigation are not limited to British practice but are of international application: these are to the effect that three-phase alternating current be the standard system of power generation; direct current be the standard system of power distribution; 1500 volts, a multiple or sub-multiple, be the standard distribution potential; and the third rail, the overhead wire, or both, be the standard distribution conductor.—Editor.

1. The Electrification of Railways Advisory Committee was appointed by the Minister of Transport, in March, 1920, to inquire into Railway Electrification.

The terms of reference were as follows:

To consider and advise—

I. Whether any regulations should be made for the purpose of ensuring that the future electrification of railways in this country* is carried out to the best advantage in regard to interchange of electric locomotives and rolling stock, uniformity of equipment and/or other matters.

II. If any such regulations are desirable, what matters should be dealt with, and what regulations should be made.

III. How far it is desirable, if at all, that railways or sections of railways already electrified should be altered so that they may form parts of a unified system.

Subsequently in October, 1920, the terms of reference were extended as follows:

To consider and advise—

I. Whether any regulations should be made to limit the drop of potential in an uninsulated return conductor on electrically operated railways.

II. If any such regulations are desirable, what limits these should impose, and under what conditions.

2. The Committee held their first meeting on March 22, 1920, and after having had before them as witnesses representatives of the principal railway companies in this country employing or proposing to employ electric traction on their systems, and also receiving evidence from the engineers to the Swedish State Railways and the Federal State Railways of Switzerland, and from British and Continental Electrical Contractors, submitted to the Minister on July 12, 1920, an Interim Report containing their recommendations in respect to certain general and fundamental matters covered by their reference, which it was understood should be placed before him as early as possible.

The Committee now desire to confirm the recommendations contained in their Interim Report, which for convenience are repeated as follows:

"*In respect to Reference I.*

"8. The Committee consider that, in order to ensure the future electrification of railways in this country being carried out to the best advantage in respect to the matters indicated in the Reference, it is desirable that certain general regulations should be made for observance by the railway companies when electrifying their lines.

"9. The Committee consider that these regulations should be directed specially to ensuring standardization of those methods and appliances which are likely to prove the most satisfactory under British conditions.

"10. They consider, further, that such regulations should put no avoidable difficulties in the way of the adoption in future, with the approval of the Minister, of any improvements in methods or appliances which may from time to time become available with increasing knowledge and experience.

"*In respect to Reference II.*

"11. In view of the desirability of the railways which are now contemplating immediate electrification knowing as soon as possible the decision of the Minister on certain fundamental matters, they recommend that regulations should be issued in accordance with the following conditions:

"(i) That in the case of those railways which have not as yet electrified any lines, as well as those which at present have electrified all or part of their lines on a direct-current system, their electrification, or extended electrification as the case may be, should be carried out on the direct-current system.

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* Great Britain.—Ed.

"(ii) That the standard pressure of the direct-current system at the sub-station busbars shall be 1500 volts, subject to—

"(*a*) The continuance of any existing 600-volt and/or 1200-volt installations, and, subject to the approval of the Minister, of their extension.

"(*b*) The adoption of half the standard voltage—750 volts—in those cases where it can be shown to the satisfaction of the Minister that advantage would arise from the use of this lower pressure.

"(*c*) The adoption of higher pressures—limited to a multiple of the standard pressure—where it can be shown to the satisfaction of the Minister that sufficient advantage would accrue.

"(iii) That both overhead and rail conductor collection should be permitted, as long as the position and general design of the conductors and structures are in accordance with recommendations which will be made in a subsequent report. In that report the Committee will also suggest the regulations required to ensure that locomotives and/or motor coaches shall be able, wherever it may be necessary, to run at two different voltages, *e.g.*, 600/750 and 1500 volts, and/or with either rail or overhead collection.

"(iv) That the generation of current for direct-current lines should be alternating three-phase at such voltage as may be desirable in each case.

"(v) That in the case of existing generating stations supplying at any frequency between 25 and 50 cycles it is unnecessary to make any change in frequency, but that it is desirable that where any one such frequency is in general use in a particular electricity district, any new power station put down in that district for supplying a railway should adopt the frequency which has been approved by the Electricity Commissioners or is in general use in that district.

"The Committee desire to add on this matter that from the evidence which has been put before them, as well as their own experience, they have come to the conclusion that alternating current supplied to the sub-stations at a frequency of 50 cycles can be used for railway purposes without any detriment to railway working.

"*In respect to Reference III.*

"12. There is only one line of any importance in Great Britain which would not come under the terms of recommendation paragraph 11 (i) above, namely, the electrified portion of the London, Brighton and South Coast Railway system. The Committee have considered with special care the very difficult questions introduced into the problem by the fact that this company long ago adopted a single-phase alternating-current system for its suburban lines, and did so with a special view to the adoption of a system which at that time appeared the only one admitting of extension from London to Brighton when this extension became feasible. The General Manager of the Company (Sir William Forbes) has come before the Committee to say that his company considers the extension to be now not only feasible but urgently desirable.

"13. The Committee is bound to recognize that if the railway is allowed to electrify its main line to Brighton on its present system, there will, of necessity, have to be a change of locomotives or multiple unit stock in any cases where other companies' trains run over that line, and that to this extent the wished-for general interchangeability will be interfered with. They recognize, on the other hand, that to change the existing suburban equipment of the Brighton Railway to a direct-current system would involve a large financial expenditure, which the railway itself could not be asked to undertake and which it would be difficult to justify to the public at the present time. It has further been stated to the Committee that the electrification of the main line is in this case very closely connected with that of the suburban lines on account of the necessity, on economical grounds, of using the same rolling stock throughout.

"14. Having all these considerations in mind the Committee recommend, as the course which on the whole has the balance of advantages:

"(i) That the electrical system of working at present in use, or actually under construction, on the Brighton Company's suburban lines need not be changed.

"(ii) That in view of the recent proposals of the Government as to grouping of railway companies, the question of the system on which the L., B. & S. C. Railway Company's proposed extensions to the coast should be carried out is now—in the event of the Government's proposals being approved by Parliament—one for special consideration from the point of view of the requirements of through working and interchangeability of traffic with the other systems forming part of the proposed Southern Group. Subject to these matters receiving the fullest consideration, and provided the completion of the proposed extension on the present system shows a substantial financial advantage, the Committee are of opinion that it should be allowed."

3. The Committee continued their consideration of the further matters, which, as stated in the Interim Report, were left over for subsequent consideration, and have again had before them representatives of the London and North Western Railway, the South Eastern and Chatham Railway, the Metropolitan Railway, the London Electric Railways, the Lancashire and Yorkshire Railway, the North Eastern Railway, the London, Brighton and South Coast Railway, the Midland Railway, and the London and South Western Railway. Mr. Leitch, formerly the Electric Traction Engineer to the Central Argentine Railway, also gave evidence, and a report was received from Mr. George Gibbs, of Messrs. Gibbs and Hill, Consulting Engineers to the Pennsylvania Railroad and other railways. The published reports by Commissions appointed in Continental countries to consider the matter of railway electrification have been obtained and placed before the Committee.

Sir Frank Dyson, the Astronomer Royal, and Mr F. E. Smith, until recently the Superintendent of the Electrical Section at the National Physical Laboratory, Teddington, gave evidence in respect to the effect on the indications of certain magnetic instruments by the operation of electric traction systems in the vicinity of the Greenwich Observatory and the National Physical Laboratory.

Further evidence on the side of the Electrical Contractors has been given by representatives of Messrs. Brown, Boveri & Company, Baden, Switzerland.

The Committee desire to put on record their indebtedness to the Railway and other Authorities, as well as to the Astronomer Royal and the other gentlemen mentioned above, for their very valuable assistance.

The Committee, having also had before them the recommendations made by a Committee of the General Purposes and Public Safety Department with regard to the clearances to be provided for overhead conductors, now recommend, in continuation of the first portion of paragraph 11 (iii) of the Interim Report, that regulations in respect to contact rail collection and overhead collection of current should be issued covering new electrical equipment operating on the recommended system.

4. In respect to contact rail collection, it is essential for the interchange of electrically operated trains, referred to in the first term of the Reference, that the contact rails should be so placed as to enable current to be collected by the same trains both on railways employing 1500 volts and on those employing 600 750 volts. The top-contact type of rail is that now generally in use for the present low voltages; the under-contact type of rail has also been largely used, and, in the opinion of the Committee, possesses advantages in regard to interference by the accumulation of ice and snow, and also in regard to the arrangement of protection for men working on the track with higher voltages. Suitably designed shoes can be run interchangeably with either the top or under-contact type of rail. Under these circumstances, the Committee are of the opinion that the contact rails employed may have either a top-contact or an under-contact surface, and they do not consider it desirable to recommend the exclusive use of either type, some varieties of which may be the subject of patents, but think that the choice in this respect should be left open, subject to the regulations below, so as not to interfere with such future improvements as are likely to be developed in either or both types.

5. The Committee consider that a standard position outside the tracks should be

defined within certain limits for the contact surface of the contact rails in relation to the position and level of the running rails, and desire to recommend that in respect to new electrically operated lines and extensions to existing lines the following regulations should be issued for securing the interchangeability of running:

- (i) The contact surface shall be in the horizontal plane.
- (ii) The gauge measured between the center of the horizontal contact surface of contact rails and the gauge line of the nearest rail of the corresponding track shall be 1 ft., 4 in.
- (iii) The vertical height of the contact surfaces above the plane of the top table of the running rails shall be:
  - (*a*) for top-contact rails, 3 in.
  - (*b*) for under-contact rails, 1½ in.
- (iv) The vertical height of the contact rail (including, where required, the protection over the top of the rail) above the plane of the top table of the running rails shall be such as to provide the necessary clearance from the load gauges from time to time in use.
- (v) The under-contact rail, where employed, shall provide for the engagement of the contact shoe being made from the side nearest to the running rails.
- (vi) Above the level of the under-contact surface (iii) (*b*) no part of the contact rail construction shall be at a less distance than 1 ft., 1½ in. from the gauge line of the nearest track rail, and below the level of the under-contact surface (iii) (*b*) at a less distance than 1 ft., 7½ in. from the gauge line of the nearest track rail.
- (vii) The vertical distance between the under side of any contact shoe in the free position and the plane of the top table of the running rails shall not be less than 1½ in.

The Committee recommend further that existing equipments which do not conform to the above may be continued in use and may, subject to the approval of the Minister, be extended.

6. In respect to overhead collection it is essential for the interchange of electrically operated trains, referred to in the first term of the Reference, that the position of the overhead live wire and the clearances between the live wire and the fixed and the moving structures, as well as the width and operating range of the collector gear, shall be such that any train may collect current from all electrically equipped railways.

7. The Committee therefore recommend that in respect to new lines and new electrical equipment of existing lines the following regulations should be issued for securing interchangeability of running:

- (i) The standard clearances, after allowance has been made for curvature and super-elevation, including any movements of the live wire or conductors and lateral movements of the collectors, under any circumstances likely to arise, shall be:
  - (*a*) Between the underside of any overhead live wire or conductor and the maximum load gauge likely to be used on the line:
    - (1) In the open, 3 ft.
    - (2) Through tunnels and under bridges, 10 in.
  - (*b*) Between any part of the structures and the nearest point of any live overhead wire or conductor, 6 in.
  - (*c*) Between rail level and overhead conductors:
    - (1) At accommodation and public road level crossings, 18 ft.
    - (2) At places where there is a likelihood of men in the conduct of their duties having to stand on the top of engines or vehicles, 20 ft.
  - (*d*) Between any part of the collector gear and any structure, 3 in.

The Committee recommend that in the case of the electrical equipment of existing lines the dimensions stated in (*a*) (2) and (*b*) may each be reduced to 4 inches as a minimum, that cases of exceptional constructional difficulty may be considered by the Minister as special cases, and that existing equipments which do not conform to the above may be continued in use.

- (ii) The horizontal distance of the contact wire from the plane through the center line of the track and perpendicular to the surface of the track rails shall be within the following limits:

(*a*) At a height of 18 ft. above rail level, 1 ft., 3 in.

(*b*) At a height of 4 in. above the maximum load gauge likely to be used on the line, 1 ft., 9 in.

(iii) The weight and construction of the contact wire and supports shall be suitable for the passage of collectors exerting an upward pressure of from 25 to 40 lb.

(iv) The width of the renewable contact surfaces of the collectors at right angles to the track shall not be less than 4 ft., and the extreme width over the horns of the collectors shall not exceed 7 ft., 6 in.

The Committee recommend that in the case of those railways that have already equipped any or all of their lines with overhead contact wires which do not conform to the above recommendations, the employment of these may be continued in use and may, subject to the approval of the Minister, be extended.

8. With regard to the second portion of paragraph 11 (iii) of the Interim Report and having regard to the practicability of further standardization of equipment by regulations, the Committee desire to confirm the views expressed in clause 10 of the Interim Report to the effect "that such regulations should put no avoidable difficulties in the way of the adoption in future, with the approval of the Minister, of any improvements in methods or appliances which may from time to time become available with increasing knowledge and experience," and to add that the Committee do not consider it desirable, in the interests of railway electrification, that further regulations (other than those recommended in this report) should be issued for the time being.

9. With regard to the extended References I and II, the Committee, after careful consideration, find that:

(i) The evidence given by the railway companies operating electric railways indicates that the cases of harmful effects due to a drop in potential substantially in excess of that allowed by Tramway Acts in earthed railway conductors have been few and unimportant, and readily corrected by the railway companies themselves on their own initiative.

(ii) The clauses for the protection of observatories inserted in the Acts of railway companies applying for powers to operate their railways electrically have had, and continue to have, a retarding effect on railway electrification. The Committee having heard in evidence officers concerned with the observatory instruments likely to be affected by the operation of electric railways, are of the opinion that the interests of observatories would in any case be sufficiently protected if the scope of the clauses referred to were limited to the portions of electric railways within the vicinity of the observatories.

(iii) Some railways, by virtue of the wording of their Acts, are under no necessity to apply for new powers for electrifying their systems, and are therefore not placed under the disadvantages in respect to limitation in the drop of potential by their Acts as in the case of the other companies.

10. Having regard to these considerations and to the views expressed in clause 10 of the Interim Report, as well as to the difficulties in imposing any definite limit to the voltage drop owing to the variety of conditions which present themselves along different portions of any railways, the Committee therefore recommend that:

(i) It is not desirable that regulations should be issued to limit the drop of potential in an uninsulated return conductor on electrically operated railways.

(ii) In cases where it is found impossible to dispense altogether with the present obligations which are imposed upon railway companies by the protective clauses inserted by the Board of Trade and other authorities into the Acts of the companies, these obligations should be specified definitely in each particular case.

GENERAL ELECTRIC REVIEW

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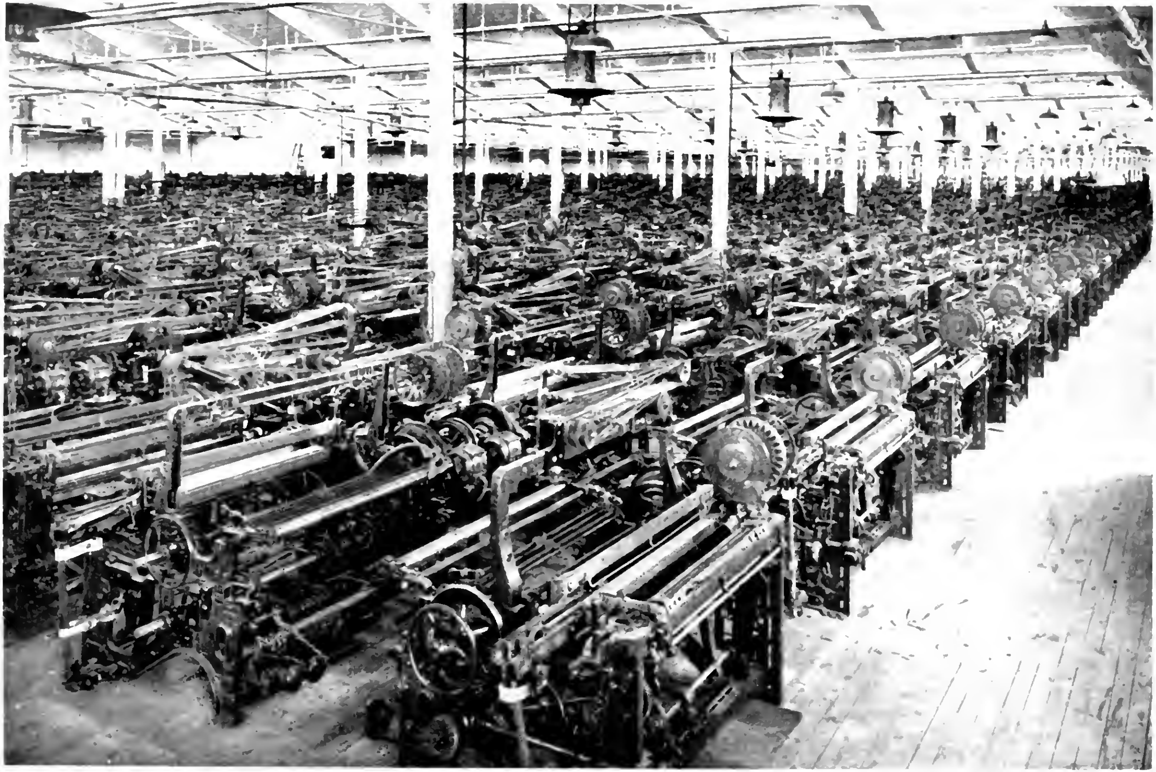

View in a Textile Mill Weave Shed, 550 Looms With Individual Motors. (See Article, Page 102)

GENERAL ELECTRIC REVIEW

WASTE NOT, WANT NOT

The copybook maxims of our childhood apply to nations as well as to individuals, and if we were to select a national slogan for the present year it would be hard to better *waste not, want not*. We have been through some fearful years of waste since 1914, as years of war must inevitably be, and now the world as a whole must face some years of want. Some parts of the world are doomed to suffer more than others, but all must suffer in some measure, our economic lives being so dependent upon trade and to an increasing extent on foreign trade.

With characteristic energy America has for some time been raising the danger signal against waste. Mr. Herbert Hoover was elected the first president of the Federated Engineering Societies in November, 1920, and one of his first acts in this new capacity was to appoint the Committee on Elimination of Waste in Industry. The report of this committee has just been published and Mr. Hoover in the preface states that the report reveals facts which may serve as the foundation for advance in American industry. This is just what we should like to see.

It is an ill wind that blows no good and there is no reason why the imperative need for economy during this period of reconstruction should not lead to permanent economic advancement in all industries.

Waste is a crime and this crime is a common vice in all industries and in every walk of life. The crime of waste is that everybody loses by it and nobody gains.

It is a crime to throw on the waste pile things which could be profitably salvaged.

It is a crime to waste steam rather than use the proper instruments to find where every pound of steam generated is going and then stop the waste.

It is a crime to reduce production by lack of proper illumination.

It is a crime to design and manufacture machines with a multiplicity of complicated parts where a few simple elements would do the job both cheaper and better.

It is a crime to build each unit of anything separately where the number wanted warrants reducing all the processes to a manufacturing basis for wholesale production.

A multiplicity of standards for the same thing is wasteful and unpractical and in the same way going to the cost of standardization for things of which only a few will be made is another form of waste.

It is also a crime to stifle and destroy human energy, new ideas and genius through jealousy and other factors, the sum total of which is often called the human element.

We might enumerate the crimes of waste at great length from the most important industrial wastes that individually may amount to millions per year to the waste in the individual domestic garbage pail, which though small in the case of each unit nationally may amount to prodigious figures, but that would be wearisome. Rather than do this, we prefer to ask our readers one question. Why has the electrical industry grown from nothing to such huge proportions in so short a life? This is the question which should interest the world to a peculiar degree today during this reconstruction period—from the largest manufacturing company to each individual housewife. The reason is perfectly simple—because the use of electrical energy is the greatest economic factor of modern times.

Who would go back today to the tallow dip or the oil lamp?

You do not have to waste time to go out and buy electricity. It is delivered to the house over wires. There is no waste. It is at your service every second of every 24 hours. You only pay for what you use. There is no dirt. There is no labor involved in its use. It is the cheapest and best and most efficient light that man has ever devised.

Who would go back to the horse-drawn tram car? Why are all our city and interurban roads electric roads?

Why are steam railways being electrified?

Why is the electric motor adopted in mill and factory and house? Human labor is more expensive today and electricity is the cheapest, most efficient and most convenient form of energy that man has found out how to use.

For a quarter of a century electricity has been practicing economy and has achieved more economic results than centuries of propaganda, with only other forms of energy available, could have equalled.

We are in whole-hearted sympathy with propaganda for the elimination of waste and the best way of getting results is the intelligent and widespread use of electrical apparatus and electrical appliances. J.R.H.

Mazda Service and Lamp Inspections

By L. A. Hawkins

Engineer Research Laboratory, General Electric Company

Service rendered to customers is one of the great assets of large modern business. It is of untold value to the customer—better than written guarantees. Mazda service is rendered directly to the manufacturers who are entitled to it, but the customers get the benefit of Mazda service wedding scientific research and development to the production of tungsten lamps. It insures the latest knowledge being applied to the product. As we see it, it exemplifies the spirit of modern big business to give the best available product to the world at large rather than endeavoring to make maximum profits by maintaining standardized lamps over long periods of time—notably during the life of a patent. In other words, Mazda service gives the best in spite of cost rather than the cheapest to produce.—Editor.

Even the casual reader of advertisements must have noticed how often the word "service" occurs nowadays. An examination of a recent issue of a technical journal, picked up at random, showed that of the thirty full page advertisements it contained, ten advertised some kind of service.

Those ten advertisements exemplified the use of the word in three different ways. First, and most common, was the service rendered by the apparatus itself; here the word was almost synonymous with "performance," "durability," or "reliability." Second, there was the technical service rendered to customers by the engineering staff of the advertiser. Third, there was a sales service, implying convenience to the customer in making a purchase. In all these uses, the service is rendered directly to the customer by the manufacturer, through either his apparatus, his technical staff, or his sales organization. The word, to the average reader, has come to imply something offered directly to him by the advertiser

It is probably for this reason that the meaning of "Mazda Service," although it has been many times explained, is still often misunderstood. Mazda Service is not rendered directly to the purchaser of Mazda lamps. Mazda lamps may give to the purchaser a service of the highest quality, but it is not Mazda Service. The illuminating engineers of the manufacturers of Mazda lamps may stand ready to place their technical knowledge at the service of anyone having a lighting problem, but it is not Mazda Service they offer The sales organizations of those manufacturers, through their thousands of agents, may maintain complete stocks within convenient reach of everyone, but that is not Mazda Service

Mazda Service is rendered, not to the individual purchaser, but to the manufacturer of Mazda lamps. The Research Laboratories of the General Electric Company collect from all over the world information about the best materials and processes for lamp manufacture, study that information, and, when necessary, make tests or investigations, and then report their findings to each lamp manufacturer entitled to receive them. In addition the Laboratories are continually conducting extensive research and experiment directed toward the production of better and more efficient light, and, when a discovery is made, it too is communicated to all Mazda lamp manufacturers. That is Mazda Service.

Now it is, of course, obvious that the purchaser of Mazda lamps, though he receives nothing directly from Mazda Service, does benefit through the lamp quality that will result if the manufacturer applies to his product the information given him by Mazda Service.

But what assurance has the purchaser that the manufacturer has made full use of that information?

Each manufacturer of Mazda lamps is under obligation to maintain the quality of his product at the standard set by the Research Laboratories, under penalty of forfeiture of his right to use the Mazda trademark on his lamps.

But what check have the Laboratories on the quality of the product?

To answer that question is the purpose of this article.

From the inception of Mazda Service, the Laboratories have studied the results of the extensive life tests regularly made at each Mazda lamp factory, and, on customers' inspections, at the Electrical Testing Laboratories and Bureau of Standards, and have run many tests to determine the effect on quality of various details of construction. At no time could the quality of the product of any factory deteriorate materially without the knowledge of the Laboratories.

But the Laboratories wished to go much farther than that. They wished to place themselves in a position where they would at all times know as much about the quality of each type of Mazda lamp in each factory as the most fastidious customer could, by the most searching inspection, learn about a single lot of lamps.

The Research Laboratories could themselves have undertaken the inspection work, but that would have required the employment and training of a large number of inspectors and a staff for compiling the reports. The Electrical Testing Laboratories, of New York City, had years of experience in inspection of lamps for customers and already possessed a trained force of inspectors and a staff experienced in compiling reports. To have the inspection work done for the Research Laboratories by the Electrical Testing Laboratories would have the additional advantage that the inspectors would not be General Electric employees and would therefore be obviously unbiased and impartial among the several lamp interests. Such an arrangement was accordingly made, and plans for the inspection work were laid.

First, the Research Laboratories, with the help of the lamp engineers, drew up a list of possible defects which should be looked for in every lamp inspected. Those possible defects number about 115. The defects were carefully defined, criteria established, limits set, and the necessary gages designed and built. Thus specifications for the inspection were established as instructions from the Research Laboratories to the Electrical Testing Laboratories, and the work was begun.

Next a method of scoring each factory on the quality of its product was devised. The 115 defects were classified in four groups.

1. Defects which may mar the appearance of lamps.
2. Defects which may affect the performance of lamps.
3. Defects which may cause lamps to be inoperative.
4. Defects which may blow fuses.

Group 1 includes such defects as a misplaced label, dirt on bulb or base, poor etching, a poorly shaped tip, stem shoulder, or button. This is the largest group, and includes 51 possible defects, none of which affects the performance of a lamp.

Group 2 includes such defects as a crooked base, insufficient basing cement, a badly discolored bulb, a cracked button rod, a filament out of a support hook, incorrect light center ength, incorrect overall length. This is the next largest group and includes 33 possible defects.

Group 3 includes such defects as a broken button rod, a cracked bulb, air in the bulb, a broken filament, a lead not soldered to the base, a defective filament joint. This group includes 26 possible defects.

Group 4 includes such defects as a loose base, a short-circuit between lead wires, or a lamp that arcs. This group includes only 6 possible defects.

Next, to each group was assigned an arbitrary figure as a penalty for each defect in that group found in inspection. The relative amounts of the penalties for the four groups were proportioned as fairly as possible to the relative seriousness viewed from the customer's standpoint of the defects in those groups. Thus, by multiplying the penalty for each group by the number of defects in that group for each hundred lamps inspected, adding the four products, and subtracting the sum from a fixed number, a score was obtained for each factory which with reasonable accuracy represented the relative quality of its product. By these scores the factories could be ranked each month on the quality of their work.

The scores and ranking serve two purposes —to call immediate attention to any factory the product of which requires investigation and improvement, and to supply the stimulus of competition in quality to factory superintendents and foremen.

The monthly reports compiled by the Electrical Testing Laboratories from the weekly reports of their inspectors are rendered to the Research Laboratories. They comprise about fifty pages each. First come the scores and ranking of each factory for the month; then the subsidiary ranking of each factory for each group of defects; then a table giving the change in scores from the preceding month, showing at a glance which factories have improved and which retrograded; then a recapitulation of rankings and a graphic plot of the scores for the year showing the trend of quality through the year for each factory; then the detailed report giving the defects per hundred for each defect for each factory; then a tabulation of the outstanding deficiencies if any in each factory; then a report of the results of inspection on defects for which the criteria or limits are still probationary for lack of sufficient data to justify the Research Laboratories in standardizing them, and which are therefore not yet included in the score but are reported to enable the Research Laboratories to judge whether the proposed inspectional criteria are fair; and finally the results of photometric checks for rating purposes.

Of most general interest is the record of the trend of quality since the inspections were initiated about a year ago. In studying those records, some allowance must be made for the decrease in production during that period which has made it possible to increase the average quality of the work of the operators by laying off those individuals whose product was inferior. The effect of this on the factory scores is in part offset by the fact that new defects have been added to the inspection so as to increase the number of possible penalties.

After all allowances have been made, the record for the year shows clearly the beneficial effect of the stimulus supplied by the inspection and the resulting competition in factory scores.

For instance, the average scores of all the factories for January and February were 912 and 927 respectively, 1000 representing a perfect score; while for November and December the average scores were 967 for each month. In other words the deductions for defects were reduced from an average total of 80½ in the first two months to an average total of 33 for the latter two, showing that during the year the defects were more than cut in half. In November the lowest score of any factory was 939, beating the average of the January scores by 27 points, and the February average by 12 points. In December, one factory dropped to 916, but the others improved enough so that the average score was the same as for November, 967.

To get an idea of what such a score means in terms of quality, suppose 1000 lamps inspected and one lamp found with a loose base and two with broken filaments. If the other 997 lamps were perfect, the score for that lot of 1000 lamps would be 965, two points below the actual average of all factories for November and December. If in addition ten of the lamps were found to exceed the specified overall length and fifty were found to have minor defects, such as a tarnished base or a poorly shaped tip, the score would be further reduced to 959, an amount equaling the actual average score for all factories for September.

This illustration is given to show how a relatively small number of defects, mostly of minor importance, pull down a factory's score. Of course, actually in 1000 lamps the variety of defects would be much greater, and the number of defects of any one kind would be smaller than in the illustration.

Another way of viewing the results of Mazda Service inspection is to observe the growth in the percentage of lamps above criticism, lamps in which no one of the 115 possible defects can be found.

In February, only one factory out of twenty had 90 per cent of its product free from all defects. Ten of the twenty had less than 80 per cent perfect lamps. One had less than 60 per cent perfect.

This was not at all a bad record, as will be realized by anyone who stops to reflect that the presence of even so minor a defect as a speck of dirt on the bulb or a tip poorly shaped will subject a lamp to criticism and prevent its being classed as perfect.

And yet in November, nine months later, eight out of eighteen factories (two having closed because of decreased production) had 90 per cent or more above criticism, and not a single factory had less than 80 per cent. In December, eleven out of eighteen had over 90 per cent above criticism, and again none had less than 80 per cent.

It was not wholly the stimulus of rivalry that produced this remarkable result. The monthly reports enable the Laboratories to spot instantly any operation in any factory that needs attention. For instance, in the October report, where all factories but one scored above 940, while one was down to 784, that one factory's record stood out like a sore thumb, pointing emphatically to the need for immediate improvement in the basing operations in that factory. Less striking deficiencies show up clearly in the detailed reports, a study of which enables the Laboratories immediately to warn the factory management of any condition which needs improvement.

It must be admitted, however, that the factory superintendents, who receive copies of the weekly reports prepared at the factory by the Mazda Service inspectors, and who figure out in advance with keen interest what their scores are likely to be for the month, seldom lose any time in correcting any trouble disclosed by the inspection, so that when the management, on receipt of the Laboratories' warning, investigates, it is usually found that the faulty conditions have ceased to exist. It goes without saying that this forestalling of their criticisms is anything but displeasing to the Laboratories. It seems to them to offer the clearest possible evidence that the Mazda Service inspection is worth while.

To an engineer, a diagram often tells more than many words. The chart reproduced in Fig. 1 shows a consolidation of the curves of factory scores for the year, and reveals at a glance the steady upward trend of quality and the bunching together of the factories in the region of high scores.

The chart also shows how the method of scoring calls instant attention to a serious defect epidemic at any factory. The first glance at the chart shows that there was something wrong with one factory in October, for while all other factories were above 940, one dropped far down to 784. A reference to the detailed report gives an immediate explanation. That factory in October suffered from an epidemic of a heavily penalized defect—loose bases. Although less than 1 per cent of the lamps inspected had loose bases, it was enough to produce the result shown by the score and chart. That same factory had no loose bases in either September or November. Had it done equally well in this one respect in October, its score, instead of 784, would have been 968.

Through Mazda Service inspections the Laboratories acquire immediate and accurate knowledge of the quality of the current product of each manufacturer of Mazda lamps, and they have the further satisfaction of knowing that the inspection in itself is an effective aid in maintaining that quality at the high level that should be and is implied by the word Mazda.

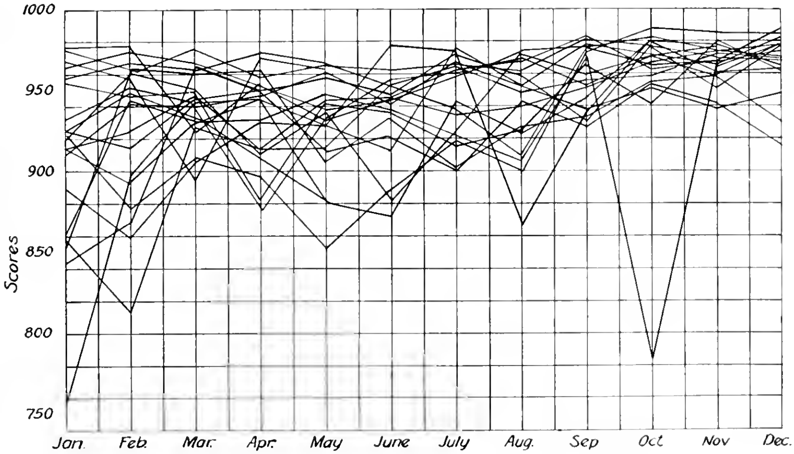

Fig. 1. Factory Scores on Mazda Service Inspection, January-December, 1921

The Superpower System as an Answer to a National Power Policy[*]

By W. S. Murray
Consulting Engineer

The project to develop a superpower system for the region between Boston and Washington was originated by Mr. Murray during war time, who urged the late Franklin K. Lane, Secretary of the Interior, to make a survey of the sources of energy in New England and along the Atlantic seaboard as far south as Washington. In time Congress made an appropriation of $125,000 for this survey, which was recently completed for the United States Geological Survey by a special staff of which Mr. Murray was chairman. The Survey considers the economic possibilities of interconnecting existing electric power plants and systems in the zone and the building of new plants at advantageous load centers. It is estimated that this sytem will effect an annual saving of over $500,000,000 by 1930, and what is of more importance, the conservation of 50,000,000 tons of coal. The yearly profit from this development will amount to 33 perc ent of the investment—a highly attractive return. Two other articles on the significance of the superpower survey are published in this issue, one by Mr. H. Goodwin Jr., dealing primarily with the industrial features, and the other by Mr. W. D. Bearce, discussing the advantages that will result from the electrification of 19,000 miles of railroads.—Editor.

It sounds like a simple sentence to say: "Electricity is the True Agent of Power." Nevertheless when a careful analytical consideration of that sentence is made you will begin to realize that it stands for a great deal more than those simple words.

Power is the *father* of all accomplishment—moral, intellectual, and physical—and electricity as its agent is one that cannot be approached by any other. Power has become a great business in the world, and no business ever succeeded without good agents. The nearest approach to electricity as an agent of power is high pressure water and yet it can be shown that electricity is fifteen hundred times better, at least so far as efficiency is concerned, in the matter of power transmission. We have arrived at the time when 400,000 to 500,000 horse power can be transmitted 400 miles without incurring too great a commercial loss.

With regard to railways, we are not concerned with the two accepted systems of electrification but we are deeply concerned with the universal power system from which they are to receive their energy. Like the industries scattered throughout the Zone, each one of them calling for their complement of power, the railways operating therein must accordingly have their quota.

The Superpower Zone embraces the territory existing from Boston to Washington and inland from the Coast about 150 miles, a total of about 60,000 square miles. Within this area there are 23,000,000 people, practically one fifth of the total population of the United States, and there are 36,000 miles of railroad of the heavy traction type. Some of these rails have already been electrified, as for example, parts of the New Haven, New York Central, and Pennsylvania, but this is a very small percentage of the total. Within the district there are 96,000 industries, and of these 76,000 require power. Already 4,000,000 kw. of generating capacity have been installed within this Zone and produce something over 10,000,000,000 kilowatt-hours yearly.

To complete the Superpower System will require the interconnection of the power plants within the Zone. To do this our transmission experts deem it advisable to use a general zone transmission voltage of 110,000. In the case of power development extraneous to the zone and at considerable distance from it, such as in the Niagara and St. Lawrence districts, it is deemed advisable to transmit at 220,000 volts, and one of the prime objects in mind for the successful and economic handling of such a potential was that such transmissions be unhampered with the requirement of multiple switching points. In other words, that the power be transmitted in bulk from the point of development to a single point of delivery for distribution within the Zone.

Let us consider for a moment the recommendation with regard to 60 cycles as a standard for the Superpower Zone. This frequency is inevitable as the supporting data of the report will show, and it means but one thing; namely, that we must begin to live into the production and use of high-powered steam-turbine generators designed for 60 cycles. It has been and it is now my belief that the single-phase system of electric traction from an electrical efficiency standpoint is higher than that of the 3000-volt direct-current systems, when there is no intervening substation between the source of power and the traction units; but the choice of the traction system is secondary in importance to the proper choice of a standard system of power from which either system of electric traction is to derive its energy. In stating that a frequency of 60 cycles should be selected

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[*] Abstract of address before the Schenectady Section of the A.I.E.E., December 2, 1921.

for the Superpower Zone, I am fully aware of the fact that this robs the single-phase system of one of its potent aids looking toward high efficiency, thus bringing the two classes of electrification more nearly together from an economical standpoint.

I am glad also to embrace this opportunity to say that I view with the deepest concern any tendency toward the recommendation of individual power systems for railroads. The public electric utilities should be sole producers of power from which railroads should receive their energy. The public utilities are in the power business, and know the power business, and should continue in the power business; and the railroads are in the transportation business, and should continue in the transportation business. The electrification of railroads will be retarded, their costs will be increased, and their reliability of service will suffer by the existence and construction of power plants to supply their individual needs. Per contra, the electrification of railroads will be tremendously accelerated when they know that adequate, cheap, and reliable power is made available to them by the people in the power business; and nothing can be made more patent than that this will be so when, through multiple power stations and transmissions, power can be tapped therefrom at many points along their lines.

We are on the verge of a great industrial expansion and the two great arms supporting it are power and transportation; and we must therefore develop a system of transportation which will permit the capacities of railways to expand to meet the necessity of carrying the raw and finished products, so that we can back up the production of the country to meet the world's competition.

With regard to coal let us not forget that while conserving that coal annually it will mean also the conservation of the labor of 50,000 miners who are literally throwing their work away while the world is yielding up this veritable treasure only to be wasted; and let us not forget that the investment necessary to a regional plant will effect economies, the return on which will cover that investment in three years.

Reference has been made to the savings that may be effected through the further electrification of industry and railroads. Returning for the moment to the electrification of railways, it is shown that the returns are not so great as those accruing from the electrification of industry. On the other hand, 11 to 19 per cent or an average of 14.2 for the electrification of 19,000 miles of track is no small sum; but the point here to be considered is the fact that this result is based on the existing traffic of 1919, to be much enhanced by immediately succeeding years. The thought that must be principal with us is that we must begin now to develop that system of traction which will permit a facility of expansion to cope with the quick growth of traffic requirements—and electrical movement is the only means to that end. We must speed up our main lines, yards, and terminals, and there is no hope that steam can accomplish this on our present limited track service in the zones where the density of traffic is high.

In the matter of hydro-electric power for the Superpower Zone, it is a fact that as of 1930 the ratio of hydro-electrically produced power will only be 21 per cent of the total to be generated. It is of greatest importance to note, however, that through the system of transmission interconnection, the maximum amount of water power available could be collected and so make each square mile of drainage area yield up the greatest number of kilowatt-hours. When the power of a single river is connected to the lines of a single system, the service factor of the river, especially those rivers where storage is unavailable, can not be made to correspond with the load factor of the load. Interconnection, however, of several systems permits diversity of load application and the service factors of rivers can therefore be better correlated with the loads of the several systems.

You may be interested to know how we got our appropriation from the Government. It was by a frank statement that the money would be used to show the people what might be done if we co-ordinated our power systems. We explained that we were not asking a dollar from Uncle Sam to construct the system, that it should be constructed lock, stock, and barrel by the private interests of this country, and we constantly kept in mind that good saying of President Harding that we should have "more business in Government and less Government in business" so that you must eliminate from your minds any thought that the Superpower System to be constructed will be owned or controlled by the Government.

There is no instrument that has advanced so much the possibility of superpower as the electric utilities. They are the very foundation for the coming existence of superpower and they are the logical ones to put it on the map.

We have shown how a large amount of coal, capital, and labor can be conserved. The electric utilities, like many other corporations through these difficult times, have been fighting for their very existence. Splendid management and the observance of every possible economy is bringing them through the storm, and out of this good work accomplished will arise the Superpower System to carry on to higher economy and results. Our only danger lies in the fact that we do not recognize immediately this great second period that is now upon us—not coming, but upon us—in which we can practice the economies cited. The public service commissions have a duty to perform in this great movement toward the elimination of waste and that will be in rewarding capital by giving them a proportionate per cent increase in return wherever it is possible for them by economic operation to make a reduction in rate. Today, the bogey as to a permissible cost of money has been set low. To build such a regional plant as has been described, one must buy money just as they have to buy bricks and machinery and unless a fair return is offered, capital can not be obtained. It is fair to assume that the rates on power have been scaled down by the Commissions to what in their conscientious judgment is fair and a fair plea is that additional reward be given to capital if, through the exercise of efficiency both in machinery and management, a further reduction in those rates can be made.

In the case of the New York, New Haven & Hartford Railroad, the load factor on that system is excessively high, due to the high ratio of passenger tonnage to freight tonnage. One of the last contracts I made for the New Haven Road was that with the New York Edison Company in which a load factor of 70 per cent was guaranteed. In the early days of 1905 when the New Haven road was electrified, we had to put 100 per cent of their dollars into the line, and 100 per cent for power into locomotives, and 100 per cent into power stations. In other words, they had to do the whole thing. Now, when we electrify, let us eliminate for the railroads the 100 per cent for the power station; let us eliminate from an investment point of view the 100 per cent for the locomotives by standardizing equipment and securing their purchase through equipment trust bonds and thus leave only 20 to 25 per cent capital requirement on the part of the railroads for the construction of their distribution and contact systems. We must construct these great power stations and transmission systems so that power shall be available to the railroads just as it is to us when we go over to a socket to turn on the light in a room, and it must be adequate, reliable and cheap.

Discussion of Address by W. B. Potter

Mr. Murray mentioned that the return on the investment would be something over 14 per cent as the result of the reduction in cost of operating railroads electrically as compared with steam. That figure is rather interesting. He mentioned a range between 11 and 19 per cent and I think that these figures are not so very far from many of the investigations we have made.

There is, however, another element entering into the economies of electrical operation which I think well worth emphasizing. The value of property is what you can get out of it, and if you can increase the amount of traffic over a railroad by 5 per cent you have increased the value of the property 5 per cent. Many of the railroads, in normal times at least, operate at nearly their full capacity, and electrification would mean an increase in the amount of tons they could handle. As to passenger service, it means trains more nearly on time. The reliability of electric power is proved, as compared with steam. While it is true that each steam unit is an independent source of power, at the same time broken down locomotives on the track are quite apt to interfere with passenger service.

The bringing together of all those little isolated plants seems to me like bringing together rainfall into Niagara—both are waterfalls. One has value, it is true, but of no particular value to move the industries of the world. But the bringing together of these individual power plants, and the creation of this superpower scheme, makes for the district covered by it a unified source for maintaining industry that could not be met throughout the world.

If the co-operation of the various interests involved is as successful in carrying out the undertaking as Mr. Murray has been in securing the co-operation of those with whom he has been associated in the preparation of this report, we can ask nothing further.

Discussion by A. H. Armstrong

The question of power supply is of first importance in every proposed railway electrification and I cannot too strongly endorse the valuable work done by Mr. Murray and his Commission in their careful analysis of power requirements and their recommendations for the future. Electrical engineers must fully recognize the utmost importance of continuous power for electrified railways, as no one cause would so quickly discredit the success of electrifications as unreliable power.

To supply that security against breakdown, which is so necessary to electric railway operation, imposes an almost prohibitive burden upon the railway company itself, if a power house containing ample reserve is installed by the railway company and used exclusively for its own purpose. The load factor of an electrified road under favorable conditions may be as high as 70 per cent but in many instances where electrification is fully justified the load factor may fall below even 40 per cent. If in addition to the variation in the daily load there is added ample provision for seasonal variations, such as grain movement in the fall on our western roads, and also there are provided reserve units in addition, it becomes apparent that the total investment in a railway power station is so great that the burden of its fixed charges seriously impairs the economic advantages of electrification.

Although the first thought of the railway operator is to look favorably upon an independent power supply entirely under railway control, a study of existing installations discloses the fact that some of our largest electrified roads depend in whole or in part upon power purchased from public utility companies. This tendency toward the purchase of power has become clearly defined during the past few years and indicates the necessity of adopting a uniform frequency of supply, in order to benefit to the fullest extent from the interconnection of power stations and systems. The recommendation of Mr. Murray and his Commission that 60 cycles be recognized as the standard frequency of power supply in the United States is in full agreement with the trend of sales of turbines and transformers manufactured by the General Electric Company during the past ten years, which clearly discloses the rapid ascendency of 60-cycle apparatus. However much disagreement there may be as to so-called systems of railway electrification, electrical engineers should be in fullest accord as to the benefits of adopting 60 cycles as the standard frequency for all future power installations.

Similar action has been taken in many foreign countries upon the recommendations of railway electrification commissions appointed by the Government to study the matter of electrifying the railways in their respective countries. In England, France, Belgium, Holland and other countries a standard of 50 cycles has been adopted for power generation and transmission, and the distribution of power at a uniform frequency throughout the country will constitute one of the greatest factors in bringing about electrification of railways. The report of Mr. Murray and his Commission may therefore be looked upon as the first serious attempt to bring about equal benefits in this country by recommending the standardization of 60 cycles, which is already so firmly established. Although this Commission lacks any power to enforce its recommendations in this respect, it is to be hoped that the soundness of its findings will be recognized by all electrical engineers and every individual effort be made to standardize a universal 60-cycle power supply.

Discussion by O. F. Allen

The total power so far used, or even contemplated for the next few years, in the centers of population of Europe, is so small compared with the tremendous problem Mr. Murray has studied, there is nothing to say on that phase of it.

It will perhaps be of interest to you if I relate one illustration of the European situation. An Italian railway now electrified delivers freight to a French railway operating by steam. I asked the engineer of the French railway if they were going to electrify under the existing industrial and economic conditions, and if they could afford to electrify. He replied: "We cannot afford not to electrify, as with the electrified lines the Italians are giving us freight faster than we can handle it. As we have a contract with them for several years to run to take the freight we have either got to double our lines or electrify them, and it is cheaper to electrify than to double track."

Another phase over there is that following the terrible destruction from the war, they have been able to study the combination of heavy traction and power plant development. The two things are going hand in hand. In France they are building quite substantial power plants up to over 200,000 kw. each, and they are laying out 220,000-volt transmission lines. It is hoped to build them in three to five years. They are combining so that they can use all their power plants in all industries, and are not seriously considering any plants of small size. The railroads are considered customers for power plants as much as other industries. They are treated as part of the power scheme, and this will help railway electrification in France,

Discussion by H. R. Summerhayes

We have already in New England a superpower system on a smaller scale: New England power companies operating a large number of hydro-electric stations. The New England situation is bringing into being an interconnecting system among many power companies, operating on a sufficiently large scale, and showing the practicability of the system Mr. Murray proposed.

There is a similar situation in the southeastern states. While they do not transmit power from one end of the system to another, the power generated at one end of the system may be carried part way and the power generated at this intermediate point transmitted further on so that finally the surplus power at the lower end of the system relieves the situation at the upper end.

Last year, under the pressure of economic necessity, that is, because of shortage of water, a number of the systems surrounding San Francisco were hastily tied together by links of transmission systems and put on one load despatcher with a resulting saving of a great amount of fuel.

In the larger system there are still some engineering problems to be met. One little difficulty is frequency, and in that I heartily subscribe to Mr. Murray's declaration that 60 cycles will be the universal frequency for the power network. When we come to the transmission of power it at first appears that a lower frequency may be desirable for a straight-away transmission, but in working out the network 60 cycles may actually become cheaper. It is, surely, preferable on account of the necessity of standard frequency and on account of the very much lower cost of 60-cycle machinery. We must remember that in the utilization of machinery—motors, transformers, etc.—in the distribution system, they represent a much greater investment than the generating apparatus.

"General Views of Grand Central Terminal Area from 50th Street Before and After Electrification"

What the Superpower Survey Means to the United States

By H. Goodwin, Jr.

Consulting Engineer, Philadelphia

Mr. Goodwin was a member of the committee that made the Superpower Survey for the U. S. Geological Survey, and is specially qualified to discuss its import. While the investigations of the Superpower Survey were to a large extent local, the fundamental economic principles and deductions will apply to almost all sections of the country; hence the findings and recommendations are of concern to the whole country, and Mr. Goodwin has elected to discuss its significance from this broad standpoint.—Editor.

The Superpower Survey has been discussed in its preliminary stages so frequently in the technical press that it should be necessary here only to remind the reader of it before proceeding to the discussion. It is described very well by the title of the report which has been issued as professional paper No. 123, of the U. S. Geological Survey, entitled: "A Superpower System for the Region between Boston and Washington."

The Superpower System is, of course, electrical, a network of moderately high voltage supplied by economical generating stations at strategic points for generation. The region studied runs inland about 150 miles, covering the intense industrial area of the North Atlantic Seaboard. The survey was made by a special staff under the U. S. Geological Survey.

But the Superpower Survey was more than is at first suggested by the title of the report. It was the first effort to determine with any real accuracy the power, fuel and electrical requirements of a large section of

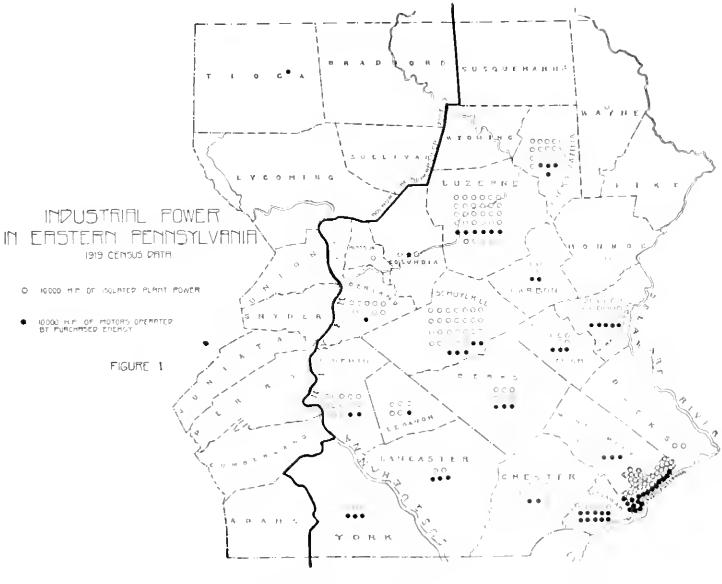


Fig. 1. Map Showing Distribution of Industrial Power in Eastern Pennsylvania

our country. The tremendous growth of the electrical industry in all its branches is a matter of record. The possibilities of the future have been an open subject for prediction and prophesy by those so inclined. Some prophets have been so enthusiastic and have spoken in such glittering generalities of the "unlimited possibilities" of the electrical future, that those who must supply the funds for the development have been inclined to discount the glowing statements. These financiers have seen other propositions developed to a saturation unappreciated by their enthusiastic advocates and have seen them crumble with the effort at over development. So a great progressive move is made by the Superpower Survey in the definite study of a large territory to determine the proper ultimate practical development, and a plan to reach that development as soon as conditions will permit.

But any initial, progressive step like this is more than a local benefit; it is a great step in advance for the whole country. The underlying economic principles are the same no matter what section is considered and the means for working out those principles will show greater similarity than diversity of local conditions would at first make apparent. So the Superpower Survey should interest every progressive individual throughout the length and breadth of our country.

Therefore the title of this article has been chosen to be: "What the Superpower Survey means to the United States." This title embraces all that is to be said, though on account of the size of the subject it is unfortunate that the article cannot include all that might be said under such a title.

Natural Divisions

Any such proposition as a Superpower System may for one purpose or another be dealt with from various aspects: executive, legal, financial, commercial and engineering.

We should have a full appreciation of these various aspects, and carry on our work in any one so as to aid those who are engaged

TABLE I: MECHANICAL POWER SUPPLY EQUIPMENT

Divided by Character of Pow

Character of Power Supply	Plant Size H.P.	ESTABLISHMENTS		POWER SUPPLY EQUIPMENT											
					Prime Movers								
		Number	Average H.P.	Aggregate H.P.	Total H.P.	Steam Engines		Steam Turbines		Internal Combustion Engines		Waterwheels	
						No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.
	No Power	407	—	—	—	—	—	—	—	—	—	—	—
Steam Power Only	1/200	452	71	32166	32166	535	31713	9	453	—	—	—	—
	201/500	87	333	29030	29030	174	27045	16	1985	—	—	—	—
	501 and above	72	1920	138052	138052	337	70878	79	67174	—	—	—	—
	Sub Total	611	326	199248	199248	1046	129636	104	69612	—	—	—	—
Purchased Electric Power Only	1/200	3701	26	95580	—	—	—	—	—	—	—	—	—
	201/200	142	312	44489	—	—	—	—	—	—	—	—	—
	501 and above	103	1050	118676	—	—	—	—	—	—	—	—	—
	Sub Total	3946	655	258745	—	—	—	—	—	—	—	—	—
All Other Power	1/200	1341	40	54293	38753	319	16741	7	286	960	15827	167	6899
	201/500	165	320	52501	32872	215	24069	12	785	56	2978	75	5040
	501 and above	155	2290	354363	208708	465	111465	54	77578	63	10622	71	9043
	Sub Total	1661	278	461157	280333	999	152275	73	78649	1079	29427	313	19982
Total Power		6218	148	919150	479581	2045	281911	177	148261	1079	29427	313	19982
Grand Total		6625	—	919150	479581	2045	281911	177	148261	1079	29427	313	19982

in the others. In this light the Superpower Survey considered commercial and engineering matters only. There are details to be worked out in regard to executive, legal and financial matters. While there are no insurmountable difficulties, it will be evident that some matters could be simplified by proper technical development, both engineering and commercial.

It is here then that the report should engage the attention of most. The results of the Survey should not merely interest us as finalities; instead, with the breadth of view which these results will impart, each one should survey his territory in like manner to see how the findings may be applied.

The division of the work of the Survey is a fundamental that was proved to be sound. Therefore a statement of it is more than narrative; it is a necessary concept for the full appreciation of the work accomplished. There were three sections of the work, viz.:

Railroads
Industries
Power and Transmission.

It was required of the first two sections to determine the amounts of the railroads and industries that might be economically electrified and the saving to be accomplished thereby. Of the third section it was required to design a system to interconnect the present utilities and carry the load determined by the other two sections. It is thus seen that commercial matters were involved in the work of the first two sections and engineering in all three.

COMMERCIAL PHASES

From the beginning it was evident that, regardless of engineering analyses or possible economies to be obtained, the final supply of power to any establishment would necessitate negotiations exactly similar to those now conducted by the new business departments of the central stations. Therefore, every effort was made to develop the data in the best form to aid the central stations in connecting the load that it was shown should be supplied by them.

AND FUEL USED IN FOUNDRIES AND MACHINE SHOPS

er Supply. 1919 Census Data

				ELECTRIC MOTORS				FUEL USED			
Operated by Purchased Energy								Coal			
Total H.P.	Electric Motors		Other H.P.	Total		Run by Current Generated in Establishment		Anthracite Long Tons	Bituminous Short Tons	Total Equivalent Bituminous Short Tons	Coke Short Tons
	No.	H.P.		No.	H.P.	No.	H.P.				
—	—	—	—	—	—	—	—	4230	3304	7114	1077
—	—	—	—	1213	8713	1213	8713	69628	153924	216564	48561
—	—	—	—	1900	19738	1900	19738	40664	105987	141987	24465
—	—	—	—	9491	133800	9491	133800	243808	598265	817865	113638
—	—	—	—	12604	162251	12604	162251	354100	858176	1176416	186664
95580	13971	95580	—	13971	95580	—	—	66177	102742	162242	109625
44489	4158	44489	—	4158	44489	—	—	24835	58478	80778	31114
118676	10144	118676	—	10144	118676	—	—	32453	147478	176578	63708
258745	28273	258745	—	28273	258745	—	—	123465	308698	419598	204447
15540	1654	13033	2507	2331	17617	677	4584	43195	101056	140056	38735
19629	1726	19454	175	2686	30564	960	11110	40088	137558	173558	39182
145655	9093	145455	200	14068	206497	4975	61042	152280	931306	1068000	95199
180824	12473	177942	2882	19085	254678	6612	76736	235563	1169920	1381614	173116
439569	40746	436687	2882	59962	675674	19216	238987	713128	2336794	2977628	564227
439569	40746	436687	2882	59962	675674	19216	238987	717358	2340098	2984744	565304

How often has a central station desired to know the amount of load that might possibly be connected in its particular territory? Or, lacking that, even the total power in use in the territory? This is the situation that presented itself to the Survey, except that it was magnified for the whole zone. Since practically none of the central stations could supply this information other means were adopted. It was decided to obtain the information directly from the railroads. But the industries still presented a great problem. The last census for manufacturers was that for 1914. The census bureau was questioned about the 1920 census then in the process of collection. The reply was that with the cooperation of the Survey they believed they could furnish the information desired.

Industrial Power

The original intention was to get just the regular information on power and fuel used by the industries in the Superpower zone. The work in the census bureau was under the direction of Mr. E. F. Hartley, Chief Statistician for Manufacturers. He entered into the proposition with great spirit and exhibited the strongest desire to make the census bureau of the greatest commercial service. The result is that instead of having just an ordinary summary of the power and fuel used by the industries, there is presented in the Superpower report the greatest, in fact, the only analysis of industrial power and related fuel use on a large scale that has ever been made.

As an example, Table I shows the mechanical power supply equipment and fuel used in machine shops. The report will contain over fifty such tables, general and detail, covering all branches of manufacturing and mining. The value of these can be appreciated by a little study of this sample. Table I shows by the column headings the various types of prime movers and electrical equipment used, and also the fuel. Looking down the left side it is seen that all the items are divided by character of power supply, and then subdivided by plant size. It is to be noted that the fuel associated with each power group is shown separately; for instance, plants operating entirely on purchased electrical power have in this industry 142 establishments with 201 to 500 horse power. The total rating of the motors is 44,489 horse power.

In these establishments there is used for other purpose than power production 24,835 tons of anthracite and 58,478 tons of bituminous coal, which is equivalent to 80,778 tons of bituminous total. This table deserves the study of every man interested in industrial power, so that when the report comes giving similar tables for all industries he may be able to grasp them quickly and understand the analyses worked out from them. From these tables the Survey determined by analysis and consultation with experts in the different industries the additional amount of power that might have been supplied to each and all the industries.

The tables, of course, apply only to the Superpower zone, but a thorough study of them should give a new sense of proportion useful in any territory. In fact it is probable, having sufficient familiarity with the special data for the Superpower zone, that useful approximations could be made from the general census tables for the other sections of the country.

TABLE II: MECHANICAL POWER SUPPLY EQUIPME

Divided by Plant Size.

Plant Size H.P.	ESTABLISHMENTS REPORTING POWER		POWER SUPPLY EQUIPMENT									
				Prime Movers								
	Number	Average H.P.	Aggregate H.P.	Total H.P.	Steam Engines		Steam Turbines		Internal Combustion Engines		Waterwheels	
					No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.
1-200	338	42	14173	7794	151	6341	2	24	21	195	41	1234
201-500	37	305	11316	6124	111	5985	0	0	2	4	2	135
501 and above	38	5550	211730	170869	327	103481	42	18588	23	48500	4	300
Total	413	575	237219	184787	589	115807	44	18612	46	48699	47	1669

Distribution of Industrial Power

But this is not all that the census did for the Survey and engineers. After each industry had been analyzed the power was tabulated by counties, subdivided by plant size. Table II shows Northampton County, Pa., as a sample. The division of power by plant size in each county was only made for the Superpower zone. But the 1920 census will show for the first time the power in each county in the United States, tabulated with the same column headings as Table II.

It is interesting to remark that these special tabulations were made economically possible by the introduction into the census of manufacturers of electrical tabulating machines.

To illustrate the distribution of power graphically, Fig. 1 shows a map of the section of Pennsylvania in the Superpower zone. Indicated thereon by open circles is the total rating of prime movers and by solid circles the motors operated from purchased electric energy. On the completion of the 1920 census of manufacturers it will be possible to construct such a map for the whole country or any portion of it.

Growth of Industrial Power

But of course, the load that might have been carried in 1919 is not sufficient information on industrial power. It was not then connected to central station systems and may not be till those systems are extended. Also the Superpower System must be constructed to care for increases for a number of years to come. This then brings in the question of growth of industrial power. The past growths were determined as a basis. The curves in Fig. 2 show by solid lines the form of the growth. The first point of interest is that if the central stations ("Purchased H.P.") continued to grow at the rate they have in the past, their load would soon exceed the total power of all the industries—an obvious impossibility. The dot and dash line shows the amount of power that might have been carried at any time as determined by the Superpower analysis of the industries. It is the object of the Superpower to have all this connected by 1930. This means that the central station curve will continue up as shown. But look at the "Isolated Plant" curve and note what the result is there. It means that this curve must turn down and show a more rapid rate of decrease of power than the maximum rate of increase. During the past few years the central stations have shut down much isolated plant power and taken practically all the increase, but enough new plants have gone in so that the total isolated plant power has been held practically constant. Now the real fight begins. Iso-

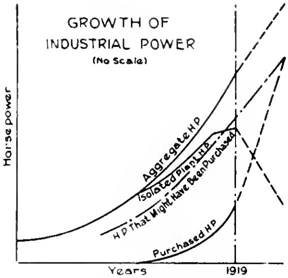


Fig. 2. Curves Illustrating Growth of Industrial Power

NT USED IN NORTHAMPTON COUNTY, PA.

1919 Census Data

Operated by Purchased Energy				Electric Motors				Number of Establishments Reporting No Power
Total H.P.	Electric Motors		Other H.P.	Total		Run by Current Generated in Establishment		
	No.	H.P.		No.	H.P.	No.	H.P.	
6379	1392	6379	0	1443	7021	51	642	—
5192	325	5192	0	347	5437	22	245	—
40861	2134	40861	0	10038	232743	7904	191882	—
52432	3851	52432	0	11828	245201	7977	192769	49

lated plants must be shut down faster than they were ever put into operation, if the present rate of growth of the central stations is to continue. With this condition confronting them, of what immense value are the data compiled by the census bureau for the Superpower Survey! How necessary is it for the central stations to study the situation most critically and formulate definite plans for procedure! And, be it remembered this is not for the benefit of the central stations only, but even more for the industries. For the central stations it means *growth*, for the industries it means *economics*, because the determinations of the Superpower Survey were predicated upon dollars and cents economies to the industries to be supplied.

Curves similar to Fig. 2 can be plotted for any states, cities or other areas throughout the country, from the final census publications, and a little further comment may therefore be useful.

Data on the power used by manufacturers were first collected by the census for 1869. Since then it has grown rapidly due to two causes, viz., growth of industry, and growth of use of power per unit of product. An appreciation of the values of these two factors is necessary to a proper understanding of the curve for a particular territory. Many old basic industries, formerly strong in the Superpower zone, most of them heavy power users, are moving west. At the same time the "finishing" trades are increasing their use of power to try to keep down costs and offset the increasing distance to the center of consumption as it moves west. These industries have the advantage of an estab-

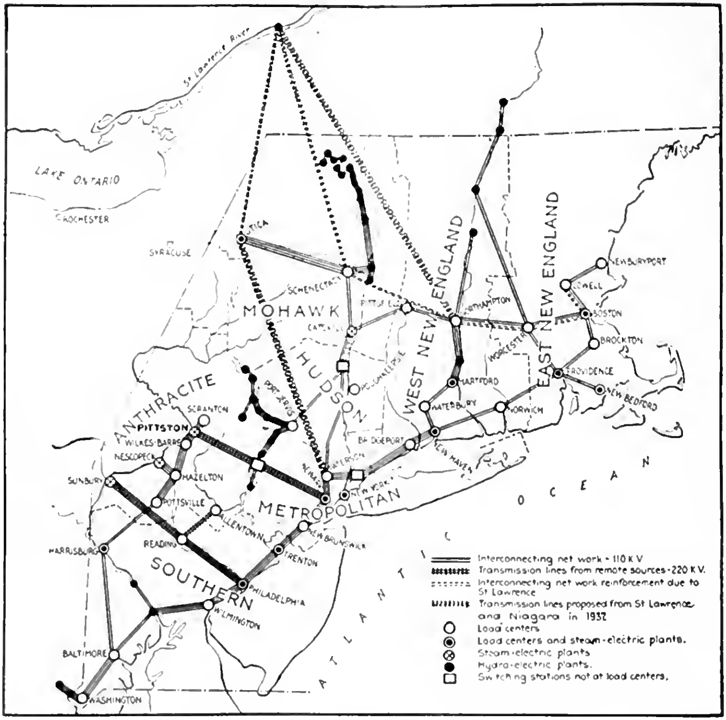


Fig. 3. Map of Proposed Superpower Transmission System for 1930

lished name and reputation, and in normal times proximity to the ports for foreign trade.

The form of the curve "Purchased H.P." is familiar to all central station men. An understanding of the logarithmic growth in the past is necessary to a prediction of its course in the future. Before the "Purchased H.P." curve started, the central stations were in existence supplying street and house lighting in all communities of importance. Motors then became commercially practical to replace some of the small engines in use by the industries. The size of these motors at first could only be comparable to the lighting loads, which were small. But the gradual addition of small units of load built up the central stations till they could handle larger loads. The three factors involved were in nature *physical*, *commercial* and *financial*. All have a cumulative effect and account for the logarithmic shape of the curve.

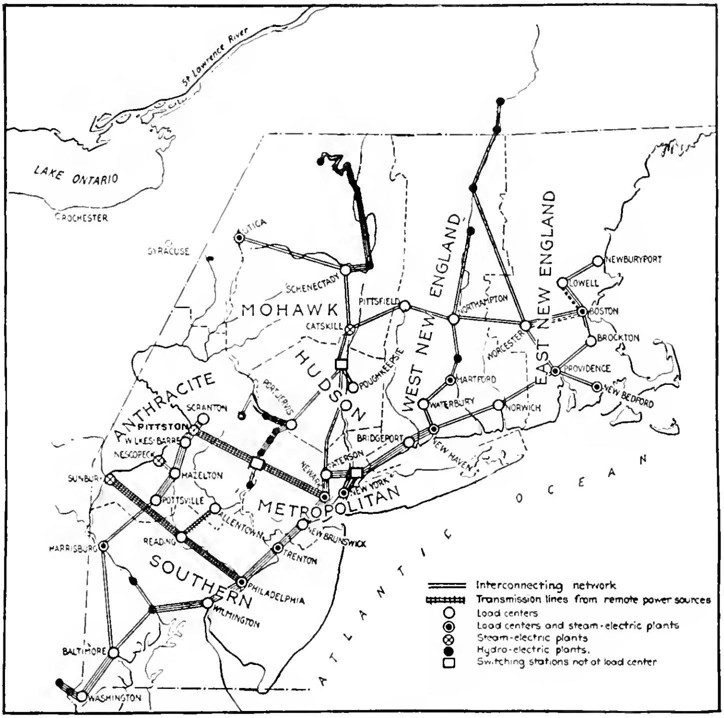


Fig. 4. Map of Proposed Superpower Transmission System for 1925

The *physical* factor has been pointed out above. A 500-kw. central station could not supply a 1000-kw. industrial load; but as the size of the station grows to 3,000 kw. to 5,000 kw. or more it is physically possible to supply the 1000-kw. industrial load, and that addition makes it enough larger to handle an even larger load.

The *commercial* factor acts in a similar way. The central station must grow to be considerably larger than an industrial load before it can generate cheaply enough to cover the distribution cost. Most larger loads have been supplied with very little profit at first, but have increased the total load so that costs have been reduced, profits increased on the smaller loads, and ultimately become profitable through the addition of larger loads.

The *financial* factor is again similar. It is hard for a new unproven enterprise to obtain capital. But when it is successfully operating and the field ahead is apparently large, it can attract new capital each year in ever increasing amounts.

New capital is necessary for the physical extensions for new loads and can be had if commercial rates are such as to insure a return. The three factors work together to produce a curve of ever increasing growth of central stations till the saturation point is reached, or those supplying the finances fear it is approaching. The curves in Fig. 2 show in what a free field the central stations have been working below "horse power that might have been purchased." But they also show that the critical or saturation point will come very speedily with similar progress in the next few years. Therefore in these curves are found justification for the optimist, reason for the conservatism of the pessimist, and a chart for the guidance of the true progressive.

In concluding this section it is interesting to note that the largest industrial establishment, measured by power used, relied entirely upon purchased power, and several others of the larger ones were also supplied very largely by central stations. Also that the industry of manufacture of electrical machinery was the most efficient in its use of fuel.

ENGINEERING PHASES

Fundamental Principle

Most fundamental engineering principles are simple and should be understood by all, but unfortunately are often clouded over by the mass of detail that enters into our large developments of the present day. The fundamental principle of design of the Superpower System is the expansion, to cover the whole zone, of that principle which has made central stations successful in their particular territories. This is the principle of unification of systems of power supply. While this has been done in some sections quite completely there are other sections where much is still to be desired. The unification of local systems combined with the general interconnection throughout a large territory would make an ideal arrangement.

The Superpower System

The idea of the survey was to determine the ultimate necessities of the zone and design a system to meet them. A ten year period was decided upon and plans prepared for 1930. To determine the development of the system the portion of it that would be needed and could be built by 1925 was also decided. Fig. 3 shows the system proposed for 1930 and Fig. 4 that for 1925.

The interconnecting network has been based on 110,000 volts. There are a few lines to be of the highest commercial voltage, and therefore figured at 220,000 volts. These latter lines are for bringing power into the load area from points of economical generation outside the load area. They are:

A line from Sunbury to Reading to Philadelphia,

A line from Pittston to a switching station for the upper Delaware water power to Newark,

Lines from the St. Lawrence, if that water power is developed some time after 1930.

Three stations are proposed in the anthracite field to use the small sizes of coal, located at Pittston, Nescopeck and Sunbury. These are not mine-mouth plants for they must be located conveniently for good condensing water, which is rather scarce in this region, and they must use the small sizes of coal from many mines. Mine-mouth plants in the bituminous field were not found practical as it would be necessary to go too far west to get condensing water.

Fig. 4 shows that by 1925 the system should be pretty well outlined but that the stations would not be developed to full size.

Studying these maps shows that New York State should continue to hold its place of industrial prominence. The water powers of the Adirondacks shown are among those most easily developed and should supply economical power to the central eastern section of that state. This same section is in the best location to receive later the power from the St. Lawrence River for further development. Industrial conditions in this section are now good, and if housing and other essentials keep up with power supply, this section should have a great future growth. Locations near the Delaware and Susquehanna water powers also offer attractions for the future, but on account of the nature of these developments they will have to be made to care for some large bulk demands rather than for the gradual development of industries near them.

Importance of Distribution

Those keenly interested in distribution have long lamented the lack of consideration that is given to its economics in practically all central stations. Generation receives close study and the last ½ of 1 per cent in efficiency is sought out like the "lost sheep." But when the current has been put on the distribution system, little more concern is shown for it. It is true that distribution is a most complicated problem, but all the more reason for giving it the required attention.

The Superpower zone was not found to be any exception as regards distribution. The records for generation were entirely satisfactory for their purpose, but it was impossible in the time assigned to secure records of the distribution of energy.

There is no question that power can be generated in large well located central stations, and even transmitted many miles to industrial centers, more cheaply than it can be generated in even the largest industrial plants. But when it is there it must be distributed. No matter whether power is generated or purchased by a central station, the distribution is there and calling urgently for attention. The Superpower Survey investigations confirmed this for the zone. So the Survey means an awakening to the value of exact studies of distribution throughout the country.

Economies in distribution extend through every detail from the consideration of the proper size secondary and transformer to use for house lighting, through the various demands of power supply, through the combinations of apparatus in substations, through main feeders to the points of bulk supply of power. Some of these points were naturally more accented by the Survey than others, but all need great study at this time.

Substation Practice

The System of the Commonwealth Edison Company, in Chicago, is acknowledged to be an example of central station practice approaching perfection in the fundamentals and has been studied by most men well advanced in the art. Yet looking at the other systems throughout the country, it would appear that the degree to which combinations have been carried in Chicago to take advantage of diversity are almost unappreciated. From one substation which is supplied by a-c. feeders the company furnishes service for light and power on a-c. circuits; and through synchronous converters working *in parallel* the same station supplies four railways with 600 volts direct current through independently metered feeder groups. The economies in investment and operation are obvious and sufficient to overcome any old prejudices against such combinations.

The transmission line of the Chicago, Milwaukee & St. Paul Railroad is owned by the railroad. But in the light of experience the electrical engineer for the road, Mr. R. Beeuwkes, said at the Pasadena Convention of the National Electric Light Association a year ago that he considered it would be better for the central station to own and maintain the transmission line. This is an example of thought and experience from the other side. If there are fundamental economies of considerable amount to be effected by the central station supplying current at trolley voltage—and it is done in many cases—surely that principle should become one of usual practice instead of the exception.

In the station of the Commonwealth Edison Company, referred to above, advantage is obtained not only from the diversity of the loads but also from the improved power-factor due to the operation of the converters. If motor-generator sets were necessary on account of the trolley current characteristics, further economy would be possible by the proper design of the motors. The motors could be designed for a certain amount of leading current, so that they could be used for correction of the substation power-factor, maintaining it at unity. The fields could then be controlled by automatic regulators set to hold the voltage constant on the a-c. bus for distributing circuits practically regardless of changes in any of the loads. This is not an expensive scheme for there are certain compensating economies in the construction of the machines.

Automatic Substation Voltage Control

To show by a specific example that such a system can supply good a-c. service with properly designed motors and regulating apparatus, calculations have been made on a transmission line that is considered as going beyond the extreme requirements for the Superpower territory, or in fact for any territory. The assumed line is 50 miles long and is to carry 30,000 kw. at 60 cycles, with 66,000 volts at the generating station. The potential at the receiving end is fixed at 60,000 volts. The size of the conductors has been taken at 500,000 cir. mils. At full load and unity power-factor the voltage drop would be 8 per cent in the line, leaving a small margin for transformer regulation. But the great point is that the drop can be kept constant at all loads and the automatic regulators will hold the voltage constant through all fluctuations of load. As the load drops the regulators would drop the power-factor, thereby increasing the proportionate line drop to hold the voltage constant. As the load swung on again the regulators would increase the fields and the power-factor, thereby decreasing the line drop and holding the voltage constant. In the extreme case of no load, the motors would carry 10,500 kv-a. with zero power-factor lagging. This does not take into account the regulation of the transformers at no load, which would aid in holding the voltage down to a great extent, with much less lagging current. Fig. 5 gives vector diagrams for full load, part load, and no load, showing how the automatic regulators will keep the voltage constant at the receiving substation by changing the fields of the motors, and so varying the power-factor.

This study is of great interest, but there is not space here to go into it further than to say that all calculations seem to indicate the necessity of operating a general system for power interchange at very close to unity power-factor during full load conditions. Therefore every piece of synchronous apparatus that can be taken over by the operating company and operated for the good of the system as a whole is a direct saving in other such apparatus. Further, operation at unity power-factor means that high reactance transformers can be used without fear of poor regulation, and may be used to the fullest extent for the reduction of short circuit intensities, with a consequent reduction in cost of the switching apparatus required.

In closing this particular item of discussion it should be noted that these developments are not purely engineering but have important commercial features.

Distribution Voltages

The careful study of moderate voltage is advocated, although it is appreciated that extra high voltages have a natural fascination. Doubtless the calculations and construction of extra high voltage lines are very interesting but both are simple compared to the complications of calculations and construction for a comprehensive distribution system.

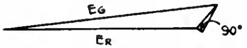
Some very interesting developments have been going on in the last few years in connection with distribution. Since the distribution of power in the zone is going to be a critical point, as has been pointed out above, it is in place here to set forth a few simple points for consideration.

The "Standards of the A.I.E.E." give a series of standard voltages. This standardization is very good and has helped immeasurably in the production of apparatus, etc. But as systems have increased and been compelled to go up in voltage, it has been found in many cases that the steps taken have been too conservative. For certain reasons some of the voltages now in use will probably become more common and standard for particular sections. It is particularly important that such standardization be carried out in the zone.

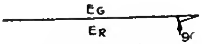
There is little question that 2,300 volts will always have a place. With its fullest development it has a capacity of from 1,000 kw. to 2,000 kw. per circuit either in three phase or quarter phase. This means that it is available for supplying all but the largest loads.

Above this there is a whole string of voltages from 6,600 volts to 16,000 volts, which were considered for many years the highest voltage safe for cables. It is in the use of these that many are now finding that they have been too conservative.

Full Load



Part Load



No Load

Fig. 5. Vector Diagram of Automatically Regulated Transmission Line

Then there comes a group from 22,000 volts to 35,000 volts. These are the highest for which standard three-conductor cable has been manufactured. On account of physical limitations it is not likely that much higher voltages than this will be used generally in three-conductor cable. On account of the same limitations there is also little advantage in the higher voltages of this group; in fact, the lower ones allow a little more flexibility of design. All voltages of cables of this group have a capacity of about 10,000 kv-a., though the lower voltages may be built for a lower capacity while the higher ones may not.

It appears then that there is little necessity for any potential between 2,300 volts and 22,000 volts, and any systems with intermediate potentials should investigate carefully before going on with extensions.

The next voltage that stands out is 66,000 volts. It has several distinguishing features. It is high enough to have a very considerable carrying capacity, as was shown in the calculation in connection with automatic substation voltage control. It is the highest voltage for which transformers and switches are built with solid bushings. (The filled bushings for higher voltages increase the cost of switches and transformers tremendously.) Single conductor cable is now available for this voltage so that transmission lines may be run underground through the heart of city districts at this voltage. Otherwise it is necessary to have a transformer substation on the edge of the city and use lower voltage cables for the underground section. This not only involves the cost of the transformer station, but puts definite limits on the operating characteristics which are not present when there are no transformers.

Lines operated at 66,000 volts are usually constructed with suspension type insulators, but there are many pin type installations from the early days, and some more recent ones with enviable records. With the greater knowledge now had on the subject of design, many engineers feel that the possibility of using pin type insulators is a most important point, and that it should receive the closest attention. Some of the particular advantages are: Rigidity, and therefore greater variety of construction arrangements; narrower right of way; better possibility of combination with towers for holding trolley wires for railroads, so that the railroad distribution system may be made the same voltage as other parts of the general distribution system without a serious compromise or erection of independent towers on the railroad right of way; and as a result of all these, a much lower total annual cost.

It may not be out of order then to consider why suspension type insulators have been so generally used on 66,000-volt lines. There were undoubtedly physical reasons in many cases. An example of this is the Pittsburgh case where the whole system has been designed to change to double voltage. But often it would appear that the psychological cause has been greater than the physical. Some one says: "While we are building let's have a real line." If the "real line" includes suspension insulators in their minds, there is no argument of economy that can persuade the use of the lowly pin type insulator. Finally, precedent points toward the suspension insulator as standard practice, and the advocate of the pin type has to face criticism as a reactionary. But in the face of this criticism it is here advocated that a detailed study be made of the pin type insulator for 66,000-volt lines.

Sixty-six thousand volts is a very worthy potential, and particularly in the Superpower zone deserves the closest study by operating men because of the short runs and frequent substations usually involved.

The Superpower report deals with major transmissions and therefore cannot go into the details of economical secondary distribution—it is too local a matter—but if local distribution is studied in the light of the information in the report it should be possible to show savings comparable with those to be made in generation.

CONCLUSION

The conclusions in the Superpower report have, of course, been worked out for the Boston-Washington region. While these are of great interest, those outside the zone should read for the fundamental truths expressed in terms of the particular region as an example.

The studies of load possibilities in each central station field are most important so that physical, commercial and financial growth may be full and logical.

Distribution is a problem neglected by most central stations, yet with tremendous possibilities for economy. It cannot be avoided, but is brought more to the fore by a superpower system for the bulk supply of energy.

The electrical industry has made tremendous progress and at an increasing rate; let all interested get behind the movement for logical, complete economical development as exemplified by the Superpower Survey.

Abstract of "Appendix C" of Superpower Report on the Electrification of Railroads*

By W. D. Bearce

Railway and Traction Engineering Department, General Electric Company

The most valuable feature of the Superpower scheme as it affects the railroads is not so much the saving in the cost of operation, great as this is, but the increased capacity that will be the result of electrification of existing tracks and yards. Steam operation cannot avoid frightful congestion at the principal railway terminals included in the Superpower zone, as was sadly demonstrated during the war; electric operation can easily do it. The economic feature of railroad electrification in the zone, while secondary, is a considerable item, representing the tidy annual sum of $81,000,000, or 14.2 per cent of the cost of electrification. Other advantages that will result from the development of the Superpower system are discussed in the articles in this issue by Mr. W. S. Murray and Mr. H. Goodwin, Jr.—Editor.

On account of the several railroad electrification projects which are being seriously considered both in this country and abroad, Appendix C of the Superpower Report of the U. S. Geological Survey is of particular interest. This section of the report was prepared under the direction of Cary T. Hutchinson and N. C. McPherson and is subjected "Proposed Electrification of Heavy Traction Railroads in the Superpower Zone."

Out of a total of 36,000 miles of railroads which have been studied in the territory embraced by the superpower zone, 19,000 miles could be profitably electrified, netting an annual saving of from 11 per cent to 19 per cent on the investment necessary. Based on the traffic handled in 1919, the amount of fuel which would have been saved if trains had been electrically operated is calculated at 8,890,000 tons of coal.

The estimated saving in the cost of operation includes a reduction in certain items of steam-railroad cost that will be effected by the change of motive power. These items, named approximately in the order of their size, are locomotive maintenance (including enginehouse service), coal and water, and wages of crew. These items make up about 90 per cent of the expense affected by the change in the method of operation. In addition to the saving on these principal items there will be some saving—an amount hard to estimate—in the maintenance of curved track and freight cars, as a result of better train handling and in certain minor items.

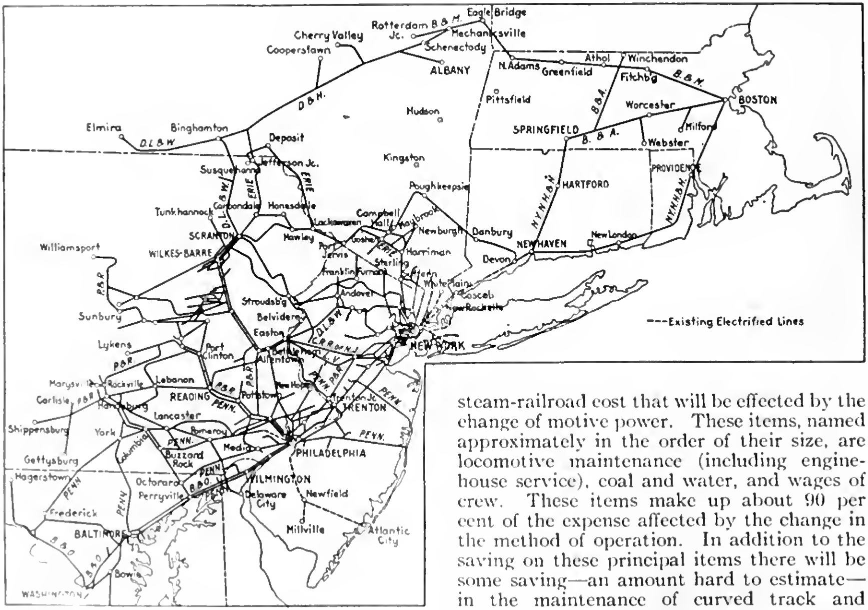


Fig. 1. Map Showing Class I Railroads Within the Superpower Zone for Which Electrification Is Recommended

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* A synopsis of this feature of the Superpower Scheme was supplied by W. B. Potter, General Electric Review, April, 1920.

The energy for train operation is assumed to be delivered to the railroad company's substation, thereby relieving the railroad company from any investment or responsibility for the operation of an independent generating plant for railway power.

The comparison of costs of investment and operation need take no account of the system of electric traction to be used except in so far as the use of different systems might entail different costs of operation and construction. The only two systems that are applicable to general traction within the superpower zone are the 3000-volt direct-current system and the 11,000-volt (or higher) alternating-current system, both with overhead distribution circuits and rail return.

The alternating-current system generally involves a lower investment cost than the direct-current system, as at low frequencies of supply, substations with rotating machinery are replaced by transformers erected along the right of way; but this saving will not be effected under the superpower system, for the frequency adopted for generation and transmission, 60 cycles, requires substations with rotating machinery for the alternating-current as well as for the direct-current system, and the capital costs of the two are nearly equal.

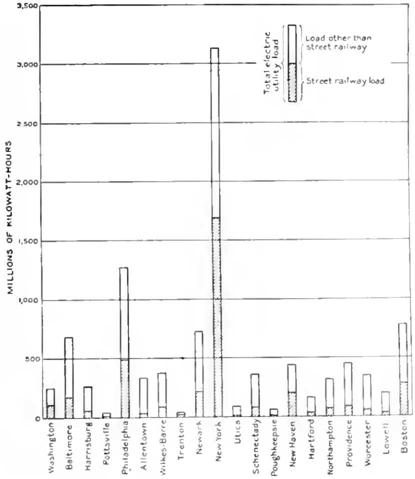

Fig. 2. Distribution of Electric-utility Load Among Load Centers of Superpower Zone in 1919

In order, then, to avoid some uncertain elements in the estimates of the cost of the alternating-current system it has been decided to base all estimates, both of operation and of construction, on the 3000-volt direct-current overhead system. Substantially the same results in money could, however, be obtained with the alternating-current system, certain gains being offset by certain losses.

The procedure of the railway division of the Superpower Survey in studying the proposed electrification comprised the collection of a large amount of physical data which were tabulated and analyzed in order to formulate conclusions. Physical and operating data were obtained directly from the officers of the roads involved, covering the year 1919. Costs of substation equipment, electric locomotives, catenary line material and other electric facilities were obtained from the large manufacturing companies and advice of competent operating engineers was sought and their criticisms were considered in making up the final estimates of costs of construction and operation. A tabulation of available operating figures shows a range of power consumption from 29 to 57 kw-hr. per thousand ton-miles of trailing train.

Test data show that in similar service one kw-hr. input to the motors in switching service is the equivalent of 29 pounds of coal used on a steam switcher. A similar figure also from various recent tests of locomotives in road service is 7.5 lb. of coal per kilowatt-hour at the locomotive. This figure is identical with that deduced by the American Electric Railway Association for a modern Mallet locomotive with superheater. Comparative figures furnished by the electrical engineer of the Chicago, Milwaukee & St. Paul Railway are 8.4 lb. per kw-hr. Confirmation of these figures is obtained from data on the several roads operating electric service in the zone affected. These data show that the coal saved in freight service is from 50 to 70 per cent, passenger service 70 to 75 per cent and switching service 70 to 85 per cent.

Maintenance of Steam Locomotives

From 50 to 100 per cent of the net saving effected by electric traction is obtained from the reduction of cost of locomotive maintenance. Statistics for steam and electric locomotives compiled from the records of the Interstate Commerce Commission are given, indicating an average cost of nearly 50 cents per locomotive mile per 100 tons weight on

COST OF MAINTENANCE OF STEAM LOCOMOTIVES FOR 1919

From Report of the *Superpower Survey*

System	Average Weight on Drivers (Tons)	Distance Traveled (Thousands of Locomotive Miles)	INTERSTATE COMMERCE COMMISSION ACCOUNTS							
			Repairs (No. 308)		Engine-House Expense (Nos. 388 and 400)		Total Cost			
							Actual		Prorated to 100 Tons on Drivers	
			Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year
Boston & Maine	80.9	24,592	25.33	$5,562	8.66	$1,904	33.99	$7,466	55.63	$12,263
New York, New Haven & Hartford	63.9	23,071	29.9	6,110	11.02	2,253	40.92	8,363	64.05	13,210
Central New England	68.6	1,844	31.23	7,578	10.37	2,540	41.60	10,118	60.65	14,755
New York Central	86.5	91,313	21.15	5,302	8.55	2,103	29.70	7,306	34.28	8,433
Delaware & Hudson	89.2	11,015	32.6	7,319	12.22	1,832	44.82	9,151	50.20	10,269
Lehigh & New England	74.2	1,212	27.8	5,521	7.82	1,554	35.62	7,075	48.05	9,545
Lehigh & Hudson River	76.3	767	27.8	4,267	8.77	1,345	36.57	5,612	47.94	7,362
Erie	90.4	26,078	45.6	9,790	9.65	2,070	55.25	11,860	61.19	13,126
Delaware, Lackawanna & Western	77.9	19,263	26.9	6,836	9.45	2,401	46.35	9,327	46.62	11,855
Lehigh Valley	85.6	17,883	40.6	7,126	8.75	1,537	49.35	8,663	57.62	10,115
Central of New Jersey	72.9	12,289	29.2	6,210	6.24	1,328	41.60	7,538	48.55	10,339
Pennsylvania	83.53	112,595	38.6	9,216	6.85	1,634	45.45	10,850	54.60	12,983
Philadelphia & Reading	78.3	22,164	32.6	6,853	8.93	1,879	31.53	8,372	53.00	11,152
Totals	80.76	364,086	31.8	$7,246	8.39	$1,911	40.19	$9,157	49.80	$11,310

COST OF MAINTENANCE OF DIRECT-CURRENT ELECTRIC LOCOMOTIVES, 1919

System	Number of Locomotives	Average Weight on Drivers (Tons)	Distance Traveled (Locomotive Miles)	Total Maintenance	COST			
					Actual		Prorated to 100 Tons on Drivers	
					Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year
Baltimore & Ohio	8	88	214,400	$24,600	11.47	$3,076	13.02	$3,491
Butte, Anaconda & Pacific	28	81	565,600	36.700	6.49	1,312	8.01	1,619
Chicago, Milwaukee & St. P.	46	225	2,181,200	340,200	15.59	7,394	6.93	3,286
Michigan Central	10	108	245,500	34,600	14.10	3,462	13.05	3,205
New York Central	73	92	1,940,900	124,400	6.41	1,704	7.00	1,862
Pennsylvania Terminal	31	103	1,348,000	225,300	16.71	7,266	16.30	7,088

COST OF MAINTENANCE OF DIRECT-CURRENT ELECTRIC LOCOMOTIVES, 1913-1919

Year	Total Distance Traveled (Locomotive Miles)	Cost per Locomotive Mile per 100 Tons on Drivers (Cents)
1913	2,422,800	5.83
1914	3,678,200	5.42
1915	3,808,800	5.44
1916	5,662,600	4.50
1917	6,797,000	5.89
1918	6,431,600	7.66
1919	6,495,700	9.77

COST OF MAINTENANCE OF STEAM LOCOMOTIVES FOR 1911–1919

From Report of the *Superpower Survey*

System	Average Weight on Drivers (Tons)	Distance Traveled (Thousands of Locomotive Miles)	INTERSTATE COMMERCE COMMISSION ACCOUNTS							
			Repairs (No. 308)		Engine-House Expense (Nos. 388 and 400)		Total Cost			
							Actual		Prorated to 100 Tons on Drivers	
			Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year
New York Central:										
1911–1915	75.36	66,356	9.04	$2,460	3.1	$ 849	12.14	$3,309	16.11	$4,391
1916	82.24	108,626	7.6	2,421	3.06	972	10.66	3,393	12.96	4,126
1917	83.60	106,403	10.0	3,051	4.07	1,241	14.07	4,292	16.83	5,134
1918	85.60	100,576	17.59	4,689	7.30	1,947	24.89	6,636	29.08	7,752
1919	86.50	91,313	21.15	5,195	8.54	2,100	29.69	7,295	34.32	8,434
Pennsylvania:										
1911–1915	75.85	94,142	12.7	3,221	2.8	710	15.50	3,931	20.44	5,183
1916	83.4	105,522	13.1	3,478	2.6	687	15.70	4,165	18.82	4,994
1917	87.6	108,638	17.5	4,620	3.4	899	20.90	5,519	23.86	6,300
1918	90.4	122,965	32.88	8,960	3.7	1,784	36.58	10,744	40.46	11,885
1919	91.0	112,595	38.62	9,175	6.8	1,627	45.42	10,802	49.91	11,870
Philadelphia & Reading:										
1911–1915	62.92	24,631	11.69	2,886	3.04	750	14.73	3,636	23.41	5,779
1916	70.83	27,422	12.28	3,397	3.19	883	15.47	4,280	21.84	6,043
1917	73.20	28,126	17.85	4,993	4.14	1,156	21.99	6,149	30.04	8,400
1918	75.4	27,080	28.17	7,423	7.50	1,975	35.67	9,398	47.31	12,464
1919	78.3	22,164	32.6	6,853	8.93	1,879	41.53	8,732	53.04	11,152
New York, New Haven & Hartford:										
1911–1915	50.7	27,027	9.6	2,171	3.00	681	12.60	2,853	24.85	5,625
1916	55.6	27,495	9.98	2,272	3.61	822	13.59	3,094	24.44	5,565
1917	57.5	26,099	14.0	3,160	4.77	1,078	18.77	4,238	32.64	7,370
1918	61.4	24,784	30.85	6,400	8.99	1,861	39.84	8,261	64.88	13,454
1919	63.9	23,071	29.9	6,110	11.04	2,253	40.94	8,363	64.07	13,088
Erie:										
1911–1915	74.1	28,768	11.21	2,430	3.45	749	14.66	3,179	19.78	4,290
1916	82.3	31,621	15.65	3,765	3.90	936	19.55	4,701	23.75	5,712
1917	87.6	29,903	24.20	5,400	6.11	1,360	30.31	6,760	34.60	7,717
1918	90.0	29.316	45.3	9,950	11.75	2,582	57.05	12,532	63.39	13,924
1919	90.2	26,078	45.6	9,790	9.65	2,070	55.25	11,860	61.25	31,481

ANALYSIS OF CREW WAGES FOR FREIGHT AND SWITCHER SERVICE, 1919

System	FREIGHT SERVICE			SWITCHER SERVICE		
	Wages per Thousand Ton-miles	Train Movement (Millions of Ton-miles)	Savings in Wages Under Electric Operation 25 Per Cent	Wages per Switcher Mile	Train Movement Thousands of Switcher Miles	Savings in Wages Under Electric Operation 25 Per Cent
Boston & Maine	$0.40	6,600	$660,000			
Boston & Albany	.42	3,266	343,000			
New York, New Haven & Hartford and Central New England	.55	8,183	1,130,000	$0.60	4,900	$980,000
New York Central	.27	10,914	738,000	.45	5,086	760,000
Delaware & Hudson	.35	5,650	495,000	.69	1,143	265,000
Lehigh & Hudson River						
Erie	.29	5,707	415,000			
Delaware, Lackawanna & Western	.31	6,200	481,000	.58	3,200	620,000
Lehigh Valley	.50	5,093	635,000	.57	3,480	660,000
Central of New Jersey	.50	4,400	550,000	.57	3,000	570,000
Pennsylvania	.38	22,545	2,140,000	.61	14,024	2,850,000
Philadelphia & Reading	.49	10,900	1,330,000	.58	7,763	1,760,000
Baltimore & Ohio	.42	3,380	355,000			
Totals		92,838	$9,272,000		42,596	$8,465,000

Average wage saving per thousand ton-miles, 10 cents; per switcher mile, 20 cents.

drivers as compared to less than 10 cents for heavy direct-current electric locomotives reduced to a similar basis.

Maintenance of Distribution and Substations

Careful provision is made in the analysis of operating costs and calculated savings for maintenance of the low tension distribution system. This is taken at $600 per mile for main track and $400 per mile for yard track. These figures are based on actual operating costs of existing roads and other general considerations.

The cost of operation and maintenance of substations is based on $1.50 per kilowatt per year, giving 0.7 mill per kilowatt-hour for a capacity factor of 25 per cent.

Savings in Wages

One of the most notable advantages of electrification is the saving in wages of train crews. This report gives a detailed analysis of crew wages of roads within the zone for freight and switching service per 1000 ton-miles and savings obtainable at 25 per cent and 33 per cent respectively. No savings are claimed for passenger service.

The report then details unit costs of construction of 3000-volt overhead catenary, substations and electric locomotives. An analysis of the number of locomotives required is included, based on the traffic.

The summary then made estimates the net cost of electrification for the 11 selected systems with net reduction in the annual cost of operation. The results are shown graphically in the chart (Fig. 4).

The following conclusions are reached by the author of the report

"The study described above has been made for all

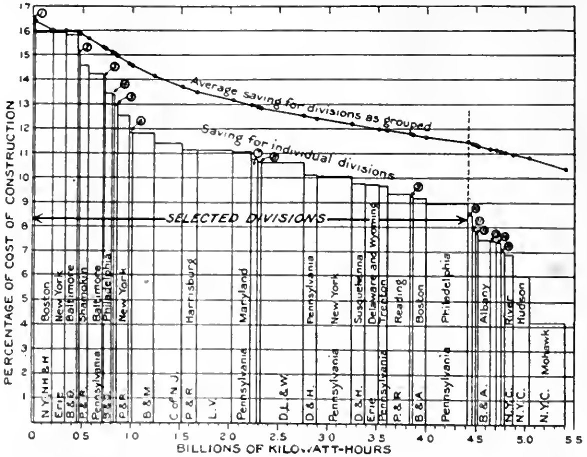

Fig. 3. Saving Effected by Electrification of Heavy-traction Railroads in Percentage of Constuction Cost, not Including Saving In Wages. Each column rep esents a railroad division or route. 1, New York and New Jersey Division, Erie; 2, Northern Division, Erie; 3, Greenwood Lake Division, Erie; 4, Jefferson Division, Erie; 5, Schuylkill Division, Pennsylvania; 6, Springfield Division, N. Y., N. H. & H.; 7, Maybrook Division, N. Y., N. H. & H.; 8, Philadelphia Division, P. & R.; 9, New York, Susquehanna, and Western Division, Erie; 10, Cumberland Valley Division, Pennsylvania; 11, Atlantic City Division, P. & R.; 12, Wilmington and Columbia Division, P. & R.; 13, Sunbury Division, Pennsylvania; 14, New Jersey and Seashore Division, Pennsylvania; 15, Lehigh & Hudson River R. R. Other divisions are indicated on the diagram

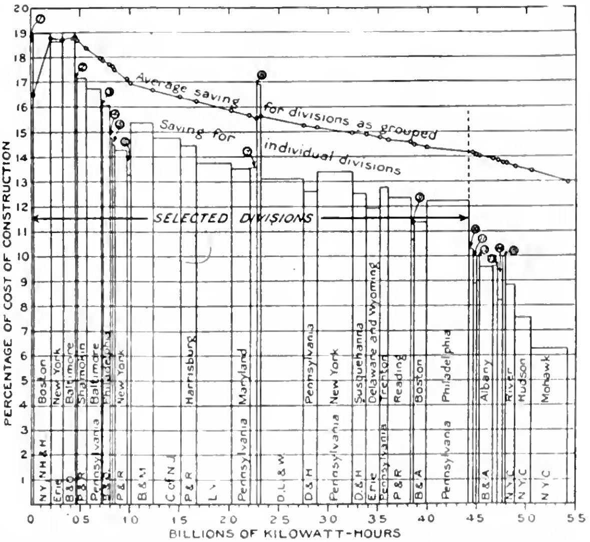

Fig. 4. Saving Effected by Electrification of Heavy-traction Railroads in Percentage of Construction Cost, Inculding Saving in Wages. Each column represents a railroad division or route. For explanation of numbers see Fig. 3

Class 1 railroad systems within the superpower zone except the Ulster & Delaware, the New York, Ontario & Western and the Western Maryland. The first two were omitted, after a preliminary examination, because their traffic was too light to warrant electrification. The Western Maryland was omitted because only a small part of its trackage is within the zone; the preliminary examination, however, indicates that the Western Maryland traffic would justify electrification. There remained then, 13 railroad systems* in the zone that were studied. In this study it was not possible to adhere strictly to the limits of every operating division reported by the railroads, and some divisions were therefore consolidated into routes. The number of divisions or routes ranged from one on the Boston & Main to nine on the Pennsylvania and aggregated 40 for the 13 roads."

The results of the study are given in Figs. 3 and 4, which show for each of the 40 divisions the annual saving, in percentage of the net cost of electrification, plotted against the energy required, in kilowatt-hours per year, together with the accumulated average percentage of saving for the divisions as grouped. Fig. 3 shows the saving exclusive of the saving in crew wages, and the divisions are arranged in the order of percentages. With these results as the criterion of economical electrification the "selected divisions" are assumed to be all that show a saving of 9 per cent or more. The group of divisions thus selected shows an average saving of 11.4 per cent. It includes 30 of the 40 divisions examined. Fig. 4 shows the saving including the wage saving for the 40 divisions arranged in the same order as in Fig. 3. For the "selected divisions" these savings range from 10.6 to 19 per cent and average 14.2 per cent. The total energy required annually for these 30 divisions will be 4400 million kilowatt-hours, and the maximum demand approximately 850,000 kilowatts.

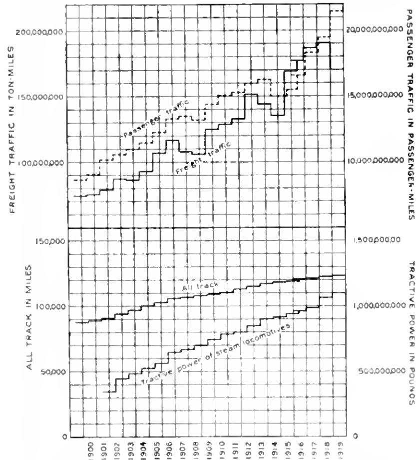

Fig. 5. Growth of Steam Railroads in the Superpower Zone in 1900–1919. Annual rate of growth compounded, 1900–1918: Passenger-miles, 5.3 per cent; ton-miles, 4.5 per cent; all track, 0.75 per cent; tractive power, 6.6 per cent

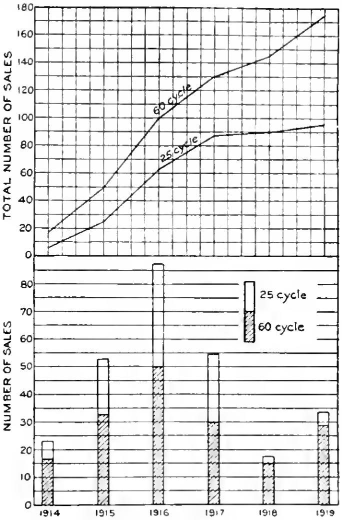

Fig. 6. Sales of 25-cycle and 60-cycle Generators in the Superpower Zone, 1914–1919

The low percentage of saving shown by the divisions not included in the selected group, except those of the New York Central, is due to light traffic. On the New York Central the train cost of transportation, the cost of maintaining steam locomotives, and the cost of coal per mile are lower than on any other system, owing in part to the fact that this is a water-level road with a large amount of through traffic; these are favorable conditions for economical steam operation and

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* The Boston & Albany was included with the New York Central, and the Long Island with the Pennsylvania.

therefore afford less opportunity for saving by electrification.

Table 35 of the report summarizes for the 11 systems that include the 30 selected divisions, the net estimated cost of construction and electric equipment and the net savings from operation, both including and excluding saving in wages. The net cost of electrification of all the selected divisions is $570,000,000, and the annual net saving in operation, including the saving in wages, is $81,000,000, equal to an average of 14.2 per cent for the entire group, ranging from 10.6 per cent for the New York, Susquehanna & Western division of the Erie to 19 per cent for the New Haven-Boston route of the New Haven.

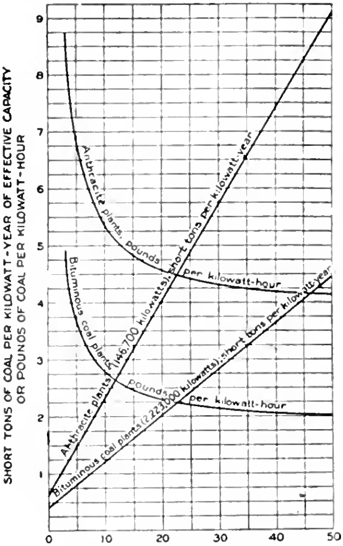

Fig. 7. Output of Electric Utilities in the Superpower Zone, 1910-1919

Fig. 5 shows the growth of traffic (both freight and passenger) of track, and of tractive power for the Class 1 railroads in the superpower zone from 1900 to 1919. The annual rate of growth has been 5.3 per cent in passenger-miles, 4.5 per cent in ton-miles, 0.75 per cent in all track, and 6.6 per cent in tractive power of locomotives.

The amount of money required for electrification is calculated to be $570,000,000. This figure is based on costs prevailing in 1919, but at present costs (June, 1921) it would be reduced by 18 per cent, to approximately $467,000,000, and before this construction can be undertaken there will be further material reductions. Probably five years from now the entire work outlined could be done for not more than $400,000,000. This is comparatively a moderate sum. Good railroad authorities have stated repeatedly that more than $1,000,000,000 a year is needed by the railroads of the United States for extensions and betterments. The part of this total to be allocated to the superpower zone, as determined by the number of locomotives, would be $150,000,000. The amount required for normal extensions and betterments for three years would therefore be sufficient to electrify the 30 selected divisions of the railroads in this territory, with an annual saving of more than 14 per cent. The most valuable feature of the change, however, is not the amount saved but the great increase in maximum capacity of existing trackage and the general advantages of electric operation.

These figures indicate that with a return of normal financial conditions all these lines should be electrified before further great expenditures have been incurred to increase in a minor degree the capacity of the existing tracks and yards. Steam operation can not satisfactorily meet the conditions of the crowded terminal herein described as the superpower zone; electric operation can easily do it.

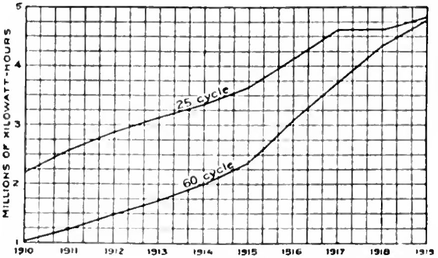

Fig. 8. Average Performance of Existing Steam-electric Plants to be Retained in the Superpower System

Fuel Conservation in Industrial Power Plants

By David Moffat Myers

Consulting Engineer, New York

We are pleased to be able to publish this article, written specially for the Review, by an author who has had such wide practical experience in the subject. He emphasizes with energy that *now* is the time to effect economies in steam plants, and that the way to do it is to use a proper equipment of recording instruments, selected to suit the local conditions. These instruments are the *eyes* of the plant and without them a plant is blind. A saving of at least 10 per cent in fuel consumption can be effected in the average steam plant by using these eyes.—Editor.

Among the most vital lessons taught by the Great European War were those which are applicable in industrial fields, but which unfortunately seem to have been all too soon forgotten or disregarded. The explanation, however, is simple. It was only natural that, after the high-pressure effort occasioned by the war, there should be a general let-down and relaxation along industrial and other lines. The Armistice marked the beginning of this let-down. The all-effective watchword "Win the War," by the very nature of the case lost its urge, its efficacy. Business was such that prices were high and money was easily made. Why should plant owners worry about costs of steam, heat, and power when excellent profits could be made without worrying?

The war and war measures have now become a part of history. True, but a new, and tremendously crucial situation now confronts us. Industry itself is most certainly threatened. It must be saved, and to that end the right methods must be quickly, widely, and intelligently adopted. At first thought this proposition may seem impracticable, for certainly no one wishes at this time to make an outlay of new capital. What is the answer, then, to the problem involved? It is this:

To secure peace time prosperity the readoption of war economy is essential.

There are only two methods whereby steam and power can be produced at lower cost. The first is, improvement in the design or equipment of a plant. The second is, improvement in the method of operation. High prices and poor quality of coal inevitably cause high power costs in manufacturing plants. If the abnormal conditions that have obtained for so long now are to be brought to an equilibrium, one or the other of the two methods just mentioned must be utilized. Even if equipment changes appear to entail unwarrantable expense, under present-day conditions, at least there is no reason why improved methods of operation cannot be successfully applied, with resultant benefit to each individual industry, and decided advantage to business as a whole.

I recommend, therefore, that a general movement be started to bring about economies in methods of operation.

If there be any who are skeptical as to the efficacy of such procedure, let them note well the fact that during the war, when it was not possible to obtain new or improved power equipment, a saving of twenty-five million tons of coal throughout this country was effected annually by means of the second method alone—by operating improvements, by securing the greatest possible efficiency from the equipment which was at hand. No better illustration could be had, to show real economy on the part both of the individual plant owner and of the nation as a whole, in whose behalf the plan was evolved and put into practice. Twenty-five million tons! A large figure—and, at that, merely the beginnings had been made when the end of the war came and these large-scale national measures were discontinued.

One is all the more impressed with the possibilities in this plan when it is realized that, even under the rush conditions accompanying the war measures, when the saving of labor and fuel was big-scale but not thorough, fuel savings of from 10 per cent to 30 per cent were reported by plant owners all over the country. As an illustration, one interesting case in point may be cited here. In a certain plant, where no change of equipment was made, half the total number of boilers were shut down, 50 per cent more steam was made with the same coal consumption as formerly, and the evaporation was increased from 6 to 9 pounds per pound of fuel.

If, then, such savings as have been cited could be accomplished even during the rush of the war, still greater economies can be effected at this period when thorough attention can be given to each individual plant. Certainly this is the time, of all times, when such economies should be planned and accomplished. There is hardly an industrial power plant in the country which could not easily make a saving of 10 per cent to 30 per cent without change in boiler or engine room, provided an exact knowledge of existing performance is available. This definite knowledge is the first requirement, and absolutely essential.

The question is, how can this definite knowledge be obtained? An equipment of proper recording instruments, selected according to local conditions, and used regularly and intelligently, will give the desired information.

The first step, therefore, is to determine by means of an adequate outfit of instruments for the purpose, whether the highest return possible is being secured from the existing equipment. *Unless such instruments are supplied by the management, the plant is without eyes and its operation is blind.* It can hardly be reasonably expected, under such conditions, that the chief engineer and those associated with him can check up on the wastes and losses in fuel, steam, and power.

On the other hand, the right equipment of instruments makes it possible for the management to know, from day to day, the actual results being obtained, the plant's efficiency under daily operating conditions. The instruments will show any combustion troubles; whether the coal is the best for furnaces and steaming conditions; what the steam production is, and where the steam "goes to"; whether the quality of coal that is being paid for is being obtained; whether any of the boilers are failing to carry efficiently their proportion of the load. These and many other questions vital to economical operation will be answered by means of proper recording instruments—and every answer will mean an annual saving of dollars, usually thousands.

One item of importance to determine is the equivalent evaporation per pound of coal. To secure accurate data in this respect, it is necessary to measure continuously the weight of feed water or steam, and the weight of coal, and to ascertain steam pressure and feedwater temperature. In addition, occasional B.t.u. determinations of the coal should be made. If this practice is followed it will enable the management to know two very important things:

1. The actual efficiency of the plant itself.
2. How the results obtained compare with standard efficiencies secured from the same kind of coal and equipment. The instruments used to make all these determinations tell *what efficiency you are securing.*

Another class of instruments is used when you have found that your efficiency actually is too low. These instruments of the second type, or class, *tell why the efficiency is low.* In other words, they determine the causes of the waste, and, this being done, you will be able to check all that is preventable. Among the most important of these instruments are flue pyrometers and the apparatus for flue-gas analyses. These indicate the one greatest loss in boiler plant operation, the (dry gas) chimney loss which may run as high as 40 per cent of the total fuel. Draft gauges also play an important part in determining the "why" of losses. Sometimes in an "efficient" plant the amount of air allowed to leak through settings will be as great as that which passes through the grates. It will be found decidedly worth while to apply to the outside surface of all brick set boilers a thorough plastic air-tight coating to prevent air leakage, and to give careful attention to all other connections where such leakage is liable to occur—for example, header and other connections, and clean-out doors and their frames.

An investment in recording instruments pays good dividends. These instruments must, of course, be selected carefully and with good judgment, and records must be kept with the greatest possible simplicity that is conducive to the securing of all essential data. It may be stated, without reservation, that an appropriate system of continuous observation and records should be instituted in every boiler plant. It may seem surprising—but it is true—that, irrespective of the design of the plant, one quarter of the coal cost may be wasted through poor methods of operating, alone; and that, at a very conservative estimate in the average plant, 10 per cent of the fuel consumption may be saved by means of an intelligent application of the methods already discussed. Even a simple change in the method of firing will often effect an annual saving of thousands of dollars.

The factory plant should employ in the boiler room the same methods that manufacturers are applying to secure efficiency in the production departments of their mills. The principle is obvious: To secure the greatest possible amount of power, light, and heat (finished products) from the given raw materials—coal, labor, and supplies—which are consumed in the power department, which is a specialized factory.

Most plants are being run blind. Every plant must be equipped with eyes, in order to see where the waste occurs and to be able to check it and prevent its recurrence. The required instruments are so simple, and the results from their use pay such big dividends, that it is surprising how many owners fail to avail themselves of the economies directly within their reach.

It is a long time since safety valves and steam gauges could be considered adequate and efficient equipment for an up-to-date plant. For each plant, with its individual conditions and its own particular layout, the proper instruments should be prescribed. Then, this having been done, the firemen can easily interpret the readings and be in position to know whether the results obtained are what they should be. If they are not, the firing and the draft controls can be corrected and adjusted to bring about the utmost efficiency in relation to required capacity. In other words, unnecessary losses, which would remain invisible except for the use of these instruments, are revealed and made subject to conservation.

Emphasis has been laid on the fact that the economies discussed can be effected through improvements in operation alone. It is important to realize at this point, however, that such improvements constitute an intelligent and essential preliminary to improvements in design as well. These things will have to be done before improvements in design can be made intelligently. Why not do them now and secure their dividends immediately? The vital fact is, that even at this particular time when few owners wish or feel able to make any capital expenditure, methods of operation can be improved. Then a little later when conditions warrant, any necessary improvement in design and equipment can be made, and the power plant will be efficient and economical from *all* standpoints.

When the ebb tide of business changes to flood—as it soon and inevitably will change—and executives are working under great pressure, it will be a poor time to have to plan for economy of heat and power. The new order of things will not be like the old—wasteful plants will not be able to make a profit. Excessively high costs of power and heating may wipe out profits, a condition that no manufacturer can afford to allow. *Now is the time to design every department with a view to the lowest operating cost, together with the highest efficiency.* If this be done, even if changes in equipment be postponed, the manufacturing plant will be prepared to advance with the rising tide of business instead of being stranded on the shoals of wastefulness and inefficiency.

There are many important problems of economy and low production costs which should be settled *now, today, at this psychological time* when there is a let-up in business and industry. For it is well to remember that if changes are going to be made later on, in the design of a power plant, the prerequisite is to study *now* the operation of the plant, obtain all possible information by means of the instruments already discussed, and then institute immediately the economies toward which those instruments point the way.

To this end, then, plant owners and managers should know how to utilize in the most modern and efficient way the waste heat from exhaust steam and from other sources. Local conditions and requirements must be carefully taken into account if all improvements are to bring the best possible results. Owners and managers should know that there is almost as much heat in exhaust steam as there is in live steam coming directly from the boilers. It must be definitely ascertained in the power plant of each individual factory or mill, whether it will cost less to produce power within the plant itself or to purchase it from outside. This problem bears a vital relation to heating and process requirements. Losses connected with the application and distribution of electrical energy and steam must be stopped, and waste in connection with their generation must be checked. All industries should clearly comprehend that practically 100 per cent of the energy in exhaust steam can be reclaimed if applied in process work or the heating of buildings; but only 10 per cent to 20 per cent of this energy is recovered by connecting a prime mover to a condenser. It must be definitely determined in each manufacturing plant, what heating system, boilers, furnaces, prime movers, and fuels will be most conducive to the greatest possible economy under its particular set of local conditions.

The correct solution of each of these problems is essential to economy. In any plant, if the solution is to be correct, the right engineering principles must be accurately applied in accordance with the existing conditions and their requirements. It is important to remember that much time is required to gather the necessary preliminary information in any plant, and still more time must be allowed for the procuring of the equipment which economy demands, and for plans, specifications, and installations.

Now is the time. War Economy is the Keynote for Peace Time Prosperity. Delay will prove fatal to economy and to the chance of any industry's getting its full share in the keenly competitive era of better business which is about to begin. Be prepared! Let all possible improvements be made *now* in methods of operation. Improvements in design and equipment can then readily be made in due time, but these should be made while a buyer's market still exists. Once an industry has taken both these steps, it will be in a position both to enjoy the greatest possible profits, and to do its part in re-establishing normal industrial and business conditions.

Significance of Data on Illumination and Production

By S. E. Doane

Chief Engineer, National Lamp Works of General Electric Company

That production can be increased by better illumination is a recognized fact. Reliable quantitative data are meagre at present, but we published certain data in our issue of December, 1921, and hope to add to these from time to time. The present article, although not extensive, is authoritative. The subject is of such economic importance that it merits nation-wide attention —Editor.

Fourteen years ago many central stations felt that they faced ruin because of the invention of the high efficiency tungsten lamps. Blinded, for the moment, to the broader view of the development, they foresaw their lighting load dwindle to one-third its existing volume because of the increase in lamp efficiency. Their fears would have been realized to some greater extent than proved to be the case had not a determined effort changed the situation to one in which the consumer benefited by increased light rather than by lessened power consumption. It is with satisfaction that we view the strides of the lighting industry since that time. We have made available a better product. Because the product has been better and the cost per unit of light has been made lower, it has been put to new uses. The result has been that lighting has played a leading part in our industrial and commercial progress. The lighting load of the central stations has grown.

Fourteen years ago, however, our thought was of a product which was in active competition with others in the same field. Our efforts were directed to the improvement of that product, and the phenomenal expansion of the various fields of application kept our attention for some little time upon the lamp itself.

We were going along more or less blindly but with determination. Our faith in the future of our product justified an enthusiastic vision of the future and it is in the fulfilling and realization of that vision that we come to the status of artificial lighting today.

Today our views are broader. Still remembering to give attention to the lamp itself, we now give much thought to the service it renders. Our sallies into the economies of lighting have unfolded enormous latent possibilities.

It is axiomatic to state that we need light in some degree in order to see. It is a matter of common, everyday experience that we take a material or object to a good strong light when we want to examine its texture or parts. We have been so long accustomed to doing this thing that it has become a habit. It is not a new idea or a scientific discovery, then, that good lighting aids vision. But we have been so close to it that we failed to grasp its significance.

We have taken this age-old knowledge and applied it quantitatively and scientifically. In our initiatory data, as yet quite meager, we have endeavored to evaluate illumination in terms of results. In this we have supplemented our everyday observations with theoretical and practical data so coordinated that the results are predicated not from selfish motives of the industry but for the great economic value it presages.

To indicate the serious hindrance which inadequate illumination puts on industry, and to show what happens when that hindrance is removed, we initiated our public tests, summarized as follows:

1. Average increase in production in iron pulley machine shop, 20 per cent. Secured at a cost equivalent to 5.5 per cent of payroll.
2. Average increase in production in soft metal bearing shop, 15 per cent.
3. Average increase in production in heavy steel machine shop, 10 per cent. Secured at a cost equivalent to 1.2 per cent of payroll.

4. Average increase in production in carburetor assembling shop, 12 per cent. Secured at a cost equivalent to 0.9 of one per cent of payroll.

These plants working on war orders were already operating at top speed before the new system of lighting was installed.

Fig. 1. Plant of the Dover Manufacturing Company, Dover, Ohio, with Old Lighting Equipment

Fig. 2. Same as Fig. 1, with New Lighting Equipment

Obviously, then, there is some relation between lighting and production. This increase in production is due not to any unnatural stimulation, but is due simply to the increased ability to see. The seconds, or even fractions of a second, saved many times during the day, inappreciable in themselves cumulatively account for more work being done.

Until ten years ago lamp-making science ran ahead of lamp application; that is, industries in their desire to obtain artificial lighting installed lamps here and there throughout a plant merely with the thought of obtaining light rather than obtaining the best use of the light. We did not know what good illumination was.

A scientific study of the proper use of light already in progress was accelerated through our engineering organizations and reported through our technical and engineering societies. Gradually we came to an appreciation of the possibilities of lighting such as prompted the tests which have been summarized above.

A typical test recently conducted by the Engineering Department of the National Lamp Works gave equally significant results from the standpoint of increased production and such by-products as decreased spoilage, decreased accident hazard and better sanitary and welfare conditions.

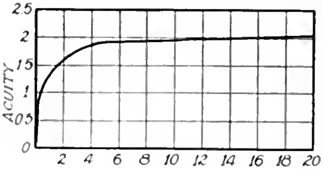

Fig 3. Visual Perception as Affected by Illumination

These tests were conducted in the press department of the Dover Manufacturing Company. This department, occupying an area of approximately 29 feet by 112 feet, is equipped with five punch presses, two milling machines, eight drill presses, one tapping machine and one tool grinder. The chief operations performed on the punch presses consist of blanking, forming, shearing, re-forming and punching hoods; and the work performed on the drill presses consists of drilling and tapping iron castings. The milling operation consists of milling the bottom of the electric and gas irons. It was, on the whole, fairly representative of the majority of small factories, or similar departments of large plants, over the country.

The plan of this test was to install a good system of lighting and then to gradually raise the illumination by a series of steps so that the production could be noted for any value of illumination.

The net average result of the good lighting system in displacing the old was that the increased expenditure for lighting was approximately 2.5 per cent of the payroll while the production increased 12.2 per cent.

A summary of the test is given below.

During the past several years, some of the best engineering thought in the country has been directed toward determining the balancing point between illumination and its economic results. We have seen that when the bounds of the old practices were overrun, benefits have followed each new standard of illumination, not in a straight line relation, it is true, but to a marked extent. An indubitable conclusion is then that above certain levels of illumination further increases are not economically advantageous. This point brings us up to various relevant data which indicate in a measure, at least, the ultimate standards in artificial lighting.

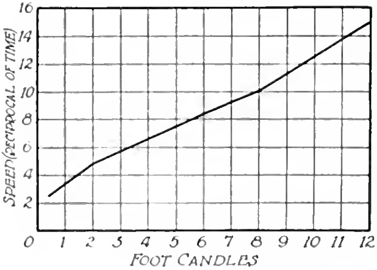

Fig. 4. Speed of Perception as Affected by Illumination

SUMMARY OF INVESTIGATION

Plant	Dover Manufacturing Co., Dover, Ohio.
Product	Electric, gas and ordinary sadirons for home and laundry use.
Test area	Press department (29 ft. x 112 ft.).
Press department personnel	Foreman, ten operators, three helpers.
Old lighting equipment	Twenty-two 50-watt clear lamps, no reflectors. Ten 100-watt clear lamps, two with reflectors. Average illumination, 0.7 foot-candles. Average illumination, at tool point, 1 foot-candles.
New lighting equipment	Twenty-seven "RLM" standard dome reflectors with bowl-enameled lamps. Average illumination, 13.5 foot-candles.
Cost of old lighting system per year*	$290.00
Cost of new lighting system per year*	800.00
Increased expenditure for lighting	510.00
Payroll per year	20,000.00
Percentage of increased lighting cost to payroll	2.50%
Percentage increase in production due to modern system of illumination	12.20%

* Cost of energy, 4 cents per kilowatt-hour.

Data such as observed and reported by Ferree and Rand,* Cobb, and others are aimed to show the relation of illumination intensities to the proper functioning of the working eye. It has been shown that as the illumination is increased from very low values, the gain in acuity is very rapid until about six foot-candles where for further increases the gain is slow but substantial. This is shown in the curve of Fig. 3. It is known that workers having eyes slightly astigmatic or with other slight errors in refraction which are so common are benefited even more by increased illumination.

Furthermore, as a person grows older, though his eyes be normal, changes of accommodation do not readily occur. For this reason workers—especially skilled workers, because oftentimes a man is in middle age before he is classed as skilled—who have reached the age where the eye no longer accommodates itself readily to changes in illumination, will be greatly benefited by a high order of illumination.

Also, speed of vision, so often neglected, but which is such an important factor in production and avoidance of accident, is nearly a direct function of the amount of illumination. This relation is shown in Fig. 4. Other facilitative factors in proper vision are shown in Figs. 5 and 6.

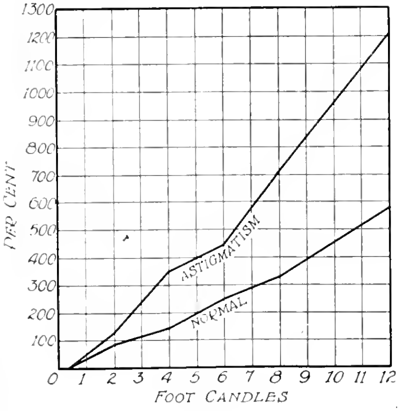

Fig 5

The above determinations showing the need of higher levels of illumination of course hold only when such negative conditions as contrasts of intensity, glare and specular reflection are obviated by the use of properly designed reflecting equipment. This suggests not only for the benefit of the lighting industry, but for all other industries as well, the desirability of marketing only good equipment and for its installation supervised by competent men with some knowledge of the essentials of effective lighting.

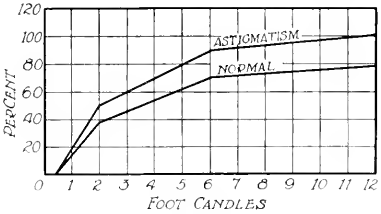

Fig. 6

Insurance companies have gone so far as to evaluate good lighting from an accident standpoint; to quote Mr. Simpson of the Travelers Insurance Company, "Reduced to a dollars and cents basis, the equivalent loss to the industries by accidents chargeable to poor lighting amounts to $300,000,000. This is a sum in excess of our yearly industrial lighting bill, and hence we can see that one result alone of the misuse and inadequate use of our lighting facilities costs more than the light itself."

In view of the stringent economies necessary in the industries, it would indeed be pertinent if we could show the economies that would obtain if all plants were so equipped with lighting facilities that there would be no drag on production efficiency. Surveys of the field indicate that far less than half the factories in the country are properly and adequately lighted as judged by present modern standards. From the production tests already cited and from others which have come to our attention, we know that a considerable loss in efficiency of operation during lighting hours is obviated by proper lighting. Quantitative data obtained in a few specific instances allow us to make this qualitative statement with regard to industry as a whole.

Fourteen years is such a brief span of life that it is rarely sufficient for so striking a reversal of viewpoint by a whole industry. Thanks to having given thought to the human needs for light, we have been able to show the public that its needs were so great that the demand for light has long since put at rest any fears which were raised by the advent of the high efficiency lamps

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* Transactions I. E. S., 1920-1921.

Electric Drive in Cotton Mills

By George Wrigley

J. E. Serrine & Co., Engineers

Enormous benefits are available to the cotton mill industry of America through the adoption of a modern method of drive. While it is true that the industry has to a very considerable extent availed itself to the advantages of electrification, most of the installations of this character were made in accordance with the large-motor-group-drive idea and lack the superior advantages now possible with individual drive. In the following article Mr. Wrigley traces the steps in the manufacture of the textile product, explains the operation performed by each type of machine employed in the process, and describes the most modern practice with respect to the drive and control of the machines.—Editor.

The development of electric drive in cotton mills represents an evolution from the use of large motors driving groups of machines to an individual motor driving each machine. Since the first textile motor application, about the year 1894, this ideal of individual drive has been clearly seen. Sporadic installations were made, with partial success, but general approval and adoption were delayed until improvements in assembly, design and details of construction placed it on a sound engineering and economic basis. Electric drive in cotton mills now means individual drive, and only with it can the maximum service be obtained.

The term cotton mills is used here to designate plants in which baled cotton is manufactured into yarn, or yarn and cloth. It is not intended to cover knitting mills, print works, finishing plants or any of the numerous specialty factories for textile conversion.

Until recent years, mill buildings were of standard, slow-burning construction with wooden floors and roof, supported by heavy timbers resting on wooden or cast iron columns and brick side walls. The cost of reinforced concrete as compared with slow-burning construction has been reduced until its excess is now only 10 per cent. It is almost impossible to obtain satisfactory large timbers and modern practice has adopted reinforced concrete construction as standard for practically all buildings. These new buildings are provided with large window openings fitted with steel sash and prismatic glass, are well equipped for temperature control and air conditioning and afford ideal conditions for manufacturing. Small mills generally have one story and larger mills from two to four stories.

Fig. 1 Modern Cotton Mill Building. This mill, equipped with individual motor drives in picking, spinning and weaving departments, has been in operation since 1917

Principal departments and processes are separated by partitions or floors. In some cloth mills the weaving is done in a separate single story building usually fitted with a saw-tooth roof and known as a weave shed.

The process of manufacture is one of cleaning the raw cotton, straightening and paralleling the fibres, removing the short fibres, twisting the fibres together to form yarn and, if a cloth mill, weaving this yarn into cloth. In some mills the product is carried through one or more of the finishing processes of mercerizing, bleaching, dyeing or printing, but generally this work is relegated to custom specialty plants.

In the opener room, usually in a section of the outlying cotton warehouse, the bales are opened and the cotton thoroughly mixed to insure uniformity. The material, in small fluffy masses, is carried through a suction pipe to the picker room, and here fed into the first of a series of machines known as pickers or lappers. In these machines, blades or projecting teeth running at high speed beat against the masses of cotton and knock out the dirt, seed burrs and other undesirable material. There are sometimes three successive processes of picking, and the machines are known as the beaters, intermediates and finishers, or as in the best modern practice, the intermediates are omitted.

The product, in the form of a soft batting, called a lap, is conveyed from the breaker to the intake side of the intermediate, where it is combined with several other similar laps so as to obtain equalization. The lap from the intermediate is carried to the finisher and in the same way combined with other laps.

The finished lap is carried by truck or conveyor into the card room and given a further cleaning between the numerous small wire teeth of the cards. These machines perform the additional function of straightening and paralleling the fibres. The material comes from them in the form of a soft, untwisted rope called sliver, which is coiled in large cans and carried to the drawing frames. For the production of specially fine yarns the sliver is passed through combers, where it is given a thorough combing to remove the short fibres. Lap machines, used with the combers, perform the function of putting the material into convenient packages for handling. This combing process is not necessary for ordinary yarns. In the drawing frames the sliver is attenuated, and the fibre further straightened and paralleled. The next process is that of twisting the sliver into the form of roving, a coarse soft yarn. This twisting is started on the slubber frames and the size of the roving gradually decreased and its hardness increased as it goes through two more similar machines known as intermediate and pine frames, or in some cases through a fourth machine known as a jack frame. All four of these machines are classed under the generic name of fly frames.

The roving is placed in the creels of the spinning frames and spun into yarn. Practically all spinning in this country is now done on ring spindles, although a few mule frames are still used for special work. In a cloth mill the filling yarn is spun directly on bobbins and is ready for immediate placing in the loom shuttles. Warp yarn must go to the spoolers, where it is put on spools, then to the warpers where many spools are combined into one very large one known as a warp beam. The yarn on this beam is passed through a slasher where it is given a sizing and then tied-in to the remnant of an old warp and placed on the looms. Following the weaving process the cloth is inspected, folded, baled and shipped to the finishing plant or is finished locally. In a yarn mill the yarn is generally twisted and put in a convenient shipping package, either on a winding machine or in a chain or a ball warper.

If the mill is on the lines of one of the power generating companies it is best to purchase power, if this can be done at the usual reasonable rates. Where such service or local hydraulic power are not available, steam driven prime movers are used. In the older steam driven mills changing over from mechanical to electric drive, the engines are frequently retained, and used to drive generators through ropes. When power is purchased on secondary contracts these engines and generators are operated during low water periods. The generators are installed in small rooms partitioned off from the manufacturing departments and furnished with forced ventilation. Steam turbine generator units are used entirely for new power units in isolated plants. Hydraulic power, where available, can be electrically generated and transmitted to the mill, allowing the main buildings to be placed safely above flood waters. Some of the older hydro-mechanical plants are being changed to electric generation and transmission and, at the same time, efficient water wheels and vertical shaft generators are being installed in place of the old units.

Cotton mill machinery is largely automatic and labor is required principally for attendance on this machinery. Very little increase in production can be brought about by any enhanced efficiency in the labor. It is only through improvements in operating conditions, machinery and methods of driving it that substantial increases can be obtained.

During working hours the power load is practically constant and the instantaneous load factor much higher than in most industries.

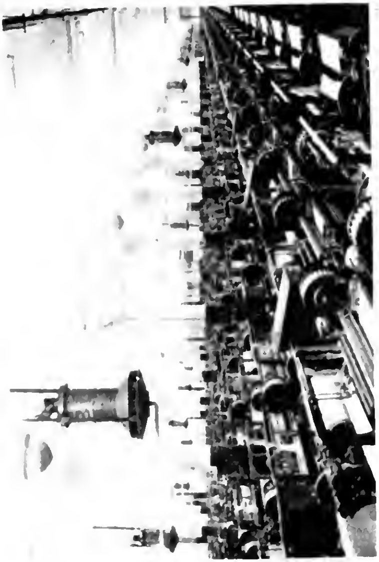

Fig. 2. Weave Room. 720 Looms Each Driven by a Small Motor. This photograph made by artificial light from indirect system

Fig. 3. Moderate Size Motors Connected to Shafts by Chain Drives. Each shaft drives 82 looms. There are 20 motors rated at 30 h.p. each in this row

Fig. 4. Warpers

Fig. 5. Slashers

The use of motors in this country has been confined almost entirely to the induction and synchronous types, except that, in the latest developments of adjustable speed applications, commutator type repulsion motors are used.

Large and moderate size motors were the logical choice for the earlier installations, and they were in fact about the only kind then available. Practically the same amount of shafting and belting was used as in the preceding forms of mechanical drive, the heavy head shafting and the belts or ropes from the prime mover only being eliminated. Under the circumstances, the losses in transmission, including motor losses, were generally the same or slightly greater than with mechanical drive and the belt slippage was decreased by only a very small amount. In some cases one large motor only, generally of the synchronous type, was used to drive an entire mill, simply replacing a steam prime mover. Large motors, necessarily low speed, were sometimes coupled to main driving shafts, avoiding the use of motor driven belts.

One practice was to equip a large or moderate size motor with two pulleys at one end and drive in opposite directions. In theory this would relieve the motor bearings of the belt pull since the two opposite pulls would neutralize each other. Unfortunately it was difficult to keep both belts tightened and, of course, one of the belts pulled on top with the slack side below. This practice has been abandoned in favor of a one-belt drive.

In those departments for which individual motor applications have not been perfected, group motors are still used, but the size of units has been gradually decreased. A very satisfactory arrangement is to install a moderate size motor for each line of countershafting, allowing, as it does, the elimination of all counter belts. With several motors in place of one large one, the chances of production loss from motor failure are considerably lessened. By proper standardization, the number of motor ratings can be kept at a minimum and repair parts or spare motors most economically carried. These smaller units are much more easily handled for installation and repairs than were the large ones.

Where it is difficult to secure sufficiently long belt centers, chain drives admirably fill the need. Many of these drives have been in successful operation for years.

Practically all motors driving groups of machines are placed with feet inverted and are mounted on the ceiling. These motors are equipped with slide rails or sliding bases designed for inverted mounting and are bolted to steel motor supports.

The anticipations of increased production and lower transmission losses were not realized with the large, group driving motors and this led to the development of the four frame motor for fly, spinning and twister frames. This four frame motor is equipped with four pulleys, each driving one frame through a belt. This arrangement eliminated all shafting and left only one belt between the motor and the machine pulley. In the earliest forms of this type a standard motor with shaft extended at both ends was used. While fairly satisfactory in operation, its application was limited to new mills or to the few old mills in which the frames could be reset to fit the fixed pulley spacing. Later developments centered on the universal type, in which the shaft is extended at one end only and connected by a flexible coupling to a long shaft running in two bearings. The four pulleys can be located on this shaft to fit any normal spacing of frames. This motor has proved quite popular and is still extensively used. Unfortunately, it necessitates the retention of the one worst belt in the entire transmission system. This almost vertical belt is subject to accumulations of oil and lint which cause excessive and variable slip. With such drives, the belts are generally cleaned once each day and immediately following this cleaning the speed of the driven machine is perceptibly increased. Within a few hours, however, the accumulations of oil and lint will cause sufficient slip to reduce the speed to the pre-cleaned basis. Belts are subject to expansion and contraction due to varying temperature and humidity and due to permanent elongation from the constantly applied fibre stress. When a belt has become sufficiently loose for the machine speed to be obviously low, it is shortened. These effects, while existing to some extent on the large counter belts, are aggravated in the machine belts. The cost of four-frame motor drive for spinning is lower for a new mill than the cost of large motors with belting and shafting and the transmission losses are, of course, somewhat lower.

INDIVIDUAL DRIVE

With modern individual drive the question of slip from the motor to the machine is practically eliminated, and production is increased by at least the amount of slip that existed with belts. As a matter of fact textile machinery, designed and adjusted to run at one proper speed, will not operate properly at a lower speed and this results in loss of production which cannot be accounted for by belt slip percentage alone.

In the opener and picker departments individual motors are generally used but are connected by comparatively short belts to the machines. Direct connected motors have been used to some extent, but the motor speeds are not always suited to the speeds of the machines and such an arrangement does not allow changes in speed to fit conditions of operation. No special demand for anything better has been made, as refinements of speed maintenance are not so important in these as in other processes. There are only a few of these machines in a mill and the mechanical difficulties in an improved design are considerable, so that development charges would hardly be warranted by results obtained.

Direct connected vertical shaft motors are sometimes used for vertical openers. The rate of feeding cotton from the opener room to the picker room can be regulated by the use of an adjustable speed motor in the opener room with a controller in the picker room. In one system a mechanical, adjustable speed device is placed between the constant speed motor and the opener feeder, and a small pilot motor operates the mechanical device. The opener room motor speed may be controlled either by hand or automatically from the picker room.

Cotton cards have large diameter cylinders of considerable weight and require for their acceleration a motor with very heavy starting torque compared with its normal rating. A further complication, in the necessity for an occasional low speed grinding operation, has delayed the development of a satisfactory individual motor drive for this machine. Trial installations of such motors have been made and it is probably only a question of time when a satisfactory equipment will be available. The best system at present uses a moderate size motor for each line of shafting.

For the amount of power used, combers require a considerable amount of shafting and belting. The application of individual motor drive to these machines has been entirely successful. A 1-h.p., 1800-r.p.m. motor, mounted on cast iron supports, is used to drive the machine by silent chain and is controlled by a switch operated from the shipper rod.

The sliver lap machine should preferably be equipped with a mechanical clutch between the motor and the driven shaft, as immediate automatic stoppage of this machine is desirable in order to avoid over-travel due to the inertia of the motor rotor.

Drawing frames are made up of one or more sections, each comprising a number of sets of rollers. Each of these sections is driven by a small belt from a countershaft, furnished as a part of the machine and running the full length of it within the base. A motor of proper size, driving this countershaft by chain, has been successfully used. A refinement that has been tried experimentally is to omit the countershaft and drive each section with a separate motor. This application has not been commercially adopted, but offers attractive possibilities for further investigation and development.

Fly frames are usually driven either through shafting and belting by moderate size motors or else by four-frame motors. These drives are fairly satisfactory but both retain the undesirable features of belting. Four frame motors must be of low speed in order to have pulleys with sufficiently large diameter for good belt contact. These low speed motor applications are slightly more expensive than individual motor drives. This leaves only

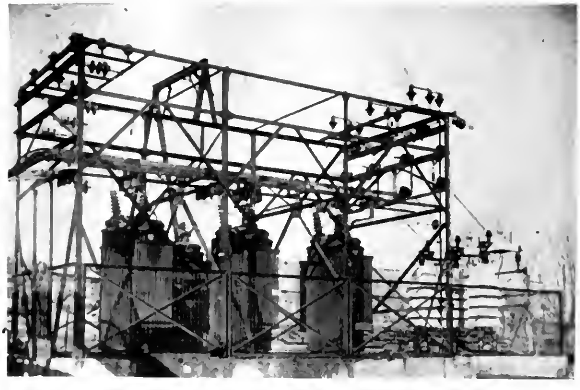

Fig. 6. Typical Mill Yard Transformer Station, 38,000 to 575 Volts, 3 Phase, 60 Cycles

two small detail troubles as obstacles to favorable consideration for individual fly frame drive. One of these troubles was the breakage of machine parts on starting and will be eliminated by spring center driven sprockets which cushion the initial shock of acceleration. The other was the comparatively short life of oil switches used for control in the earlier installations. This rapid wearing was due to the heavy blows of the shipper rod and to the very large number of operations. The new magnetically operated switches, with easily inspected and renewable parts, will eliminate this difficulty.

Individual motors for fly frames should be totally enclosed, since in a motor of this size, approximately 2½ h.p., it is comparatively easy to dissipate the heat losses by direct radiation. This design does away with all trouble from lint, which is present in considerable quantities in this department. Present plans contemplate the installation of these individual motors on cast iron supports attached to the end of the frame and equipped with horizontal chain drives.

The earlier individual drives for spinning and twister frames embodied the use of motors direct connected to the cylinder shafts. While reasonably successful, these drives did not allow the necessary latitude of speed changes. The successful development of silent chain drives finally provided a highly satisfactory transmission between the motor and driven shaft. These drives are efficient, quiet and long lived. They allow speed changes to be made with comparatively small expense and effort.

Chain drives for spinning frames have been reasonably well standardized. Chain speeds of approximately 1500 ft. per min., a pitch of ½ in. and centers of 9½ or 10½ in. are customary.

The requirements of practically all ring spinning frames today are met by the application of 5 or 7½-h.p., 1750-r.p.m. induction motors. Twister frames, depending on the size of the frame and material handled, require from 5 to 20-h.p. motors. These motors differ only slightly from standard induction motors, but have the following special features: The shafts are tapered and provided with nuts and lock washers for the proper holding and easy removal of the chain sprockets. Bearings are of the waste packed type, providing sturdy, easily maintained bearings and eliminating the possibility of trouble from the hanging up of oil rings. Terminal fittings and extended leads are provided to obviate the use of joints at the motor terminals, these leads being long enough to reach from the motor to the controlling device. Screens are provided over the motor heads to prevent the extrance of bulky masses of lint or other foreign matter.

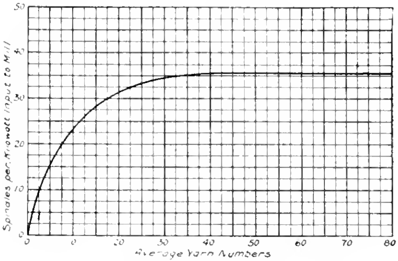

Fig. 7. Curve Showing Average Indicated Power Input to Cotton Mills

The adjustable speed motor with automatic control will probably be the ultimate refinement in the driving of ring spinning frames. With this motor and control the speed of the motor is raised and lowered automatically with the rise and fall of the ring rail and is also raised as the bobbins fill with yarn. It is claimed that these adjustable speed motors will provide means for still further increasing production but high first cost has operated against their more extended application.

A special fly wheel type of belted motor has been developed and successfully applied to the driving of mule spinning frames.

One horse power motors with gear drive have been found reasonably satisfactory for the operation of moderate size spoolers. With fabric pinions fairly good results can be obtained, but a chain drive is now being developed for these machines.

Group drive exclusively has been used for warpers. These machines require a very slow motion in case of the breakage of any one strand of yarn. No individual motor application has been designed that will show sufficient advantage to justify the cost involved for the special equipment required. With the belt drive this low speed is satisfactorily taken care of by automatically shifting the belt to a very narrow face pulley.

Slashers are driven through belting and shafting. A very good arrangement is to provide one motor for the exhaust fan and one for the slashers and kettles. No satisfactory individual motor has been developed for this application, and the problem is like that involved in the warper drive.

The tying-in machine requires a $\frac{1}{4}$-h.p., 5000-r.p.m. motor for its operation. It is necessary to provide a direct-current motor for this machine because a satisfactory alternating-current motor of the proper speed and limited dimensions has not been developed for this work. This direct-current motor in turn requires a motor generator set for its supply of current and it is customary to install a standard set of approximately 1 kw. capacity which will take care of two machines.

One make of winder uses practically the same combination of individual motor and chain drive as for a spinning frame. For another make several smaller motors are used, each driving by a belt to a group of spindles.

The application of individual motors to looms has been uniformly successful even from the initial installations. Records from thousands of motors in operation indicate clearly that increased production and low maintenance cost are facts. In these drives the motors are totally enclosed and have the same detail features as the motors for spinning frames. Spur gearing is used between the motor and the driven shaft. The motors are generally of the low torque, constant running type and the loom is started and stopped by a friction clutch. Large groups of the motors are started together from some central point by push button controlled magnetic contactors.

CHARACTERISTICS OF TEXTILE INDUCTION MOTORS

60 Cycle—3 Phase

Average Guarantees of Several Manufacturers

H.P.	R.P.M.	Volts	EFFICIENCY			POWER-FACTOR		
			½ Load	¾ Load	Full Load	½ Load	¾ Load	Full Load
½	1800	220	79	82	82.5	57	69	78.5
1	1800	220	82.0	85	85.5	63.5	76.5	82.5
5	1800	550	83	85.5	86.0	73.5	81.5	87.5
7½	1800	550	84	85.5	86.0	80.0	86.0	88.5
10	1800	550	84	85.5	87.0	80.0	86.0	90.0

Except for a few special cases, no individual drives have been designed for cloth room machinery. This department also offers possibilities for well designed applications.

The proper amount of moisture in cotton mills is necessary in order to make the fibre work smoothly, to minimize static electricity and to replace the natural moisture of the fibre which is otherwise lost in the manufacturing operations. It is customary to provide this moisture by means of one of several air conditioning systems, the most popular of which embodies humidifying head units distributed throughout the mill.

The humidifying heads consist of spray nozzles in which the water is atomized under high pressure in combination with fans which distribute this water vapor. Each of these heads is equipped with a motor of approximately $\frac{1}{16}$ h.p. These motors are of the vertical shaft type and direct connected to the fans.

For mills operated by purchased power, it is customary to install a motor-driven fire pump. With such an installation the insurance companies allow the steam boilers to be shut down in yarn mills during the summer months. Weaving mills, of course, must maintain steam heat for the slashers, but are allowed to let the steam pressure fall during the nights and on Sundays. Generally these motors are of 100 h.p. capacity at 1800 r.p.m. and the three-stage centrifugal pump will deliver 1000 g.p.m. against a head of 200-lb. pressure. Insurance requirements include a separate bank of transformers for the operation of the motor and where possible a second source of electricity supply.

New elevators are furnished with direct connected motor heads and the controls are of the ordinary hand operated type. In old mills with mechanically driven heads it is customary to install a belted motor for each elevator and control this by a magnetic switch actuated by push buttons at the several floor levels.

Adjustable speed motors are desirable for several of the finishing processes. In some cases slip-ring induction motors, but generally commutator type repulsion motors, are best for this service. Direct-current motors furnish the nicest speed adjustment, but in general their use involves the extra first cost and extra operating expense of motor generator sets.

Oil switches have been used almost exclusively for the control of individual spinning frame and twister motors. In some installations automatic oil circuit breakers were used. Recently there has been developed a simple form of enclosed magnetically operated air break switch which will probably supersede the oil switch and circuit breaker. With this switch time limit fuse plugs or thermal relays will be used for overload protection. The switch will be operated from push button stations, one "jog" button and possibly two "start and stop" buttons being provided for each frame.

Snap switches with accurately rated cartridge fuses have been used for loom motor control and protection. These are being superseded in the newer installations with a quick-make and quick-break switch fitted with time limit fuses.

Four-frame motors are thrown directly on to the line with automatic oil circuit breakers, mounted on the ceiling and operated by ropes or a rod. Standard hand-operated automatic starting compensators are used for the control of the larger motors driving shafting.

In cotton mill operation, routine changes are occasionally made that require additional power from the motors. We are apt to think that a partly loaded motor is inefficient. As a matter of fact, the efficiency of a motor at three-quarter load is, in nearly all cases, practically as good as the full load efficiency of a motor three-fourths its size. Mill owners are more interested in continuous and reliable power supply than in any slight difference in efficiency. Power factor decreases rapidly at light loads. The questions of efficiency and power factor, while important, should be made secondary to that of ample motor capacity for continued good service and extra demands. Power factor can be corrected by either static or synchronous condensers. In most cases the former is preferable due to its lower losses and the less attention required.

The following tabulation shows the average characteristics of several makes of textile motors.

The transmission distances are generally short so that moderate voltages and copper sizes may be used. New installations have all conductors in rigid conduit throughout,

TYPICAL MOTOR INSTALLATIONS

25,000 Spindle, Print Cloth, Weaving Mill

Individual Drives in Picking, Roving, Spinning and Weaving Departments—Group Drive on Cards and Cloth Room Machinery

Department	No. Motors	H.P. Ratings	Total H.P. Rating
Opening	1	7½	7½
Picking—Breakers	2	7½	15
Picking—Finishers	3	5	15
Picking—Fan, etc	1	10	10
Carding	3	25	75
Drawing	2	5	10
Fly Frames	42	2½	105
Spinning—Warp Frames	48	7½	360
Spinning—Filling Frames	44	5	220
Spooling	6	1	6
Warping	1	5	5
Slashing—Slasher and Fan	1	10	10
Slashing—Kettles and Pump	1	5	5
Weaving	550	½	225
Cloth Room Machinery	1	25	25
Miscellaneous			
Humidity Heads	70	$\frac{1}{16}$	4⅜
Humidity Pumps	1	25	25
Tieing-In Machine	1	¼	¼
Machine Shop	1	10	10
Fire Pump	1	100	100
Elevators	2	7	14
Total	782		1247⅛

Average Total Output from Motors – 826 B.H.P.

$$\text{Instantaneous Load Factor} - \frac{\text{Motor Output}}{\text{Motor Rating}} = 66.2 \text{ per cent}$$

Average Motor Rating – 1.6 horse power.

but older systems used a combination of open wiring and conduit. With wiring installed in conduit it is difficult to test the larger motors controlled by automatic compensators, unless means are provided for cutting the portable testing instruments into circuit. The most satisfactory device for this is a test receptacle and plug. Either an ammeter or an indicating wattmeter may easily be connected in circuit without interrupting the operation of the motor. Ammeter readings are quite satisfactory near full load and are easily taken.

Fig. 8. Textile Type Motor for Looms

For each individual motor a cut-out box with fuses is installed. Dummy fuse cartridges with leads connected to the portable instruments are readily handled with wooden pliers, and by cutting in on one phase at a time readings can be readily taken without interrupting the operation of the motor.

The larger motors are fitted with terminal boxes and the smaller motors with extended leads and receptacles for the reception of flexible conduit. This practice does away with the old exposed motor leads so frequently seen even with enclosed conduit installations.

In spite of its advanced development, electric drive for cotton mills is still far from perfect. Details that require further investigation and improvement are the incorporation of the motor as a part of the driven machine instead of an appendage as at present, the standardization of sizes and parts to make motors of the several manufacturers interchangeable, and improvements in the driven machines themselves through the elimination of wasteful friction and better utilization of the electric drive. As an instance of the latter it should be noted that the unnecessary friction loss in a spinning frame is approximately 80 per cent of the total power required to drive it. Nearly all of this loss takes place in the spindle bolster, due to the heavy band pull in one direction. It is possible that some means could be found for neutralizing this pull and minimizing the friction loss.

Many prophetic objections have been raised against the use of individual motor drives. Numerous installations comprising thousands of small motors that have been operating satisfactorily for years give the best answer to these objections.

Individual electric drive has developed and will survive because, by increasing production, it enables a mill to make yarn or cloth at a lower price per pound than can be done by any other form of drive.

There are 34,387,000 cotton mill spindles in America. Assuming a fair average allowance of 1 h.p. of motor rating for each seventeen spindles, indicates that a total of 2,022,700 h.p. of motors would be required to drive them all. It is estimated that 43 per cent of these spindles are now driven by large motors, 10 per cent by individual motors and 47 per cent by mechanical transmission. The available market for individual motor drive, including changeover from large motors and from mechanical transmission, is therefore 90 per cent of 2,022,700 or 1,820,430 motor rated horse power, not including new mills that may be built in the future.

Fig. 9. Textile Type Motor for Spinning Frames

The Insulation of High Voltage Transmission Lines

CONCEPTION OF A MILLION VOLT LINE

By F. W. Peek, Jr.

Pittsfield Works, General Electric Company

Porcelain is the only material available at present for high potential insulators, and in selecting porcelain insulators equal consideration should be given to the mechanical and electrical properties of the material. It is necessary to consider what abnormal conditions will be encountered in service and to approximate these as closely as possible by tests. Uneven potential distribution over a string of insulators, which at one time threatened to be a serious obstacle to ultra high-voltage transmission, has been corrected by the development of a "shield." Corona discharge is another serious factor, but this loss can be reduced to satisfactory limits by the use of tubular conductors. Recent laboratory experiments at a million volts introduce the vision of a million volt transmission line, and while the specifications are formidable they may be within the bounds of possibility.—Editor.

It is the purpose of this article to review the various factors affecting the insulation of transmission lines.

Mechanical

The only material available at present for line insulators is porcelain. In many ways good porcelain has excellent electrical qualities. However, electrical qualities must be considered in conjunction with the mechanical qualities and stresses to which an insulator is likely to be subjected in practice. The stresses due to mechanical surges of the line, changes in temperature, wind and sleet loading, etc., may be quite severe. Since porcelain is mechanically weak it should be used to the best advantage. Designs should be such that the mechanical stresses are reduced to a minimum. In the cemented type of insulator the greater part of the trouble has been due to the expansion of the cement and metal parts causing very gradual cracking. Electrical failures finally occurred through the cracks. The importance of the mechanical characteristics of line insulation has of late years been recognized and improvement has undoubtedly been made in the cemented type by a better design and by the use of cushions. Porosity has also been a factor. These causes of deterioration on high and low voltage lines alike are mentioned here because of the fact that the cure is not yet complete and this problem must not be lost sight of in the discussion that is to follow. Before leaving this subject, however, it is important to mention that the Hewlett insulator, because of its loose fitting metal parts and freedom from cement, has been free from deterioration. It has made the best use of a difficult material.

Tests

In former years the selection of insulators has been based almost entirely on electrical tests. This is obviously not logical since no electrical test will anticipate future cracking due to internal strains or brittle porcelain, nor indicate porosity in dry porcelain. The desired results, after a good design has been selected, can probably best be attained by testing a small percentage of the product to destruction from day to day after the usual electrical and inspection tests have been made, the object being to determine if the product is up to standard and of uniform quality.

In our investigation we made first the electrical tests, followed by mechanical impact tests to destruction. Samples were then taken from the head and thick part of the units and subjected to a porosity test. The porcelain was placed in three arbitrary electrical, mechanical and porosity grades and a graphical chart made indicating the percentage in each. A datum has thus been established for comparing the present and future product with the past.

While discussing the subject of testing, it may be well to review the electrical tests. Various kinds of tests have been suggested from time to time as a means of detecting porous porcelain or other faults in insulators. No electrical test is known that will anticipate mechanical failure or detect porous material when it is dry. Most of the tests are of interest only in the study of design and in development work.

1. The 60-cycle test or test at operating frequency is the best for general use and is most practical and desirable as a standard test. It can be accurately reproduced. It is the most effective in testing either old or new insulators. It will readily puncture porous insulators that have absorbed moisture.

2. Resistance measurements are generally of use only in detecting porous or cracked insulators that have absorbed moisture. On new, dry material they indicate very little even when measurements are made at 50 or 100 kv.

3. Damped high frequency tests are often made. Generally a frequency of the order of 100 kilocycles is used. This is obtained from an oscillating circuit giving 120 very

highly damped wave trains per second. It acts as a series of impulses. Because of time lag a higher voltage can be applied without spark-over than at 60 cycles. It will not detect old porous insulators that have absorbed moisture. The discharge has a tendency to spread over the insulator surface and it may, in this way, detect flaws in the petticoats more readily than some other tests. This test is not desirable as a standard because it is very difficult to duplicate results.

4. The lightning impulse test is of use as a design test in determining the impulse ratio, etc.

5. Undamped high frequency tests will cause failure in insulators at very low voltage due to heat. It is a condition that does not occur on transmission lines.

6. The d-c. spark-over voltage is $\sqrt{2}$ times the 60-cycle spark-over voltage. It varies somewhat, depending upon whether the caps are + or −. The puncture voltage is relatively much higher.

7. The 60-cycle test has the desirable characteristics of all the other tests, except that possibly it does not so readily detect flaws in the petticoats. This feature is not always important but can be added to the 60-cycle test by making the arc of the insulator part of an oscillatory circuit by limiting the current in the arc by resistance. By this means the oscillatory wave is superposed upon the 60-cycle wave.

Long time tests at high voltage are dangerous and should be avoided.

Abnormal Conditions on Transmission Lines

The abnormal voltages that are likely to occur on transmission lines and need be considered in connection with the insulator are:

1. Cloud lightning in most cases occurs on the line as an induced stroke. A very steep wave front voltage travels over the line. At one instant an insulator may be subjected to normal voltage and a fraction of a millionth of a second later to the normal voltage plus or minus the lightning voltage. Fortunately the lightning spark-over voltage of an insulator is always higher than the 60-cycle voltage. The lightning spark-over voltage is also not affected by rain or moisture. Observations that we have made on transmission lines show that the danger from lightning decreases rapidly with increasing line voltage. In general, it was found that the voltages were of steep wave front. Many discharges took place on gaps set at the lower voltages. The discharges on the higher voltage gaps were less and less until finally very few were found at a needle gap setting for about 200 kv. This would perhaps correspond to about 400 kv. in actual volts. A direct stroke may, of course, be higher.

2. Other transients that are of importance on transmission lines are those caused by arcing grounds on systems with isolated neutrals and those caused by switching. Such disturbances as we have been able to measure are either in the nature of a surge or a *highly damped* high frequency oscillation. Disturbances of this character sometimes reach double line voltage but more often cause very little rise in voltage across the line. They may, however, build up to high internal values in inductive apparatus. Fortunately the grounded neutral system is fast replacing the isolated system.

3. It can be safely said that *undamped high frequency* (radio frequency) disturbances practically do not exist on transmission lines and need not be considered in selecting insulators.

The spark-over voltage of an insulator for any transient disturbance that is likely to occur on a transmission line is always higher than the 60-cycle spark-over voltage.

Insulator failures or spark-overs may be caused by excessive voltages, by weakened insulation, or by a combination of the two. Available data indicate that the greater number of insulator failures have not been primarily due to excessive voltages or to "high frequency" but to weakened insulation.

In parts of the country where there is a long dry season, dirt collects on the surfaces of the insulators. When this dirt becomes wet with the first rain, dew or fog, the surface becomes conducting and the spark-over occurs at a very low value. It is somewhat similar to placing a fuse suddenly across the string. This trouble may be accentuated when there has been mechanical deterioration and part of the string has become useless. The percentage of failures is small because it requires a combination of circumstances as to dirt, moisture, etc., to establish a conducting path sufficiently long to cause complete spark-over before the dirt is burned off or washed away.

The following laboratory data are of interest in this connection:

No. of Units in Series	SPARK-OVER KV.				
	Dry Clean	Wet Clean	Dew Clean	Dry Dirty	Dew Dirty
9	537	380	542	537	160

Ionization of the air around the line conductor due to incipient corona or other causes, may be dismissed as a probable cause of mysterious spark-overs. Tests made in a closed box when the ionization was much stronger than would be possible in the open air showed no reduction in spark-over voltage.

Insulator Practice

An insulator or bushing is generally so selected that the wet and dry spark-over voltage at normal frequency are several times the operating voltage. This ratio between spark-over voltage and operating voltage is called the "factor of safety." The average factor of safety used in practice for the pin type insulator, the suspension insulator, and the transformer and switch bushing are given in Figs. 1, 2 and 3 respectively. The three curves are plotted together in Fig. 4. These may be called experience curves, since the sizes were varied until a reasonable freedom from trouble resulted. It would not be expected that the ratios would be the same for all types of insulation; for instance, at a given voltage the ratio is lower for the pin type insulator than for the suspension insulator, but the pin type insulator is generally used on wooden poles and the suspension insulator on steel towers.

The characteristics of the curves are logical. The factor of safety should be higher on the low voltage lines. This follows because all lines in a given locality are subjected to virtually the same lightning voltage. The high voltage lines are thus relatively less affected.

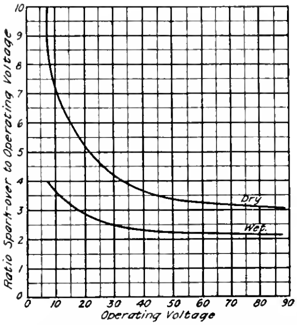

Fig. 1. Experience Curves—Factor of Safety at Various Voltages, Pin Type Insulators

A minimum wet spark-over ratio of two at the higher voltages seems logical. Owing to

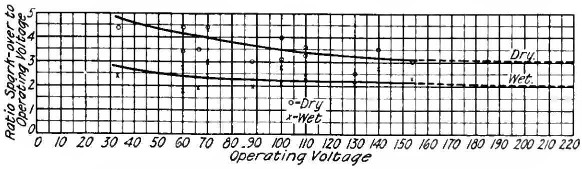

Fig. 2. Curves of "Factor of Safety" at Various Voltages Compiled from About 50 Lines, with Suspension Insulators, Under Different Climatic Conditions. Points Show Maximum and Minimum Values

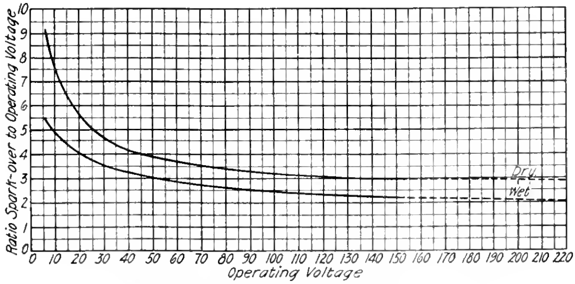

Fig. 3. Experience Curves—Factor of Safety at Various Voltages, Transformer and Switch Bushings

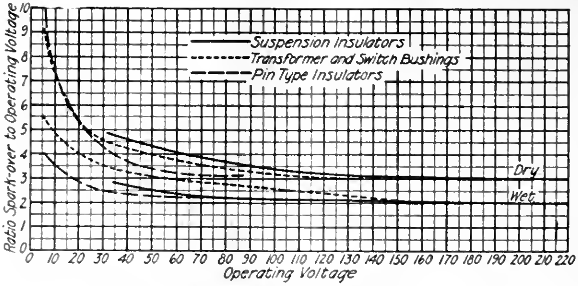

Fig. 4. Experience Curves—Factor of Safety at Various Voltages, Suspension Insulators, Transformer and Switch Bushings, Pin Type Insulators

internal disturbances low frequency surges of double voltage may appear on the line.

In selecting insulators each case must, of course, be considered separately. The factor of safety is of use, however, as an indication.

High Voltage Lines

When insulators are placed in series in a string the voltage does not divide evenly.[1] A very high percentage is across the unit nearest the line. Typical curves are given in Fig. 5. Fig. 6 shows the percentage of applied voltage across each unit in a string of ten. Even distribution would put ten per cent on each unit as indicated by the dotted line: When there are more than five units in a string 20 to 30 per cent of the applied voltage will be on the line unit. It is evident that this becomes of great importance at the higher voltages. For instance, at 110 kv. operating voltage the stress on the line unit is 19 kv.; at 220 kv. it is 38 kv.

The reason for the uneven distribution is shown graphically in Fig. 7. There are a

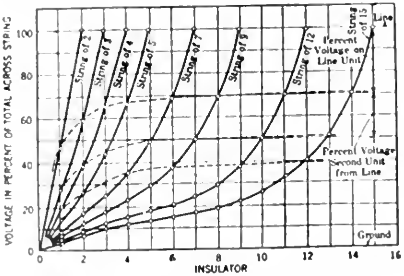

Fig. 5. Typical Voltage Distribution Curves on Strings of Suspension Insulators

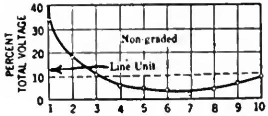

Fig. 6. Voltage Distribution on String of Ten Insulators

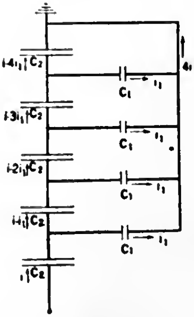

Fig. 7. Cause of Uneven Distribution. The Capacities to Ground C_1 Cause an Uneven Distribution of Current Through the Insulator Capacity C_2

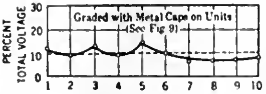

Fig. 8. Voltage Distribution on String of Ten Insulators

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[1] Ryan and Henline, "Unit Voltage Duties on Long Strings of Suspension Insulators," A.I.E.E., July, 1920; Peek, "Electrical Characteristics of the Suspension Insulator," I, A.I.E.E., Vol. XXI, 1912; A.I.E.E., July, 1920; "Present and Future of the Line Insulator," *Electrical World*, Jan. 24, 1920; "Transmission Insulation in America," *Electrical World*, Nov. 27, Dec. 4, Dec. 25, 1920.

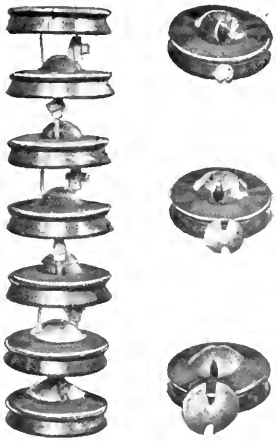

Fig. 9. Suspension Insulators Graded with Caps or Plates

number of ways that this may be corrected. Fig. 8 shows corrected distribution by varying the capacities of the units along the string in proportion to the currents. Fig. 9 illustrates a method of doing this. The spark-over characteristics of a string graded in this way are shown in Fig. 11. There is a tendency to cascade.

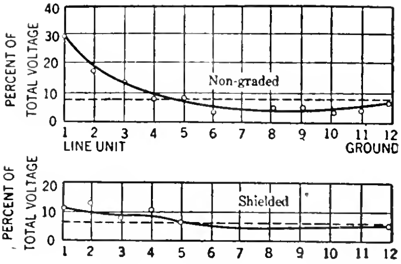

Fig. 10. Voltage Distribution on a String of Twelve Insulators

Fig. 10 shows the result of distributing the voltage by the shield in Fig. 12. The spark-over characteristics are shown in Fig. 13. The shield, in effect, eliminates the capacity to ground as shown in Fig. 14. It has the advantage over other methods in that all the units in the string are the same; it eliminates corona and directs the arc away from the string. By means of the shield, unit stresses on 220-kv. lines are readily reduced below those at present existing on successful 110-kv. lines. By better distributing the surface stresses on the individual units, the shield also tends to increase the spark-over voltage when the string becomes dirty. The relative characteristics of the two methods may be summarized as follows:

Fig. 11

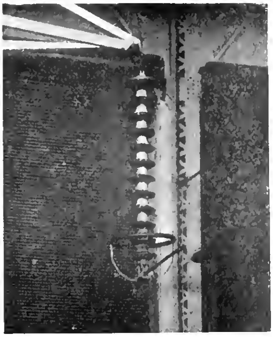

Fig. 12

Fig. 13

Fig. 11. Dry 60-cycle Spark-over of a Mixed String. Large Units at Line End; 10-in. Discs at Tower End. Capacity of units adjusted with metal caps to obtain uniform voltage distribution. The arc cascades badly along the entire length of the string. **Fig. 12.** Suspension Insulator String Shielded with the Ring Shield. **Fig. 13.** Dry 60-cycle Spark-over on a Suspension Insulator String Shielded with the Ring Shield

Shielding

(a) Reduces the voltage stress on the line unit by one third to one half.

(b) Prevents corona on the units.

(c) Directs the arc away from the string.

(d) Reduces surface voltage stress from one fourth to one third and thus increases the spark-over above that on the non-shielded string when part of the unit becomes conducting by dirt.

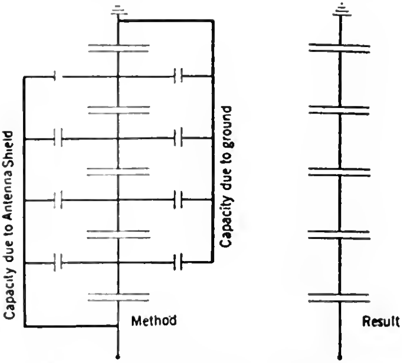

Fig. 14. Shielding by Eliminating the Effect of the Capacity to Ground

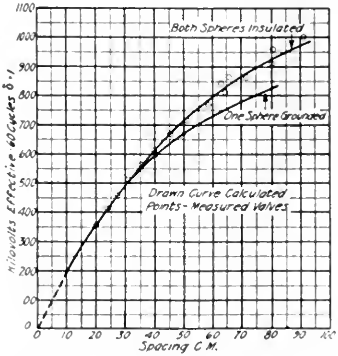

Fig. 15. Spark-over 75 cm. Spheres

(e) Prevents high local stress due to transients by establishing the proper field through the air and not through the reactance of the links and hardware.

(f) Does not require special insulators.

Grading by Metal Plates or Different Sized Units

(a) Reduces stress on the line units.

(b) Causes corona formation.

(c) Causes arc to cascade badly along string.

(d) The addition of capacity plates increases the hazard by adding extra edges for corona formation, and, by covering a larger area, requires a larger part of the porcelain to be perfect.

(e) Requires several different types of units.

Extra High Voltage Lines

Lines are at present underway for 220 kv. operation. It is very important, therefore, to make tests at much higher voltages to see if the curves and laws established at the lower voltage still hold, in order to be ready when economic conditions require higher voltage lines.

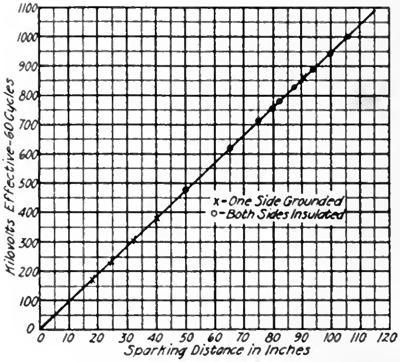

Fig. 16. Needle Gap Spark-over

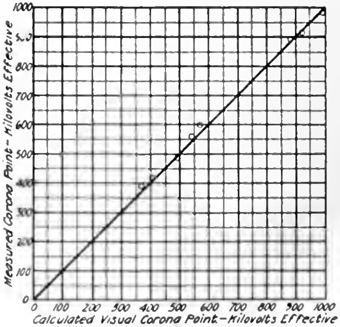

Fig. 17. Comparison of Calculated and Measured Visual Corona Voltages on Brass Tubes

Such an investigation has recently been made in the High Voltage Engineering Laboratory at Pittsfield. Measurements were made up to about 1,100,000 volts or 1100 kilovolts.

In this investigation tests were made on the typical electrodes that occur on a transmission line. The needle gaps represent the non-uniform dielectric field; the sphere gap, the uniform field, and the line insulator the typical surface. Corona tests were also made.

TABLE I

CORONA ON PARALLEL BRASS TUBES

60 Cycles

Spacing Inches	Cm.	Visual Eff. Cal.	Corona Kv. $\delta=1$ Observed
Diameter 3.5 Inches, 8.9 Cm.			
75.5	192	790	730
111.5	283	876	895
147.5	375	915	915
183.5	466	990	990
Diameter 1.75 Inches, 4.45 Cm.			
73.7	188	490	490
109.7	279	538	560
145.7	370	568	600
181.7	463	604	675
Diameter 1.0 Inches, 2.54 Cm.			
73	185	340	370
109	277	364	380
181	460	402	415

The investigation was made at 60 cycles with a transformer capacity of 1000 kv-a. Voltage was carefully checked to 700 kv. by stepdown transformers. The higher voltages were determined by ratio corrected for regulation. The maximum error should not be more than 5 per cent.

The needle gap curve is given in Fig. 16. There is no discontinuity. It is an extension of the approximately straight line needle gap curve of the lower voltages. A spark-over is shown in Fig. 18.

The sphere gap curve is given in Fig. 15. The curve is in agreement with calculated values.[2]

Visual corona tests were made on 1, 1¾ and 3½-in. diameter parallel brass tubes at various spacings. These tests show that the laws established at the lower voltages still hold.[3] The comparison of calculated and measured values is given in Table I and Fig. 17. Corona at the higher voltages is shown in photographs, Figs. 19 and 20.

The line insulator spark-over curve up to 1100 kv. is given in Fig. 22. It is interesting that 1100 kv. can be placed on a string of such insulators without spark-over. At low voltages the stress on the line unit of a string

Fig. 18. Spark-over Between Needle Points at One Million Volts. Distance about nine feet

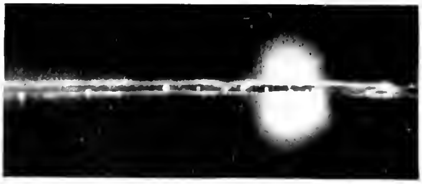

Fig. 20. Corona at 800-kv. 1-in. (2.54 cm.) Diameter Tube 144-in. (366 cm.) Spacing

Fig. 19. Corona at 900-kv. 3.5-in. (8.9 cm.) Diameter Tube 144-in. (366 cm.) Spacing

Fig. 21. Automatic Shielding by Corona (See Fig. 23)

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[2] Peek, "Dielectric Phenomena in High Voltage Eng.," p. 93.

[3] Peek, "Dielectric Phenomena in High Voltage Eng.," p. 203.

of 22 insulators would be 20 per cent of the applied voltage. A stress of $0.20 \times 1000 = 200$ kv. might, therefore, be expected at one million volts. Since a single unit sparks over at about 75 kv., the whole string would be expected to spark-over as soon as the voltage became that high on the line unit. This would presumably occur at 375 kv., since 20 per cent of 375 is 75 kv. However, such a string does not spark-over even at a million volts. The reason is that the string is automatically graded by corona. Where the stress is highest the air breaks down as corona and in effect affords a shield which tends to grade the string. See Fig. 21. This corona would be undesirable and even dangerous in practice, so it is replaced by the shield shown in Figs. 12 and 13. A daylight view of Fig. 21 at 1,000,000 volts is shown in Fig. 23. Arc-over of a string of 18 units is shown in Fig. 24.

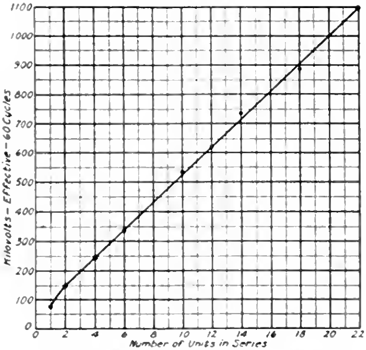

Fig. 22. Spark-over of Suspension Insulators

A Million-volt Transmission Line

The voltage of a line should always be determined by economic conditions. It is interesting to discuss the characteristics and practical possibilities of a million-volt transmission line regardless of the fact that present economic conditions do not require such a line. The present importance of the problem is to know how to predetermine the characteristics of the higher voltage lines in order to be ready when conditions demand them. This discussion will be limited to the possibilities of the system from the viewpoint of insulation. Only the transformer, the transmission conductor and the line insulator need be considered. The low voltage apparatus would not be different from that at present in use except for the ability to handle, regulate and control the large amount of energy necessary to make such a line economical.

The transformer would not differ radically from the present-day transformer. The bushing is the most difficult element of this apparatus.

The calculation of the size of the conductor necessary for such a line is of interest. At sea level and 20-ft. spacing, three-phase, a 5-in. diameter smooth conductor is found necessary at 1000 kv.

Thus

$$c_o = 21.1\, m_o\, r\, \delta \log_e \frac{s}{r} \text{ kv. to neutral}$$

$m_o = .94$, $r =$ radius in cm, $s =$ spacing cm.

$c_o = 578$ kv. to neutral

$E_o = 1000$ kv. between lines

$$p = \frac{244}{\delta}(f+25)\sqrt{\frac{r}{s}}\,(e-c_o)\;10^{-5}\text{ kw/km}$$

$= .1\,(e-578)^2$ kv/mile three-phase. At 1000 kv. between lines the loss is thus zero.

If the voltage is increased 10 per cent the loss is

$$p = .1\,(635-578)^2 = .1\,(57)^2 = 325 \text{ kw/mile}$$

This is quite large. By examining the equation it will be seen that a *peculiarity of the very high voltage line* is that the *corona loss increases very rapidly with a slight percentage increase of the voltage above the critical point.* This is so at the higher voltages because the loss increases as the square of the difference

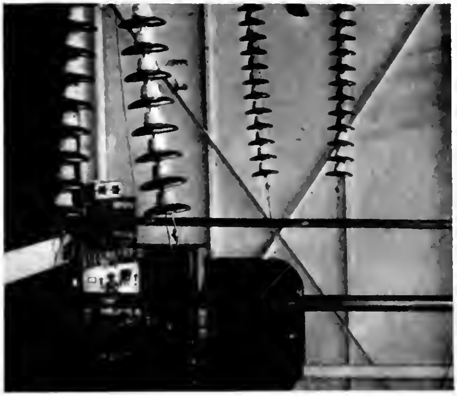

Fig. 23. Lines Insulated for One Million Volts

between two voltages. A small percentage increase means a large actual voltage increase.

This is well illustrated by comparing the loss on a 1000-kv. line and a 220-kv. line for a 10 per cent increase in voltage above the critical value.

For 1000 kv.:

$p = .1\ (578 - 578) = 0$

At 10 per cent increase

$p = .1\ (635 - 578) = .1\ (57)^2 = 325$ kw/mile

For a 220-kv. line

$p = .05\ (127 - 127) = 0$

At 10 per cent increase

$p = 0.5\ (139 - 127) = .05\ (12)^2 = 7.2$ kw/mile

Because of the large increase in loss when the voltage is increased or the critical voltage lowered, it may be desirable to operate such lines with a larger margin between the critical and operating voltage.

Rain on the average lowers the critical voltage 20 per cent.

The loss during a storm would then be:

$p = .1\ (e - .8 \times 580) = .1\ (116)^2 = 1080$ kw/mile

This would be over a million kilowatts loss on a 1000-mile line.

For small loss during a storm it would be necessary to increase the diameter of the conductor to 6.5 inches.

In the calculation above a smooth tube is assumed. Other forms of conductors are possible. For special conductors or cables however, it is necessary to make sure that the component parts are properly proportioned with respect to the complete conductor. If this is not done m_v and m_o may be low. The strands must not be too small in a large cable.

The capacity current of such a line would be 4.43 amperes; the kv-a. per mile, 7650.

The line insulator offers the most difficult problem. The length of the insulator would be 15 to 20 ft.

An approximate picture of a million-volt line may now be drawn—6½-in. diameter conductors suspended by insulators 15 to 20 ft. in length and spaced at least 20 ft. apart. This is not so formidable as might be expected.

In order that a million-volt line may be economical the amount of power transmitted must be enormous. Although the losses and charging current seem high, they would not appear so if expressed in terms of the power supply.

With long lines, where quarter, half and full wave lengths of the operating frequency are approached or approximated, the line characteristics and the effect of capacity current differ greatly from the shorter lines. This can, of course, be taken care of by synchronous condensers and other means. It is not proposed to discuss this matter here.

The immediate use for these very high voltages is in the laboratory. For instance, we have had for a number of years in the High Voltage Engineering Laboratory at Pittsfield, a lightning or impulse generator capable of producing voltage waves of a known shape and a duration measured in millionths of seconds or microseconds.[4] The range of this lightning generator has been extended from 800 to about 1500 kv. The current discharge is measured in hundreds or thousands of amperes. This is far in excess of lightning strokes induced on transmission lines and probably approximates voltages on lines caused by direct lightning strokes.

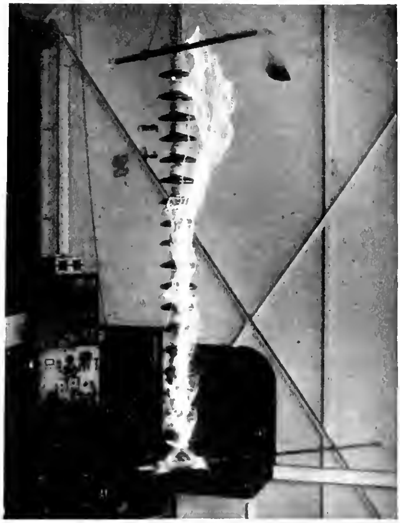

Fig. 24. Insulator Spark-over at About 900-kv.

Experiments with the high electric gradients or stress possible by these very high voltages should help to extend our knowledge of the constitution of matter. The outcome of the many laboratory uses of a "million volts" is, indeed, difficult to predict.

I acknowledge the assistance of Messrs. Will L. Lloyd, Jr., Royal Meeker and E. O. Heidel, in making the high voltage tests. The high voltage photographs were made by Mr. Lloyd.

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[4] Peek, "Effect of Transient Voltages on Dielectrics," A.I.E.E., Sept., 1915.

Automobile Headlight Regulation

By L. C. Porter and R. W. Jordan

Edison Lamp Works of the General Electric Company

During the last three or four years we have published several articles dealing with the problem of reducing the glare from automobile headlights. A great deal has been accomplished in minimizing this hazard that attends travel by night along our highways, partly through improved head lamps and bulbs and partly through legislation. However, the problem is a long way from satisfactory solution and it is natural that many changes in legislation by the various states should have been enacted during the past year. This article reviews the present status of automobile headlight legislation and will be of interest to every owner of an automobile and to those legislators and their advisers who are shouldered with the responsibility of enacting laws which will be both reasonable and effective in promoting safe highway travel.—Editor.

The introduction of powerful electric headlights on automobiles created the necessity for regulating measures to restrict their use, and the past year has seen a tremendous advance in legislation respecting automobile headlights. This is a good thing for the lamp business; for the safer and more comfortable it becomes to use our highways at night, the more night driving there will be and the greater the lamp sales. A further advantage of restrictions on candle power and methods of using lamps is the trend toward lamp standardization.

The prime object of practically all headlight legislation has been the reduction of glare in order to make it safe for the approaching driver or pedestrian. A secondary consideration has been to provide sufficient light so distributed on the road as to enable the driver to see clearly any objects which might cause him trouble, i.e., to make it safe for the driver.

Many states passed laws prohibiting "glaring" headlights; but what constitutes a glaring headlamp, and how can you measure it? The same lamp viewed on a brightly lighted city street or a dark country road may prove comfortable or exceedingly trying to look at.

Realizing the necessity of some definite measurable units to meet this situation, the Illuminating Engineering Society, cooperating with the Society of Automotive Engineers, made some very extensive and thorough investigations and tests. As a result of these, they drew up a tentative specification for the performance of head lamps on the road in measurable terms, i.e., beam candle power.

This specification states that the light projected ahead of an automobile shall not exceed 2400 candle power directly in front of the car at an elevation of one degree above the horizontal through the headlamps, or any point above that, nor 800 candle power one degree above the horizontal and four degrees to the left of the aixs of the car. Also, that the light projected ahead of the car must be at least 4800 candle power, and preferably 10,000 somewhere between the horizontal and one degree below the horizontal.

Certain other specifications as to spread, etc., have been added,* but these two main requirements are the ones on which most of the later headlight regulation has been based. Slight modifications have been made by various states. To date, Connecticut, Massachusetts, Pennsylvania, Maryland, California, Ohio, Maine, Nebraska, Iowa, Delaware, Wisconsin, New York, and the Province of Ontario, Canada, have legislation embodying the above requirements, and these States have 45 per cent of the total automobile registration in the United States, and 40 per cent in Canada. These various laws may be typified and grouped as follows:

A. During the period from hour after sunset to hour before sunrise display at least two lighted lamps on the front and one on the rear of such vehicle which shall also display a red light visible from the rear. Numerals of license plate shall be visible ft. The spotlight must be of such construction that the center of the beam does not strike the highway at a greater distance than ft. ahead of the vehicle except when the beam is swung degrees to the right or left no limitation is placed upon the height to which beam is raised. The lights of the front lamps shall be visible ft. ahead.

In Table I blanks indicate those portions of law "A" which are not effective in that particular state.

B. The following States have practically no headlight laws:

1. Arkansas. (Counties and cities may regulate headlights.)
2. Colorado. (Must have lights at one-half hour after sunset.)
3. Louisiana. (Same as Arkansas.)
4. Oklahoma. (Same as Arkansas.)
5. Tennessee. (None.)
6. Texas. (Present law not upheld by courts.)

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*Illuminating Engineering Society's Transactions. Vol. XV, No. 9, page 855.

C. The following States publish a list of lawful lenses and devices for limiting the beam. The standard is practically the I.E.S. recommendation. 45 per cent of the total registration of automobiles in this country are represented by this list.

1. California. Spotlights at 100 ft. shall not throw beam over 42 in. high.
2. Connecticut. Limit of 21-c.p. lamps. Spotlight to right of center and must hit road not over 30 feet ahead of vehicle.
3. Delaware. List not out to date. At 75 ft. or more ahead, beam shall not rise over 48 in.

TABLE I

	Name of State	Hours After Sunset and Before Sunrise	Numerals Visible	Spotlight on Road Feet Ahead	Beam Swung Degrees	Front Light Visible Feet	Additional
1.	Alabama	½	50 ft.	...	...	..	Lights need not be lit under street light.
2.	Georgia	1	Plainly	...	...	...	Lights must be always lit.
3.	Idaho	1	...	...	...	200	....
4.	Illinois	1	50 ft.	...	...	200	Dimmed at 250 ft. unless equipped with lenses.
5.	Indiana	½	100 ft.	50	...	200	Need not burn lights while standing in town.
6.	Kansas	1	....	...	...		Lenses or dimmers
7.	Minnesota	1	....	100	30	200	Lenses 32 c.p.
8.	Mississippi	½	....	...	...	200	....
9.	Montana	1	100 ft.	...	.	200	....
10.	New Mexico	1	....	...	..	.	....
11.	Rhode Island	½	60 ft.	...	..	200	....
12.	S. Dakota	½	....	50	...	.	Must have lens or dimmer.
13.	Virginia	1	Effectually	...	..	100	....
14.	Wyoming	1	50 ft.	...	..	500	Must use dimmer.

4. Iowa. At 75 ft. or more ahead, beam shall not rise over 42 in. Maximum 32 c.p. Spotlights to right of center of road.
5. Maine. At 75 ft. ahead, not over 42 in. Maximum 32 c.p. Spotlights not more than 2 ft. above road 30 ft. ahead. A new list of lenses to be out soon.
6. Maryland. At 75 ft. ahead not over 42 in. Maximum 32 c.p. Spotlight on road not over 30 ft. ahead.
7. Massachusetts. Maximum 21 c.p gas-filled.
8. Nebraska. At 75 ft. or more ahead, beam shall not use over 42 in. Spotlights not more than 30 ft. in front of vehicle. Maximum lamps 24 c.p.
9. New Jersey. Beam not more than 56 in. above road. No spotlight can be used for driving purposes. Maximum lamps 24 c.p.
10. New York. At 75 ft. ahead beam must not be higher than 42in. Maximum 24 c.p. Spotlights same as headlights.
11. Ohio. At 75 ft. ahead beam must not be higher than 42 in. Maximum c.p. 32.
12. Pennsylvania. At 75 ft. or more ahead of lamps beam must not be more than 42 in. Maximum 32 c.p. Spotlight shall not extend to left of center of road.

D. The States listed in Table II have laws essentially such as this:

From (*a*) hour after sunset to (*a*) hour before sunrise, display at least two lighted lamps on the front of such vehicle and also display a red light visible from the rear. All lights over 4 c.p. equipped with reflectors shall be so arranged, designed, diffused or deflected that no portion of the beam of light shall at a point (*b*) feet or more ahead of the lamps rise more than (*c*) inches above the level surface on which the vehicle stands. Spotlight must be so constructed that the center of the beam does not strike the highway at a greater distance than (*d*) feet ahead of the vehicle except when beam is swung (*e*) degrees to right or left no limitation is placed upon the height to which beam may be raised. The lights of the front lamps shall be visible (*f*) feet ahead. Maximum candle power of lamps is (*g*) candle power.

Where a blank occurs in Table II, that portion of the law above is omitted.

The law for Oregon states that:

Lights on from ½ hour after sunset to ½ hour before sunrise.

A substantial object must be clearly discernible 200 feet directly ahead, and 100 feet directly ahead and 7 feet to the right of the axis.

Lights must be so adjusted or operated to avoid dangerous glare or dazzle.

Lights must be dimmed when a vehicle is approaching, or put out and spotlight used instead.

States limiting the maximum candle-power of the lamp:

Arizona	32 c-p.
California	32 c-p.
Connecticut	21 c-p.
Iowa	32 c-p.
Maine	32 c-p.
Maryland	32 c-p.
Massachusetts	21 c-p.
Michigan	32 c-p.
Minnesota	32 c-p.
Missouri	36 c-p.
Nebraska	24 c-p.
New Jersey	24 c-p.
New York	24 c-p.
Ohio	32 c-p.
Pennsylvania	32 c-p.
Utah	32 c-p.
Washington	27 c-p.
West Virginia	32 c-p.
Wisconsin	32 c-p.

States declaring the distance ahead at which headlights must be visible:

Arizona	Reasonable
Connecticut	500 feet
Delaware	200 feet
Florida	200 feet
Georgia	Reasonable
Idaho	200 feet
Illinois	200 feet
Indiana	200 feet
Iowa	500 feet
Maryland	200 feet
Mississippi	200 feet
Missouri	500 feet
Montana	200 feet
Nebraska	Reasonable
Nevada	Reasonable
New Jersey	250 feet
New York	250 feet
Oregon	500 feet
Pennsylvania	200 feet
Rhode Island	200 feet
South Carolina	200 feet
Vermont	200 feet
Virginia	100 feet
Washington	500 feet
Wyoming	500 feet

States declaring that a substantial object must be distinguished at a certain distance ahead:

California	200 feet
Delaware	25 feet
Iowa	75 feet
Kentucky	200 feet
Maine	200 feet

TABLE II

	State	(a)	(b)	(c)	(d)	(e)	(f)	(g)	Additional
1.	Arizona	1	75	42	100	30	..	32	
2.	Florida	½	200	48	..	..	200	..	If not equipped with lens, dimmers must be used.
3.	Kentucky	..	75	42	..	..	200	..	
4.	Michigan	1	75	42	200	..	..	32	May use dimmers.
5.	Missouri	½	..	42	..	..	500	36	Spotlights may be used in country.
6.	Nevada	1	..	42	..	..	..	..	Lenses or dimmers must be used.
7.	New Hampshire		75	42	30	..	..	..	
8.	North Carolina	½	75	42	..	..	..	..	
9.	North Dakota		75	42	30	..	..	..	
10.	South Carolina	½	75	42	..	..	200	..	
11.	Utah	½	75	42	100	30	200	32	
12.	Vermont	¾	75	42	30	..	200	..	
13.	Washington	½	75	42	75	..	500	27	
14.	West Virginia	..	75	42	..	..	200	32	
15	Wisconsin*	..	..	60	50	30	..	32	Maximum 21 c.p. for spotlight, 32c.p. for headlights.

*The law for Wisconsin states:

At 100 ft. ahead at a height of 60 inches not more than 2400 candle power.

At 100 ft. ahead, 7 ft. to left and at a height of 60 inches not more than 800 candle power.

Any other lights at 100 ft. ahead and at a height of 60 inches not more than 800 candle power.

Massachusetts	160 feet
Michigan	200 feet
Minnesota	200 feet
Missouri	150 feet
New York	200 feet
Ohio	200 feet
Oregon	200 feet
Pennsylvania	200 feet
Utah	200 feet
Washington	150 feet
West Virginia	200 feet
Wisconsin	200 feet

States regulating spotlights:

Beam not to be directed on highway more than a given distance ahead except when swung 30 degrees or more to right or left.

Arizona	100 feet
Minnesota	100 feet
Utah	100 feet
Wisconsin	50 feet

Beam not to be directed on highway more than a given distance ahead.

Michigan	200 feet and to right of center
Nebraska	30 feet
New Hampshire	30 feet
North Dakota	30 feet
Oregon	75 feet
South Dakota	50 feet

Beam not to be directed more than a given distance ahead when approaching vehicle is in sight.

Connecticut	60 feet and to right of center
Indiana	50 feet
Maryland	30 feet and to right of center
Ohio	50 feet
Vermont	30 feet
Washington	75 feet and 6 feet to right of center

Beam shall be so directed that at a certain distance ahead it shall not be over a certain height above road.

California	42 in. at any distance
Delaware	48 in. at 75 ft. (at left of center)
Massachusetts	24 in. at 30 ft.
Maine	24 in. at 30 ft.
Pennsylvania	42 in. at 75 ft. (and directed to right of center)
West Virginia	42 in. at 75 ft.

Iowa—Beam shall not be directed to left of center of road when meeting car.

Missouri—Beam must not be directed into eyes of approaching driver in country. May be used in cities in emergency.

Wyoming—In case of emergency or in rounding curves, spotlight may be used.

New Jersey—Spotlight permitted only for reading signs.

Apparently, the most general means of obtaining a beam of light from a Mazda lamp is by the use of a parabolic reflector. In order to take a relatively narrow beam from such a device and turn it down toward the road, also spread it out somewhat, a considerable number of auxiliary devices have been developed in the form of cover glasses, etc. Many of the States test these various devices and issue lists of the ones approved for use in the State. In such cases, the maximum candle power of the lamps to be used with each device is specified.

In general, a slightly higher candle power gas-filled, or Mazda C lamp is permitted than vacuum, or Mazda B lamps.

Many of these cover glasses, or lenses, have been approved by all States issuing lists. See Table III.

Besides these there are some 115 other makes which have been approved by some States, but not by others.

There is an increasing tendency in the various States to limit the candle power of the lamps. Massachusetts and Connecticut limit this to 21 c.p. for any device. In fact, the Massachusetts law goes so far as to require the use of 21-c.p. gas-filled lamps. It has been thoroughly demonstrated that a 21-c.p. lamp with a good headlight device gives an excellent driving light.

Many Ford cars are equipped with double filament lamps, the high candle-power filament being used for driving purposes and the low candle-power filament for dimming.

Until recently, no matter what headlight device or lamps were used, it was necessary to accurately focus each lamp, and when a lamp burned out it was necessary to focus the replacing lamp. Many people did not understand how to do this, and many of the headlamps did not have good facilities for doing it. So there has been a demand for a headlamp and a Mazda lamp each made so accurately that it would not be necessary to refocus. Advances in the manufacture of brass lamp parts as well as in Mazda lamps has enabled the production of a unit such as that of the new Willes Saint-Claire car headlamps. The Mazda lamps used in these lights are made on automatic machinery that locates the filament in the bulb with respect to the pins on the base, with far greater accuracy than was previously practicable. This feature, together with the accurate and rigid construction of the headlamps, makes focusing unnecessary. This is a lead which other manufacturers will surely follow, and the result will be marked improvement in the glare reduction. Probably 80 per cent of the glaring headlights in use today are glaring because they are not properly focused.

TABLE III

LIST OF LENSES LEGAL IN ALL STATES WHICH PUBLISH APPROVED LENSES

Candle Power of Lamps

	CALIFORNIA		CONNECTICUT		MAINE	MARYLAND		NEW YORK		PENNSYLVANIA	
	(b)	(c)	(b)	(c)	Not Over 25 Watt	(b)	(c)	(b)	(c)	(b)	(c)
Baush & Lomb	17	20	18	22	“	21	26	Old 17 New 17	15 24	18	25
Full Ray	27	32	23	24	“	26	32	24	24	20	32
Clamert Type A.	17	20	24	24	“	26	24	23	24	14	15
Controlite	21	20	17	22	“	22	28	18	20	17	21
Conophore	Noviol 24 Clear 27	20 32	Noviol 24 Clear 21	24 24	“	Noviol F32 B16 Clear F20 B24	32 21 22 21	Clear 24 Noviol 24	21 24	Noviol B16 F19 Clear B15 F16	21 32 21 27
Dillon	10	12	E 16	21	“	E 23 F 19	26 23	E 24	24	15	21
Holophane	22	25	15	21	“	Old 17 New 20 No. 855 29	22 23 32	22	20	15	21
Legalite	17	20	Old 19 New 24-	24 24	“	26	31	17	20	15 M-111 19	21 22
Liberty	24	26	24	24	“	27	32	17	21	20	32
Macbeth	27	32	24	24	“	25	31	21	24	16	32
McKee	Amber 17	22	L 15	21	“	21	32	Old 17 New 18	21 23	Amber 17 Clear Type 22	21 32
National	17	20	19	24	“	16	21	19	24	19	27
Osgood	27	32	15	21	“	25	32	20	20	15	21
Patterson Lenz	27	28	21	24	“	18	25	21	21	18	27
Raydex	Style B 27	32	B 24	24	“	23	21	Old 22 New 24	20 24	15 B 32	21 32
Sun Ray	22	20	Stand. Type 17	21	“	Standard 26 Other 18	29 25	Standard 23 Other 17	24 20	16	24
Violet Ray	27	27	21	22	“	19	21	24	24	15	23

Electrical Precipitation of Cement Mill Dust

By G. A. Witte

Engineer, Western Precipitation Company, Philadelphia, Pa.

The article on electrical precipitation which appeared in our December issue described a commercial installation designed to recover the fume losses from furnaces treating tin ore and drosses. The present article deals with the precipitation of cement mill dust. While the earlier applications of the Cottrell process in this field were made primarily for the purpose of removing the cause for litigation, resulting from dust nuisance, the operation of the process has been found to be productive of a revenue in the form of potash value recovered in the dust. The extent of this return on the precipitator investment varies from plant to plant because the geological formation of the raw material influences its potash content. In this regard it is of interest to note, however, that in the average plant a precipitator collects dust amounting to 5 per cent of the raw material entering the kilns, this dust contains 3 to 15 per cent water soluble potash, and recoveries as high as 90 per cent of this potash have been obtained on a commercial scale.—Editor.

Numerous articles have discussed the diversity of application of the Cottrell process of electrical precipitation of suspended particles from gases. It has been a source of interest to follow the development of this process as applied to different industrial problems, and the diversity of application has supplied most of the material for the discussions which have appeared in print. As a result, the general reader may not be familiar with the extension of operations within certain specific industries.

The cement industry gives a good example of the extension of the use of the electrical precipitation process for the treatment of dust-laden gases as well as the manner in which the process has become standardized. Although the first commercial unit for the treatment of cement mill gases was not built until 1912, there are now 112 kilns in the United States operating in conjunction with electrical precipitation equipment. Of these about 50 were originally installed primarily for the mitigation of the dust nuisance and partly for the collection of potash. During the war time high prices of potash most of the dust collected from 45 of the 73 kilns then equipped was sold for the potash value contained in the dust. (The remaining 28 kilns were operated upon raw material so low in its potash content that the collected material was not marketable for the potash value therein contained.)

The first work incident to the application of the Cottrell electrical precipitation process to the treatment of cement kiln gases was conducted at the factory of the Riverside Portland Cement Company at Crestmore, near Riverside, California. This work was started in 1910 and the first commercial unit was installed in 1912. The problem at this plant was to clean the gases coming from the rotary cement burning kiln, and the only object which the Riverside Company had for installing the equipment was to overcome the dust nuisance problem which at that time was the cause of intense litigation. It was claimed that the dust which settled over the nearby citrus groves caused damage to the trees and crops for a distance of over five miles from the plant. As these citrus groves were exceedingly valuable, the resulting litigation constituted a matter of vital importance to the factory. This litigation was finally terminated as a result of the installation of the electrical dust control equipment.

Fig. 1. Cottrell Precipitator Installation for Treating Cement Kiln Gas at the Dexter Portland Cement Company, Nazareth, Pa.

As has been repeatedly discussed in technical articles, there are several commercial types of Cottrell precipitators. Two of these types have been applied in the treatment of cement kiln gases, namely, the so-called plate treater and the so-called multiple pipe treater. The first plant built at Riverside, treating the gases from ten kilns, consists of plate type treaters, while a subsequent plant, treating the gases from two additional kilns, is of the multiple pipe type. In the former, the plate electrodes consist of properly reinforced wire mesh, each electrode being 4 ft. wide and 16 ft. long. Four discharge electrodes operate in opposition to each of these collecting electrodes. In the multiple pipe treater the collecting electrode tubes are 12 in. in diameter and 10 ft. long.

Fig. 2. Photograph Taken Before the Installation of Cottrell Precipitators at the Plant of the Riverside Portland Cement Company, California; compare with Fig. 3

In practice the structural material incorporated in the design can be varied considerably. In the plate type of treater, the collecting electrodes can be made of light sheet metal, wire mesh, or corrugated iron, the choice depending upon the local conditions met at the factory. The high-tension or discharge electrodes also vary considerably in practice. They can either be wire or chain, or even more complicated members, depending upon the nature of the gases and the character of the material to be collected In most of the installations built for the precipitation of cement kiln dust, No. 16 soft iron wire is used for the discharge electrodes; and most of the installations built up to the present time are of the multiple pipe type, the collecting electrodes being 12 in. in diameter and 16 ft. long. In the original Riverside installation each kiln was equipped with two separate units of the plate and wire type of construction, each unit containing 52 screen collecting electrodes 1 ft. wide and 16 ft. long and 196 discharge electrodes. At the present time there are 24 plate and wire type treaters in operation, as well as 60 multiple pipe treater units.

The efficiency of the plate type precipitator is slightly lower than that of the pipe precipitator for equivalent ground area. However, the choice of type of treater depends upon local conditions and no general rule can be given by which the choice can be determined. The plate type of treater offers one difficulty not inherent in the later types of multiple pipe structures; namely, the difficulty of properly distributing the gases uniformly throughout and between a large number of plates in a horizontal flue.

The treaters applied to cement kilns are usually under suction and can either be operated on stack draft or fan draft; that is, the treaters are usually installed between the source of draft and the kiln. However, in certain cases conditions make it desirable to supply a source of draft between the kilns and the precipitator. In the original Riverside installation, treaters were built at the top of the existing stacks and each treater was then supplied with a small separate outlet stack. In several recent Cottrell installations in connection with waste-heat boiler plants, the kilns operate on fan draft and these fans deliver the gases to the electrical precipitators. Of the 112 kilns at present equipped with precipitators, 44 operate on natural draft and the remainder on fan draft.

In all installations (except two), 10-kv-a. motor-driven single-phase alternators, operating in conjunction with 10-kv-a. transformers, furnish the power for energizing the electrodes. There are in all 93 sets of such equipment in use at cement plants within the United States.

The set of electrical equipment usually consists of a motor, single-phase alternator, mechanical rectifier driven in synchronism with the alternator, transformer, switch board, and motor starter. In place of the motor-generator set it has been found desirable at times to substitute a synchronous motor in which case power is taken directly from the factory line supplying other electrical equipment in the mill. Such equipment is not as serviceable as the more independent motor-generator outfit if the factory circuit has varying or fluctuating characteristics.

In practice it is usually customary to transform 220 volts to 75,000 volts and then to rectify the high potential current by means of a mechanical rectifier. In this way intermittent direct current is supplied to the precipitator. All of the multiple pipe type precipitators now in operation are energized from a 75,000-volt circuit, as described, while the plate and wire type treaters are energized from a 50,000-volt circuit.

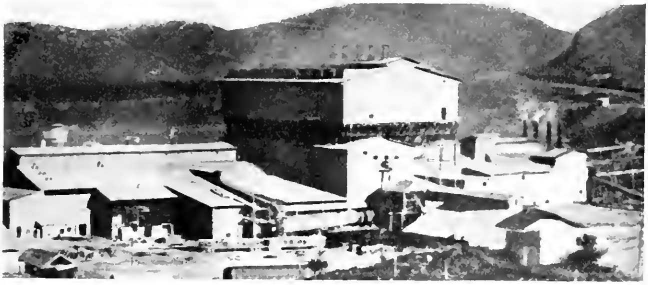

Fig. 3. Photograph of the Riverside Portland Cement Company's Plant Taken After Cottrell Precipitator Equipment was Installed

Fig. 4. The Effectiveness of the Cottrell Precipitator is Graphically Illustrated by This Photograph of a Five Days' Catch of Dust at the Plant Shown in Fig. 3

The material collected from the kiln gases consists of dust and alkali fume, both potash and soda. The dust is the material mechanically blown out of the kiln and, as this is partly burned raw mix, the dust usually has not the same composition as the raw mix entering the kilns. In general it is a little low in its lime content. In coal fired kilns the material is usually more "off mix" than in oil fired kilns due to the admixture of coal ash. However, the composition of the collected material is usually sufficiently close to the composition of the normal raw mix to permit its being returned to the kilns directly, provided it is added at regular intervals and in such places in the system as to insure its becoming thoroughly mixed with the general supply of raw material fed to the kilns. The average amount of material collected at any cement plant is about five per cent of the total raw material fed into the kilns. If the collected dust is returned directly to the kilns it has a value equal to the cost of producing an equivalent amount of new raw material.

In most of the plants during war times the dust was not returned to the kilns for the purpose of producing cement, for in most cases the collected dust had a greater value as potash fertilizer or as a source of high grade potash salts. The potash content of the dust depends upon the amount of potash contained in the raw material and also to the extent to which this potash is driven off or volatilized during the burning operation in the kiln. The United States Department of Agriculture made an extensive investigation of cement by-product potash, and, as is shown in its Bulletin No. 572, the amount of potash driven from the kilns varies considerably between different plants. This variation is dependent in some cases on the nature of the raw material and in others on the manner in which the cement clinker is burned.

The water soluble potash contained in the collected dust also varies considerably at different plants. In addition to the variations due to the potash content in the raw mix and to the heat treatment in the kiln, we here have an additional factor introduced, this being the effect of the ash resulting from the coal used in burning the cement. It has been found that there is a considerable interaction between the potash fumes and the coal ash, and unless special precautions are taken a considerable portion of the potash recombines with the floating coal ash particles in the kiln. However, such recombined potash is slowly soluble and can be extracted from the material by proper treatment.

Depending upon the potash content in the collected dust, which may vary from three to fifteen per cent water soluble potash, calculated as K_2O, the collected material can be used as a lime potash fertilizer, or can be used in mixed fertilizers, or can be leached for the production of high grade potash salts. In connection with the general work incident to the collection and production of by-product potash in cement mills, the Western Precipitation Company has developed methods for treating the dust for the production of high grade salts for fertilizer or chemical purposes. Recoveries as high as 90 per cent of the total potash contained in the dust have been obtained on a commercial scale, the resultant potash salts being potassium chloride of 99 per cent purity.

Where the potash content in the dust is not great enough to warrant treatment, the dust can be returned to the kilns for the production of cement. Thus the Cottrell process is a source of profit and improves mill conditions as far as dust elimination is concerned.

CEMENT PLANTS IN WHICH COTTRELL PRECIPITATORS ARE INSTALLED

United States

Name of Company	Location	Gas cu. ft. per min.	Number of Kilns
Alpha Portland Cement Co.	Cementon, N. Y.	100,000	5
Clinchfield Portland Cement Co	Kingsport, Tenn.	310,000	5
Coplay Cement Mfg. Co	Coplay, Pa.	150,000	3
Dexter Portland Cement Co.	Nazareth, Pa.	100,000	6
Huron Portland Cement Co.	Alpena, Mich	168,000	8
Ironton Portland Cement Co.	Ironton, Ohio	80,000	6
Newaygo Portland Cement Co.	Newaygo, Mich.	155,000	3
Riverside Portland Cement Co.	Riverside, Cal.	720,000	12
Santa Cruz Portland Cement Co.	Davenport, Cal.	250,000	10
Security Cement & Lime Co.	Hagerstown, Md.	226,000	5
Universal Portland Cement Co. No. 7	Duluth, Minn.	160,000	4
Universal Portland Cement Co. No. 4	Buffington, Ind.	525,000	12
Universal Portland Cement Co. No. 6	Buffington, Ind.	455,000	13
Universal Portland Cement Co. No. 5	Universal, Pa	700,000	20
Total U. S., 14 plants		4,099,000	112

Foreign

Name of Company	Location	Gas cu. ft per min.	Remarks
Asano Portland Cement Co.	Tokyo, Japan	45,000	Lime kilns
Asano Portland Cement Co.	Tokyo, Japan	70,000	Rotary cement kilns
Asland Portland Cement Co.	Barcelona, Spain	50,000	
Dalen Portland Cement Co.	Brevik, Norway	137,000	
Patentaktiebolaget Jungners Kalkcement	Slite, Sweden	53,000	
Total foreign, 5 plants		355,000	

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.

Carrier-current Communication

Radiotelephonic Communication Over High Tension Networks. (In French.)
Radioélectricité, Oct., 1921; v. 2, pp. 149-152.
(Short account of "wired wireless" applications in France.)

Cars, Electric

Bus and Car Costs Compared. Andrews, H. L.
Elec. Rwy. Jour., Oct. 29, 1921; v. 58, pp. 769-771.
(Compares figures on motor bus, trolley bus and safety car operation as previously presented by Thirlwall and by Stocks.)

Trackless Trolleys at Work Abroad. Jackson, Walter.
Elec. Rwy. Jour., Nov. 12, 1921; v. 58, pp. 859-863.
(Description of installations in Bradford and Leeds, England, with operating statistics.)

Charts

Use of the Tangent Chart for Solving Transmission Line Problems. Brown, Raymond S.
A.I.E.E. Jour., Nov., 1921; v. 40, pp. 854-864.
(Mathematical article in which the charts to be used are presented and explained.)

Commutation

Commutation on Direct-Current Machines. Shenfer, Claudius.
A.I.E.E. Jour., Nov., 1921; v. 40, pp. 842-850.
(Theoretical.)

Condensers, Steam

Steam-Condensing Plants. Bancel, Paul A.
Mech. Engng., Nov., 1921; v. 43, pp. 711-716, 758.
(Fixed and operating charges in surface-condenser installations, and a new type of high-efficiency condenser.)

Electric Drive—Steel Mills

Electrical Development in Steel Mills. Gerhardt, R. B.
Iron Age, Nov. 3, 1921; v. 108, pp. 1135-1136.
(Statistical report of progress during the past year.)

Electric Meters

Kv-a. Demand Found by Two Synchronized Demand Meters. Fletcher, S. A.
Elec. Wld., Nov. 5, 1921; v. 78, p. 927.
(Short account of method used by the Alabama Power Company.)

Electric Motors, Induction

Physical Conceptions of Induction Motor Operation. Lebovici, J.
A.I.E.E. Jour., Nov., 1921; v. 40, pp. 851-853.

Electric Motors—Starting Devices

New Starting Method for D.C. Motors. Vidmar, Milan. (In German.)
Elek. Zeit., Sept. 29, 1921; v. 42, pp. 1096-1098.
(By lifting certain brushes during the starting period, the current is so reduced as to make a separate starter unnecessary.)

Electric Power

Performance and Cost of the Superpower System. Wellwood, Arthur R.
Power, Nov. 8, 1921; v. 54, pp. 725-730.
(Lengthy statistical article, with graphs.)

Electric Transformers

Abnormal Pressure-Rise in Transformers, and Its Remedy. Torikai, R.
I.E.E. Jour., July, 1921; v. 59, pp. 740-750.
(Theoretical.)

Electrical Machinery—Parallel Operation

Equipment of Smaller Water Power Plants with Induction or Synchronous Generators for Parallel Operation with Large Steam Plants. Kyser, Herbert. (In German.)
Elek. und Masch., Oct. 30, 1921; v. 39, pp. 533-538.
(General discussion bringing out new viewpoints. Serial.)

Fires, Electrical

Classification of "Electric Fires." "Kassandra."
Elec. Wld., Nov. 12, 1921; v. 78, p. 968.
(A suggestion looking toward a more careful use of the term "electric fires.")

Flywheels

Use of Flywheels on Electrical Machinery. Fox, Gordon.
Power Pl. Engng., Nov. 15, 1921; v. 25, pp. 1099-1101.
(Explains advantages for certain applications, and shows how to calculate the weight necessary.)

Inductive Interference

Interference with Communication Circuits.
Elec'n (Lond.), Oct. 21, 1921; v. 87, p. 515.
(From a lecture by L. Truxa, reported in Zeit. des Österr. Ing. und Arch.-Ver., v. 73, p. 149. Results of investigations on Austrian railways.)

Lubrication and Lubricants

Essential Qualities of Oil for Steam Turbine Lubrication. Dahlstrand, J. Y.
Elec. Rev. (Chgo.), Nov. 19, 1921; v. 79, pp. 770-772.
(Short article on general requirements.)

Machine Tools

Control of Machines by Perforated Records. Scheyer, Emanuel.
Am. Mach., Nov. 10, 1921; v. 55, pp. 743-747.
(Illustrated paper on pneumatic and electric control of machine tools, particularly schemes using perforated paper records for automatic control.)

Magnetic Analysis

Magnetic Analysis of Steel. Sanford, R. L.
Am. Mach., Nov. 24, 1921; v. 55, pp. 836-839.
(Illustrated article on apparatus and methods for magnetically testing steel for its physical and mechanical properties.)

Power Factor

Power Factor in Polyphase Circuits. Nyman, A.
Power Pl. Engng., Nov. 1, 1921; v. 25, pp. 1058-1060.
("A review of proposed definitions.")

Solving the Power Factor Problem. Drewry, G. F.
Bul. of Hyd. Pr. Comm. of Ont., July-Aug., 1921; v. 8, pp. 173-178.
(On the relation between rates and power factor, and on methods of measuring the power factor of the customer's load.)

Use of Condensers for the Improvement of Power Factor. Varret, R. (In French.)
Revue Gén. de l'Elec., Oct. 22, 1921; v. 10, pp. 551-560.
(Extensive article on theory and application, together with graphs for use in deciding on the proper reactances and their locations on the line.)

Protective Apparatus

Protection of Transmission Lines with Condensers—Part I. Lewis, George.
Elec. Rev. (Chgo.), Nov. 5, 1921; v. 79, pp. 691-694.
(Illustrated article on the use of static condensers. Serial.)

Radio Stations

Most Powerful Radio Station Opened.
Elec. Wld., Nov. 12, 1921; v. 78, pp. 987-988.
(Short description of the Radio Corporation of America's new high-power plant at Rocky Point, near Port Jefferson, Long Island. See illustration, p. 962.)

Radiodynamics

Transmission of Handwriting by Wireless an Accomplished Fact.
N.E.L.A. Bul., Nov., 1921; v. 8, pp. 666-667.
(Tells of the recent successful test of the Belin system.)

Railroads Electrification

Plan for Electrifying Sections of 11 Railroads.
Rwy. Age, Nov. 5, 1921; v. 71, pp. 881-885.
(Discusses the railroad electrification portion of the Superpower Survey report. Includes diagrams and maps. Further consideration of the subject is in Electric Railway Journal, Nov. 5, 1921, pp. 819-823.)

Rates

Electric Supply: Present Conditions and the Hopkinson Principles. Blaikie, J. R.
I.E.E. Jour., July, 1921; v. 59, pp. 701-713, 719-739.
(An English plan for determining rates for electric energy according as the consumer requires power six days or seven days a week. Also considers the "coal clause.")

Rates for Electricity Compared. Barnes, A. S. L. and Locke, L. S.
Bul. of Hyd. Pr. Comm. of Ont., July-Aug., 1921; v. 8, pp. 161-164.
(Tabulated figures showing comparisons of rates charged by the Hydro-Electric Power Commission of Ontario and 80 other companies in Canada and the U.S.)

Ship Propulsion, Electric

Electric Propulsion of Ships. Than, W. E.
A.I.E.E. Jour., Nov., 1921; v. 40, pp. 823-825.
(A general discussion, with diagrams, of electric propulsion for war and merchant ships. Includes table of statistics on electrically propelled ships.)

Steam Turbines

Some Engineering Uses of Stainless Steel.
Engng. (Lond.), Oct. 28, 1921; v. 112, pp. 592-594.
(Illustrated article on properties of stainless steel, especially as applied to turbine blading. Same, in substance, in *Engr.* (Lond.), Oct. 28, 1921; pp. 447-450.)

Turbine Efficiency Calculations. Christopher, Paul F.
Power Pl. Engng., Nov. 1, 1921; v. 25, pp. 1039-1042.
(Presents a number of charts for use in calculating turbine performance.)

Steel, Alloy

Stainless Steel and Its Properties.
Engr. (Lond.), Nov. 11, 1921; v. 132, pp. 304-305.

Stray Currents

Measurement of Earth Currents. McCollum, Burton.
Elec. Rwy. Jour., Nov. 5, 1921; v. 58, pp. 809-813.
(Description of construction and use of a new instrument for measuring stray earth currents.)

Switches and Switchgear

Standard Pipe and Fittings for Outdoor Switching Frames. Moore, L. J.
Elec. Wld., Nov. 19, 1921; v. 78, pp. 1020-1023.
(Outdoor switch-frame construction as practiced by the San Joaquin Light & Power Corporation.)

Water Turbines—Speed Regulation

Speed Regulation in the Hydraulic Plant. Devendorf, N. L.
Power, Nov. 15, 1921; v. 54, pp. 764-767.
(General conditions that must be met and illustrations of several types of governors.)

NEW BOOKS

Alternating Currents. Ed. 2. Magnusson, Carl Edward. 559 pp., 1921, N. Y., McGraw-Hill Book Company, Inc.

America's Power Resources. Gilbert, Chester G. and Pogue, Joseph E. 326 pp., 1921, N. Y., The Century Company.

Automatic Telephony. Ed. 2. Smith, Arthur Bessey and Campbell, Wilson Lee. 430 pp., 1921, N. Y., McGraw-Hill Book Company, Inc.

Electric Furnace. Pring, J. N. 485 pp., 1921, N. Y., Longmans, Green and Company. (Monographs on industrial chemistry.)

Elements of Specification Writing. Ed. 2, rev. Kirby, Richard Shelton. 153 pp., 1921, N. Y., John Wiley and Sons, Inc.

Heat Treatment of Soft and Medium Steels. Giolitti, Federico. 374 pp., 1921, N. Y., McGraw-Hill Book Company, Inc. (Translated by E. E. Thum and D. G. Vernaci.)

Heating Systems. Ed. 2. Raynes, F. W. 324 pp., 1921, N. Y., Longmans, Green and Company.

Power House Design. Ed. 2. Snell, Sir John F. C. 535 pp., 1921, N. Y., Longmans, Green and Company. (Electrical engineering series.)

Thermodynamics. Emsweiler, J. E. 266 pp., 1921, N. Y., McGraw-Hill Book Company.

Whittaker's Electrical Engineer's Pocket-Book. Ed. 4. Neale, R. E. (Ed.) 671 pp., 1920, N. Y., Sir Isaac Pitman and Sons, Ltd.

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RICHARD HENRY RICE

Manager of the Lynn Works of the General Electric Company from 1918 Until His Death
Which, We Regret to Announce, Occurred on February 10, 1922

IN MEMORIAM

RICHARD HENRY RICE

It is with profound regret that we have to record the death of Mr Richard Rice, the Manager of the Lynn Plant of the General Electric Company. Mr. Rice died suddenly of heart failure while snowshoeing at Bolton on Lake George, N. Y., on February 10th. The tragedy of Mr. Rice's sudden death is much intensified for his relatives and friends alike by virtue of the fact that his last days were days of intense personal sorrow. His son, Richard Drury Rice, had died on February 2nd at the Royal Victoria Hospital in Montreal. Mr. Rice had just performed the sorrowful duty of bringing his son's body from Montreal to Lynn for burial, and it was during that painful interval between the funeral and interment that the father died at camp where he had gone to fortify his strength.

Mr. Richard Rice had lived the useful life of a manly man—had lived the life that fulfills our conception of what an engineer's life should be.

He was born at Rockland, Me., on January 9, 1863. He was the son of Albert Smith and Frances Weston (Baker) Rice and he received his early technical training at the Stevens Institute, Hoboken, N. J. His first wife, Mary Sue Durgin of Concord, N. H., whom he married in 1887, died in 1891 and in 1898 he married Alice Woodman Kimball in New York. He leaves a widow; and leaves two daughters by his first marriage, Mrs. Susan Northrop of Lynn, and Mrs. Phyllis McKnight of Schenectady.

His technical and professional experiences were varied and thorough. His early manhood was spent in working for various railroads and other mechanical and engineering concerns in different parts of the country. In 1903 he became connected with the General Electric Company as a consultant on steam engineering. For years he was in charge of the Steam Turbine Department of the Lynn Works. In 1918 he was appointed Manager of the Lynn plant. As a tribute to his originality it may be stated that he had taken out more than 50 patents He was a member of many technical societies and of many clubs and he found time among his other duties to perform such public service as to be a member of the State Fuel Conservation Committee during the war. He was also a member of both the Boston and Lynn Chambers of Commerce.

Such, in brief, is a memorial notice of Richard Rice—but how unsatisfying to his many, many friends. What we really want to put on record is that we more than respected him—we loved him. Why is it that we have this feeling toward some men and not toward others? We have stated that Mr. Rice had lived a life that fulfilled our conception of what an engineer's life should be and we believe that that is why we loved him.

He was clever—he was capable—he was a man of achievements—he was a conspicuously successful man in his profession—he was the Chief of a large organization of men. And yet Mr. Rice was simple, in the most charming sense of the word. He seemed to respect all men and to look for the good that was in them and all men respected him. He was democratic—he was kind. Whoever heard Richard Rice say a small or an unkind thing about another human being? Who remembers a mean or petty action of his?

He gave more to the world than he attempted to take from the world. Some men take more than they give—he gave more than he took. He gave more in counsel—more in kindness—more in sympathy. He helped everyone he could help—every time he could help them. That is why his associates, companions and friends loved Richard Rice and why they so sincerely mourn his loss.

Thank God, that such men as he get to the top.

J. R. H

THE DEVELOPMENT OF CALIFORNIA'S WATERPOWERS

California has inherited wondrous riches from Nature in her mineral deposits and petroleum fields, but more valuable and enduring than either are her abundant waterpowers. She has a climate that is ideal for intensive agriculture, but her soil is only fertile in part, and some of her most productive lands were once arid wastes and are wholly dependent upon irrigation for their bounteous crops, accomplished in many cases by the employment of large amounts of power for the operation of pumps and dredges.

California has no coal deposits and her industries must rely upon power developed from fuel oil and from the flow of her numerous rivers and their tributaries. California now ranks as the foremost petroleum producing state of the nation; but it is almost a certainty that in the next few years she will experience a serious shortage in this valuable commodity. Consequently the industrial and agricultural hopes of California, and of the other Pacific Coast states as well, are founded on the possibility of developing and utilizing the waterpowers of the section.

Already California has tasted the bitter experience of insufficient power, when in 1920, owing to unprecedented drought, the output of hydroelectric plants was greatly reduced and it was necessary for the Railroad Commission to institute drastic regulations for the distribution of electric energy, petroleum, and natural gas throughout the state. It is no longer necessary to impress upon the people that the future growth and prosperity of the state depends upon the development of hydroelectric energy to anticipate the demands that will be made by the rapid growth in population, which during the past few years has averaged 11 per cent annually, or about three times the normal rate of increase for the country.

The 1920 power shortage was estimated to be 100,000 h.p., or sufficient electric energy to serve 65,000 residences, 1000 factories and irrigate 300,000 acres of land; while the loss to the state in suspended building operations, the development of lands, and the manufacture of goods was figured in hundreds of millions. Although painfully, California has learned her lesson well, and all the larger electric utilities are now working on ten-year programs for developing the waterpowers within their spheres of operation.

The average potential energy that is economically susceptible of development on the streams of California is about four million h.p., only about one-fourth of which has been developed. During the present year an additional 50,000 h.p. will be put to work, and without figuring on the electrification of railways, which is almost certain to come with the rise in cost of fuel oil, it is estimated that the waterpowers of the Golden State will be completely developed in from 10 to 15 years. The power companies are even looking beyond this period, to the development of the Colorado River, where 2,500,000 h.p. is available at an estimated expenditure of $800,000,000. This is a gigantic project and transcends in scope any other plans for power development that have yet been conceived.

For every 5000 h.p. of hydroelectric energy there will be required an expenditure of approximately $2,000,000 to generate, transmit and deliver the energy to the consumer, or a total of over $100,000,000 for the year 1922; and for every dollar spent by the power company in developing this energy, it is conservative to say that $2 will be expended in utilizing it.

All of this development must be financed. Where will the money be procured? It is impossible for an electric public utility to make its plant additions out of earnings as is customary with many industrial corporations, because in the case of the electric utility the capital turnover occurs only once in, say, four of five years, whereas in the industrial it may occur several times during the year. Thus, it is necessary to raise the capital for new hydro developments through bond issues and sale of capital stock.

It has ordinarily been the custom to seek capital from outside and unrelated sources for most industrial expansion; but the power companies of California have instituted the excellent plan of raising the money at home, among the people who will profit directly from its expenditure—making them partners in an enterprise upon whose growth and efficiency their own prosperity is largely dependent. Of course, not all the capital requirements of the power companies are raised in this manner, but a large portion, of which the executives are justly proud, has been secured through this plan.

The electrical fraternity has a direct, almost personal interest in the "biggest job facing California," which is analyzed elsewhere in this issue by A. H. Markwart and E. J. Beckett, both with the Pacific Gas and Electric Company. B. M. E.

Future Power Demand of California

By A. H. Markwart

Director of Engineering, Pacific Gas & Electric Company

In order for an electric utility to be able to provide service to a rapidly growing population it is necessary to anticipate the demand over a period of years, and the only basis on which estimates can be made are the rates of increase in population and power demand over the equivalent period of years immediately passed. Public utility rates are closely regulated and it is economically impossible to develop facilities much in advance of requirements, as the standing charges on the idle equipment will reduce the net revenues unprofitably. Mr. Markwart reviews the probable power requirements of California year by year for the ten-year period 1920-1930, and in ten-year intervals for the following forty years. The economical balance between electric power developed by steam from crude oil and from water power is discussed, bearing in mind the need of reliability of service and the more dependable nature of steam-generated power where water power must be transmitted from remote points over transmission lines that are exposed to the elements.—Editor.

Lord Bacon has truly said that there are three things which make a nation great and prosperous; viz., a fertile soil, busy workshops, and easy conveyances for men and commodities from one place to another. He might have added the fourth, power, for this will produce the other three. We speak of the wealth of our mines, when as a matter of fact our best mine—water power—is above the ground and the prosperity of our state depends upon this and the people to use it.

The soil of California in part is sufficiently fertile, but a larger part and great semi-arid region has been made fertile principally by the industry of our people and the application of water. Thousands of acres, once sandy wastes, would except for the skillful use of our inheritance be lying useless and unproductive. In any irrigation practice, flooding and pumping must go hand in hand in the successful watering of our semi-arid lands. One or the other alone correspondingly raises or lowers the water plane unduly, either of which condition is detrimental, and water power is the compromise.

Our manufactories are growing apace, and the state can no longer be considered as only mining and agricultural. Our factories now furnish employment to large numbers of the population, and manufacturers now produce articles which were heretofore not to be had except from eastern workshops. Recently a representative of an eastern factory selling steel transmission towers asked why local shops could underbid him in tower material, when the unfabricated product had to come from the East. He was surprised to learn that this community could manufacture a tower through all the production steps from the open hearth furnace to the galvanizing process. Many other examples might be cited to show the growth of the state with respect to manufacture.

As time goes on transportation must be accomplished by the use of water power, for it is certain that the use of oil in steam locomotives must be reduced—it must for two reasons, namely, it is inefficient, and oil exhaustion is threatened.

One of the most important questions before the public is the development and utilization of our water resources for the generation of power to meet the demand and to conserve our rapidly diminishing supply of oil. We view with alarm the exhaustion of this unrenewable natural resource; and it becomes more and more apparent as time goes on that the oil must be conserved for those uses for which power is not applicable. But even aside from this prime consideration, the price of oil is now such that it is no longer possible, except over peaks, to produce kilowatt-hours cheaper from oil than from water; and the difference in favor of water is becoming greater.

But until the reliability of hydroelectric plants with the transmission to load centers is as certain as that of steam plants, steam reserve in the metropolitan districts must be maintained, if not at the peak which is preferable, at least in sufficient quantity to insure continuity of preferred service. But normally such plants must be used to supply kilowatts, if this function can be imagined, instead of kilowatt-hours, leaving the production of kilowatt-hours to be determined by consideration of economy based on the proper division of the peak load to be carried on steam. Fuel for this purpose and many others must of necessity be supplied.

The oil situation has occupied the minds of many and is now serious despite the encouragement seen in the recent bringing in of new fields. The production in California in 1918, 1919 and 1920 was 99¾, 102.2 and 105 million barrels respectively. The consumption during 1920 was 113 million barrels, or 8 million barrels in excess of production. Crude oil shipments grew from 150,000 barrels per day in early 1910 to 300,000 barrels per day in June, 1914, during which time the production exceeded shipments and resulted in an increase in gross stocks of from 20 million to 60 million barrels. The price at the wells varied from 50 cents in 1910 to 38 cents in 1914, averaging about 35 cents. After this there was a decline in shipments to 200,000 barrels per day in December, 1915, followed by an advance to 320,000 barrels by the latter part of 1916, then a decline to 250,000 barrels in October, 1918, and at the end of 1920 a rise to 325,000 barrels per day. During the period from the summer of 1914 to the end of 1920, the gross stock diminished to 20 million barrels, with a constantly increasing price of from 38 cents at the well until it reached $1.60.

Fig. 1. Hat Creek Power Plant No. 2, Pacific Gas and Electric Company. This is a Stream Flow Plant, there being no dams or reservoirs in connection with the water supply. Installed capacity 12,500 kv-a.

*The bringing in of the Elk Hill fields saved the situation for 1920, and this together with the Huntington Beach discovery caused production for 1921 to exceed that of 1920; and it is this increased production that will replenish the storage stocks that have been drawn upon since 1915. A demand of from 300,000 to 350,000 barrels per day may be expected at a price to the consumer of around $2 per barrel except during periods of flush production when the price will doubtless be lower. However, over an extended period the tendency may be expected to be upward rather than downward. As to competition in price of steam-electric energy and hydroelectric energy, the following is offered:

On the basis of a capital expenditure of $250 per kilowatt for generation and transmission to load centers, and assuming money at 8 per cent, hydroelectric energy, with steam auxiliary in an amount sufficient to maintain good economy, can be delivered on a 65 per cent load factor at load centers for not to exceed 0.75 cents per kilowatt-hour. Against this there is always the possibility of installing steam plants to burn oil, coal or natural gas, provided the supply of fuel is assured and the price fixed.

Assuming a capital cost of new steam plants at $100 per kilowatt and allowing $50 for cost of partial transmission to load centers, with interest at 8 per cent, operation, maintenance and depreciation at 9¼ per cent on steam plant capital and 4 per cent on transmission capital, to compete, fuels would have to be available at the central stations at approximately the following prices:

Oil, per barrel	$0.95
Coal, per ton	3.10
Natural gas, per thousand cu. ft.	0.16

Any utility entering upon a program to supply large blocks of energy through the agency of steam plants would have to be assured a supply of fuel at a price not subject to wide fluctuation, for a power company could hardly expect to supply power, say to a manufacturing company, on the basis of a price which was subject to the changes in the price of fuel. Such a procedure would not encourage industry, and would lead to complications. On the other hand, the cost of hydroelectric power remains substantially constant owing to the fact that its cost is occasioned to a large extent by the fixed charges.

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*Oil production in 1921 was 114,600,000 bbl. Oil consumption in 1921 was 122,600,000 bbl. Storage stocks at end of 1921 32,000,000 bbl.

Doubtless new oil fields will be brought in from time to time, discoveries will continue, but despite this the handwriting is on the wall. The same situation exists elsewhere in the United States. The oil supply is limited and its use must cease in time, but the evil day may be prolonged by the elimination of many of the uses to which fuel oil is now put.

In contemplating our immediate problem we must not overlook the needs of the future. At this time the keynote in the electric power industry should be "Vision"; and those interested must plan ahead for answering the demands in 1922 and 1925 and beyond. Any power company should plan to meet the needs of its consumers and believe that its prosperity and that of all parts of the territory it serves is dependent upon an ample power supply.

So it is believed that only by the economic development and transmission of additional hydroelectric power to supply electric energy in dependable quantities will the companies of the state be in a position to meet the actual energy demands to come upon them in the future.

Records of the output of the various utility companies of the state are available for a period of years, and owing to a shortage of power during the war, practically all of the public utility companies were interconnected to utilize whatever diversity of supply and demand that existed.

TABLE I

KILOWATT-HOUR OUTPUT FROM HYDRO AND STEAM 1911 TO 1920 INCLUSIVE FOR STATE OF CALIFORNIA

Based on Railroad Commission Records for all Public Utilities Including City of Los Angeles and Other Smaller Municipal Plants

Year	HYDRO		STEAM		TOTAL		Steam in Per Cent of Total
	Millions of Kw-hr.	Per Cent Increase	Millions of Kw-hr.	Per Cent Increase	Millions of Kw-hr.	Per Cent Increase	
1911	1,068.0		334.0		1,402.0		23.8
1912	1,143.0	7.0	455.0	36.2	1,598.0	14.0	28.5
1913	1,263.9	10.6	715.2	57.2	1,979.1	23.8	36.2
1914	1,746.0	38.1	356.3	50.2 Decr.	2,102.3	6.2	16.9
1915	1,816.8	4.1	394.5	10.7	2,211.3	5.2	17.8
1916	1,992.2	9.6	357.1	9.5 Decr.	2,349.3	6.2	15.2
1917	2,142.5	7.5	495.5	38.8	2,638.0	12.3	18.8
1918	2,254.3	5.2	710.7	43.4	2,965.0	12.4	24.0
1919	2,241.3	.6 Decr.	993.6	39.8	3,234.9	9.1	30.7
1920	2,493.0	11.2	1124.6	13.2	3,617.6	11.8	31.1
Total Increased	1,425.0	134.0	790.6	237.0	2,215.6	158.0	
Annual Increased		9.9		14.4		11.1	

Table I shows an increase in nine years as follows:

Hydro

From 1,068,000,000 to 2,493,000,000 kw-hr. or approximately 134 per cent which is 9.9 per cent compounded annually.

Steam

From 334,000,000 to 1,124,600,000 kw-hr. or approximately 237 per cent which is 14.4 per cent compounded annually.

In total

From 1,402,000,000 to 3,617,600,000 kw-hr., or approximately 158 per cent which is 11.1 per cent compounded annually.

It also shows that steam output ranged from a minimum of 15.2 per cent to a maximum of 36.2 per cent of the total output.

Taking the records of the Railroad Commission and the Power Administration, the past growth of the state may be expressed in figures as in Table I

Taking the character of peaks obtaining in the past, the oil at $2 per barrel, a figure of the order of 10 per cent is the proportion of the kilowatt-hours utility companies should carry on steam for economic production and reasonable standby. If a greater percentage is produced, it means that the cost per kilowatt-hour is greater than it would be if produced from additional hydro plants. With this as a criterion, it appears that the entire period, and particularly during the first and last three years, except as oil was cheaper at times, the steam output in per cent of the total was too high for the best economy. Neglecting desired standby provisions, it is obvious that as the price of oil goes up or down, with other conditions remaining the same, the percentage of kilowatt-hours to be carried on steam should be correspondingly decreased or increased.

TABLE II

ANTICIPATED GROWTH OF LOAD 1921 TO 1930 INCLUSIVE FOR STATE OF CALIFORNIA

Based on Past Rate of Growth of 11.1 Per Cent

Year	Millions of Kw-hr.	Average Load in Kilowatts	Increase in Kilowatts	Peak in Kilowatts	Increase in Kilowatts
1920	3,618	412,000		687,000	
1921	4,020	459,000	47,000	765,000	78,000
1922	4,466	510,000	51,000	850,000	85,000
1923	4,961	567,000	57,000	945,000	95,000
1924	5,512	630,000	63,000	1,050,000	105,000
1925	6,124	700,000	70,000	1,167,000	117,000
1926	6,804	777,000	77,000	1,295,000	128,000
1927	7,559	863,000	86,000	1,438,000	143,000
1928	8,398	959,000	96,000	1,598,000	160,000
1929	9,330	1,065,000	106,000	1,775,000	177,000
1930	10,356	1,182,000	117,000	1,970,000	195,000

Taking the increase in output which has prevailed as a basis of judgment, it would seem that any forward looking policy should have in it the idea of providing sufficient facilities to care for at least as much growth in the near future as has obtained in the past, unless there are extenuating circumstances to discount this reasoning; and these facilities must be completed by the time they are necessary for the production of the energy which it is believed will be required. A reasonable anticipation for the next ten years may be expressed in tabular form as in Table II.

Table II shows that if the growth obtains as stated, the output in 1930 should be 10,356,000,000 kw-hr., which is almost three times that of 1920.

In determination of probable peaks the load factor consideration is important. In one company 65 per cent has been attained, but a study indicates that the load factor for the state is somewhat less than this. Table II has been based upon a load factor of 60 per cent and this figure was used in the determinations of the probable future peaks. On this assumption the peak load, which was 687,000 kw. in 1920, will be 1,970,000 kw. in 1930; and the annual increases in peak will range as indicated, from 78,000 for 1921 over 1920, to 195,000 kw. for 1930 over 1929.

Returning to the question of the kilowatt-hours to be furnished from steam on a purely economic basis, no consideration being taken of standby requirements, the best economy in kilowatt-hour cost is to be obtained by carrying approximately 90 per cent of peak loads on hydro plants and 10 per cent on steam plants. Under this condition, the former will produce 98 per cent and the latter 2 per cent of the kilowatt-hours. Additional steam up to 25 per cent of the peak may be carried without material increase in the kilowatt-hour cost, and this will produce 10 per cent of the kilowatt-hours and permit the hydro plants to operate on a load factor of not less than 72 per cent. These general statements are based upon \$2 oil, 8 per cent money, and capital cost of steam and hydro plants of \$100 and \$250 per kw., with annual costs for operation, maintenance, and depreciation of 9¼ and 4 per cent respectively.

The proper amount of additional steam to be installed to meet standby conditions and furnish insurance to service is a matter of debate and should be determined by the character of the load carried and the kind of service which is required and other policy considerations.

One large company, the Pacific Gas & Electric Company, carried a peak load during 1920 of 259,000 kw. This company had a total installation in steam of 120,000 kw., or 46 per cent of the peak for the year, which produced approximately 34 per cent of the kw-hr. for the year. This capacity in steam on the basis of 25 per cent would be sufficient for this particular company until the yearly peak reached at least 480,000 kw.; this allowing for sufficient steam for some standby, and meeting the requirements for economic production.

TABLE III

ANTICIPATED GROWTH OF LOAD 1930 TO 1970 FOR STATE OF CALIFORNIA

Based Upon Assumed Rates of Growth for the Ten-Year Periods

Year	Average Load Kw.	Rate of Increase	Annual Rate	Peak 60 Per Cent Load Factor	Required Steam 25 Per Cent Peak	Required Hydro 90 Per Cent Average
1920	412,000	187	11.1	687,000	172,000	371,000
1930	1,182,000	187	11.1	1,970,000	473,000	1,064,000
1940	2,364,000	100	7.2	3,940,000	985,000	2,128,000
1950	3,546,000	50	4.1	5,910,000	1,478,000	3,191,000
1960	4,433,000	25	2.3	7,388,000	1,847,000	3,990,000
1970	5,054,000	14	1.3	8,423,000	3,106,000	4,549,000

For the purpose of this discussion, assume then that there should be provided for the state as a whole, steam installations to the amount of 25 per cent of the anticipated peaks, this amount being within the limit set for economic production of kw-hr. This would mean that the hydroelectric industry of the state should meet its anticipated peaks by installing plants in the proportion of 75 per cent of hydro and 25 per cent of steam.

Using the same capital costs noted, which are embrasive, that is, steam plants at $100 per kw., and hydroelectric plants at $250 per kw., from diversion to primary substation, and allowing $150 additional to each for distribution costs to consumer, these unit figures are raised to $250 and $400 respectively. Applying these to the increase in peaks which reasonably may be anticipated in the proportion for steam and hydro plants as stated, and not overlooking the fact that there is something like 315,000 kw. of steam now installed which should be sufficient until 1926, there is indicated capital requirements per year for the electric power industry of the state ranging from 31 million dollars in 1921 to 71 million in 1930, or for the ten-year period a total of 470 million dollars, and this does not include the necessary expenditures at consumers premises which will run into figures of like proportions.

It is on some such basis of reasoning that the companies of this state should lay out their programs for the near future if they intend to provide sufficient facilities to satisfy the demands which may come upon them. Such a method of attack will develop a program sound at least for a few years, and if it is found that the rate of growth decreases within the next few years construction programs can be modified to meet the situation.

In this connection mention should be made that the rate of growth of 11.1 per cent which has obtained in the past is about three times as great as the annual rate of growth of population. From this, it might appear that the market for energy would soon reach a point of saturation with a corresponding chance of over-development of facilities. But counter to this, there is always the problem of caring for loads of a character not now provided for, a notable example being power to replace steam for railway operation. Until this class of load is carried it is not likely that the rate of growth will fall to a figure of the order of the rate of growth of population, which is some 3.75 per cent. Furthermore, if industry and agriculture are to be fostered, power must be the forerunner.

But it is proper to assume that the past rate of growth will not continue indefinitely. In Table III is given the anticipated state load by ten-year periods from 1930 to 1970 inclusive, based upon assumed rates of growths for the ten-year periods. The rate of increase for the ten years from 1920 to 1930 is taken as 187 per cent, which is 11.1 per cent compounded as established for the nine-year period preceding 1920. For the four ten-year periods 1930 to 1970 the rate taken is variable, the last rate of 14 per cent being the anticipated rate of growth in population for the ten-year period from 1960 to 1970.

Table III takes account of the economic production of kilowatt-hours, as discussed in the foregoing, that is, 10 per cent to be supplied from fuel by carrying 25 per cent of anticipated peaks on steam plants, and 90 per cent from water by carrying the remaining 75 per cent on hydro plants. This results in a hydro load factor of about 72 per cent. It is believed that streams can be regulated to this extent. The peaks shown in the table represent the total installed capacity of steam and hydro except such additional standby steam installation that may be dictated by a service policy.

This brings up the question of resources. In the foregoing, consideration has been given to the demand for power. Some comment as to the supply is equally important. The potentialities of the state are great, but not sufficient to meet our needs for an indefinite period.

The most comprehensive estimate of the water power resources of the United States is that which was made by the United States Geological Survey in 1908 for the National Conservation Commission. The Survey's original estimate was revised in 1912 by the Commissioner of Corporations in his report on "Water Power Development in the United States." The potential water power of the State of California as revised is given as 7,818,000 horse power as an assumed maximum, and as 3,424,000 horse power as a minimum. These estimates are based upon utilization of 90 per cent of the stream flow in that length of stream which is considered susceptible to development, and upon a plant efficiency of 75 per cent. The minimum estimate represents the amount of power that could be developed from the use of the average annual minimum stream flow "for the lowest two consecutive seven-day periods of each year." The maximum represents the amount that could be developed from the use of the average maximum continuous stream flow available for six months during the year. Estimates for potential horse power thus prepared are in the nature of approximations, and no account is taken of storage to effect stream regulation which is so essential on most California streams to develop them to their practicable ultimate. With storage the continuous horse power will probably lay between the two estimates with a tendency to approach the higher value, but what it will actually be will be difficult to determine without closer knowledge of the storage possibilities and the actual developments on given streams. However, a figure of 5,500,000 horse power may be taken as safe and conservative; expressed in electrical units this is 4,125,000 kilowatts. If this is assumed to be continuous and if the rate of growth obtains as shown in Table III, with steam capacity in proper proportion, it should be sufficient to answer the demand for power for many years, as indicated by the last column of Table III. It must be recognized that this study is speculative, as it is based upon assumptions which may never be realized. But at any rate it seems reasonable for the next five to ten years; and with respect to our needs for this period we need only to contemplate the situation with regard to the fuel problem to realize that the timely development of our water power is vitally essential to our prosperity.

Obviously, the construction programs of the power companies of California should call for the expenditure of many million dollars within the next ten years to develop, transmit and distribute hydroelectric power if they are to be in position to meet the demands which will surely come upon them. Owing to the fact that there was no reserve whatever in 1920, even after the curtailment of the use of energy by the power administration, no deferring of construction is permissible even if the anticipations for the few years immediately thereafter may not be fully realized, for emphasis should be given the fact that the annual rate of past growth to an average of 11.1 per cent passed from a minimum of 5.2 per cent to a maximum of 23.8 per cent. Such a range in the rate of growth is quite likely of recurrence.

To meet the anticipated growth the power companies of the state have ambitious plans for the future, and several large hydroelectric developments are under way or in contemplation. Most of the potential energy of the streams of California has been rendered available by reason of the advances in the science of transmission engineering which has increased the economic radius of transmission so that now it may be said that practically all of our larger water power opportunities are favorably situated for development.

Financing the Biggest Job Facing California

By E. J. Beckett

Assistant Treasurer, Pacific Gas & Electric Co.

In the preceding article Mr. Markwart outlines the probable future power requirements of California. His estimates are conservative and in all probability will be realized, which means that in a relatively few years all the State's water powers will have been developed. Enormous amounts of new capital will be required by the power companies for this work, and one of the greatest problems that will have to be solved will be the means of obtaining the necessary money. Security of principal and a fair rate of return are essential in order to attract capital, and in these respects the utility companies of California are unique. The State has gone further in the support of its public utilities than any other state in the Union, and its Railroad Commission probably accepts a larger amount of responsibility for the financial standing of these companies than any similar commission. Mr. Beckett is enthusiastic over the prospects of obtaining the hundreds of millions of dollars that will be expended for water power development during the next decade.—Editor.

The task of finding funds for the development of the immense water power resources of the Western States is not one which concerns only a few power company executives. It is, directly or indirectly, a matter of personal moment to every resident of this western territory and it is of direct and immediate interest to all those engaged in the manufacture and sale of electrical apparatus and appliances throughout the country.

When it is stated that a billion dollars will be expended in hydroelectric construction in the states west of the Rocky Mountains in the ensuing ten years, of which $500,000,000 is to be spent in California alone, the figures are so large that the mind can hardly grasp their real significance. The statement, however, that of the amount to be expended by California power companies (to select only a few of the items of cost) $42,000,000 will be spent for power plant equipment, $37,500,000 for line transformers and devices, $34,500,000 for substation equipment, and over $21,000,000 for meters, may give a better perspective of the vital significance of this program to the electrical industry; and these figures of course are only a fraction of the increased business which will inevitably follow the growth of industry and population naturally consequent upon the creation of large additional quantities of hydroelectric energy.

Large-scale production is really the basic factor which has made possible the high standard of living to which this country has become accustomed. This standardized production in immense volume is founded upon the twin pillars of a wealth of raw material and an abundance of cheap mechanical power We still have the raw materials, but we cannot hope to continue successfully to compete with the low wages and long hours of labor prevalent in other countries of the world unless cheap power in unlimited quantities is assured. It is no mere figure of speech, therefore, to state that the utilization of the inexhaustible energy now running to waste in the streams of the country is a matter of national concern.

The program of California's power companies, anticipating the expenditure of one-half billion dollars by the close of 1930 in the intensive development of her splendid hydroelectric resources, is the most comprehensive of any state in the Union. Will it be possible to secure at reasonable cost the immense sums essential to a vigorous and successful prosecution of the work? The accomplishments of the past, the necessity of the present, and the promise of the future prompt an emphatic affirmative. Not only will the work be done, but California and the West cannot afford to leave it undone.

California's Need for Power

California ranks second among the states of the Union in potential water power development. Its water power resources are estimated to be greater than the potential power of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia and Florida combined. This list includes all states bordering on the Atlantic. The actual utilization of the state's hydroelectric resources is, however, still comparatively in its beginnings. Twenty-one years ago 30,000 h.p. had been developed. In 1920 the installed capacity of the hydro plants was just about one million horse power; and it is anticipated that by 1930 an additional million and a half horse power will have been brought into use. The state is already considerably the largest producer of hydroelectric energy in the country, the output in the first ten months of 1921 aggregating 2,765,257,000 kw-hr., or substantially in excess of the combined output of the states of New York and Washington, which stand next on the list. The following table compiled from a recent report of the United States Geological Survey shows the figures of the first four states, which produced practically one-half of the total output of the entire country, California's production alone aggregating 22.3 per cent of the total:

Kilowatt-hours Produced by Water Power
Ten Months to October 31, 1921

	Kw-Hr.
California	2,765,257,000
New York	1,745,527,000
Washington	929,817,000
South Carolina	586,050,000
Total 4 states	6,026,651,000
All other states	6,392,596,000
Total United States	12,419,247,000

It is no exaggeration to say that the tremendously increased output of electric energy has been largely responsible for the state's rapid growth in the past two decades. In the census period of 1910-1920 California advanced from twelfth to eighth position among the states in point of population, the actual addition of 1,049,312 persons being exceeded by a comparatively small margin by only two states, New York and Pennsylvania; and in ratio of growth California advanced more than three times as rapidly as either of the other two.

An impression still prevails among some Easterners that California is largely a health and pleasure resort, dependent upon her climate for a livelihood. But—without denying the salubrity of her climate—it must be said that the state's prosperity rests upon a deeper foundation. California already ranks eighth among the forty-nine states in the value of its manufactured products and fifth in the variety of its industries. It is fifth in banking resources, and fourth in the value and volume of farm products, being exceeded in the latter respect in 1920 only by Texas, Iowa and Illinois, in the order named. In the last ten years the state's crop value has increased from $146,500,000 to $587,500,000, largely through the irrigation of previously arid areas, which requires a substantial utilization of energy for pumping. Already the consumption of electricity on California farms is greater than that on all the farms of all the remainder of the United States combined; and it is estimated that approximately 2,000,000 additional acres of land will be brought under irrigation as a result of the increased energy to be made available in the next ten years. California leads all states in the output of gold, its total production of minerals in 1920 being valued at $242,142,000. And in these various branches of human activity—in manufacture, in agriculture, and in mining—cheap power backed by the aggressive industry of her people is the real key to the state's prosperity.

California has no adequate supply of coal. Alternating with Oklahoma she is the largest producer of fuel oil in the country; but the 1920 production of 105,700,000 bbls., the largest in the state's history was over 4,000,000 bbls. short of the actual consumption within the state's boundaries last year. The fuel oil supply is being exhausted and its use should be superseded as far as practicable by the utilization of the almost unlimited water power resources. In this connection, electrification of the railroads of the state is already receiving serious consideration.

About two-thirds of the state's output of electric energy is now produced by water power, and the remaining one-third by fuel, chiefly oil, with natural gas as an auxiliary. The diminishing supply and inevitable ultimate exhaustion of the latter agencies render the development of more hydroelectric energy not only desirable, but imperative. The demand for the energy which the great power companies of the west are now creating is assured beyond the peradventure of a doubt. The only question which can possibly arise is as to the ability of the companies to raise the necessary funds.

METHODS OF FINANCING

Broadly speaking, there are only two methods by which capital funds may be secured by public utility companies, namely, from surplus earnings and from the sale of securities.

Earnings

It is impossible to realize from the earnings of electric utilities a sufficient sum to finance more than a small proportion of a construction program of the character here involved. I am, however, induced to say a few words in this connection as the result of the experience of the Pacific Gas and Electric Company in conducting a campaign for the direct sale of preferred stock to consumers, the question having been asked a good many times by apparently intelligent and well informed business men, as to why it was necessary to sell stock instead of making improvements and extensions out of earnings.

This means of providing for extensions is possible in the case of a large number of industries which are able to handle a considerable volume of business with a comparatively small investment, many concerns being able to turn over their invested capital several times a year. In the public utility business, however, the proportion of invested capital required to produce a given volume of earnings is perhaps greater than in any other line of industry. It is a general rule that even the most conservatively financed hydroelectric companies are compelled to invest $500 in plants and transmission and distribution systems, etc., to yield a gross revenue of about $100 per annum. And in many cases the ratio of capital to income is higher than this.

It is true, however, that every well-managed utility corporation does plow back into its properties a substantial portion of its earnings each year through the medium of sinking fund payments, and depreciation and other reserves; but the bulk of construction funds must necessarily be obtained from the sale of securities.

Sale of Securities

Investors in corporate securities are of two classes:

(a) Stockholders who purchase an actual share in the company's business and become partners in the undertaking.

(b) Bondholders who loan money to the company for a definite period of time, at a fixed rate of interest, their principal and income being secured by mortgage upon the company's property.

A corporation with a well-balanced financial structure usually issues both bonds and stock—bonds, because on account of the security of the offering, money may be borrowed at comparatively low rates of interest; and stock, because the greater the amount of capital secured from the sale of this class of security, the larger will be the equity behind the bonds and hence the lower will be the interest rate which must be paid to secure funds from the sale of bonds. It seems pretty generally agreed that the most economical method of securing capital for the conduct of a growing concern is to obtain from 55 per cent to 65 per cent of the necessary funds from the sale of bonds and the remainder through stock sales.

Limitations Upon Issuance of Bonds

While the issuance of bonds secured by mortgage upon physical properties is undoubtedly the cheapest method of securing funds, there are obvious limitations upon the issuance of this class of securities and, generally speaking, the greater the restrictions placed upon the amount of bonds which may be issued, the better the security is regarded by investors and consequently the lower is the interest rate which has to be paid by the issuing corporation. Practically all the larger California hydroelectric companies have now adopted what is known as "open-end" or unlimited mortgages as being the most desirable and economical means of securing borrowed capital. The authorized amount of bonds which may be issued under these mortgages is made sufficiently large to cover the requirments of a number of years, and bonds are issuable from time to time in series bearing such rates of interest and dates of maturity as may be agreed upon at the time of issuance. This form of mortgage is sufficiently elastic to cover changing financial conditions over a period of years, and has been adopted, substantially in similar form, by the Pacific Gas & Electric Company, Great Western Power Company, San Joaquin Light and Power Corporation, California-Oregon Power Company and other utilities. Under the terms of the mortgage the par value of bonds issued is limited to 75 per cent, or in some cases to 80 per cent, of the costs of additions, betterments and extensions to the company's properties, with the further restriction that additional bonds may be issued under the mortgage only when the total annual interest charges on all bonds outstanding are earned at least 1¾ times. Bonds are usually sold at a discount, that is, for less cash than their face value; and it is therefore evident that considerably less than 75 per cent of the funds required for the company's expanding business can be obtained from bonds, the remainder being necessarily obtained from junior securities.

Issuance of Preferred Stock

Practically all of the California utilities have outstanding preferred stock issues which have priority, both as to principal and dividends, over the common stock; in other words, it is necessary to pay preferred stock dividends in full before a dollar of dividends can be paid to the common stockholders and in the event of liquidation the preferred stockholder receives the full par value of his stock together (in the case of cumulative preferred stock) with accumulated dividends before any disbursement whatever is made to common stockholders. As an additional safeguard for the preferred stockholder, some of the utilities have made their preferred stock non-assessable by the company. All common stock is assessable. These advantages naturally make it possible to obtain funds through the sale of preferred stock at a lower cost than from the sale of common stock, but in order to create a real equity for the preferred stockholder and in order to supply the additional funds necessitated by reason of preferred stock being sold for less than its par value, it is essential to sell common stock.

Issuance of Commom Stock

From what has been said it is apparent that the issuance and sale of common stock is a desirable feature of any comprehensive financial plan extending over a period of years. The common stockholder is the shock-absorber in a corporation. He assumes the real risks of the enterprise. When earnings fall below normal the common stockholder is the first to feel the effects of this condition, since the bondholder and the preferred stockholder are assured of their dividends before any disbursement is made to the common stockholder. On the other hand, his opportunities for profit are commensurately greater than in the case of the holders of senior securities for the reason that the amount of dividends which may be paid him is not limited to a certain annual rate, as in the case of the holders of the other two classes of securities mentioned, but is limited only by the profits of the business and the policy of the management.

WHY THE $500,000,000 WILL BE FORTHCOMING

This brief discussion of some of the elementary principles of corporate financing is intended merely as a very general outline of the machinery by which new capital may be secured. In order, however, to obtain the vast sums necessary to develop the state's hydroelectric resources it is essential that California power companies must be able, in competition with the billions of dollars of corporate issues placed every year upon the money markets of the country, to offer special inducements to investors to attract the requisite funds. Fortunately for this state, the utilities are in a position to offer securities of sufficient attractiveness to insure their being able to obtain the desired new capital

Capital invested in progressive and well-managed California power companies is usually well secured. No new securities can be issued except under authority of the State Railroad Commission, which is recognized throughout the country as an impartial and well-balanced regulatory body. Every dollar of new capital received is invested in plants and properties, subject to the supervision of the Commission.

Public utility issues are generally recognized as the most stable class of investments in the market today, with the possible exception of Government, State and Municipal bonds which yield a substantially smaller return to the investor. It is a fundamental feature of California electric utility operation that the gross earnings of the various companies continue to grow in spite of the periodic business depressions which sweep the country and which frequently have so adverse an effect upon a great many industrial issues. The war and readjustment period tested to the utmost the stability of public utilities. They continued to operate and give adequate service to the public in spite of tremendously increased costs and comparative immobility of rates, and emerged from the ordeal stronger than ever before. A splendid indorsement of the strength of electric company securities is contained in a list of utility bonds in the United States in default of interest which was published a few weeks ago by the *Wall Street Journal*. The list contains only four small electric companies (other than those corporations operating street railroads) operating in the United States which are in default of interest payments, the entire amount of bonds in default aggregating only $7,419,000; and of this total $6,419,000 constituted part of the funded debt of a gas and electric company serving a portion of Tennessee, leaving but $1,000,000 of electric power company bonds in default in the remaining 48 states. When one considers that over two and a quarter billions of dollars of electric company securities are in the hands of investors, it will be realized that this record is truly astonishing and cannot be even approached by any other class of securities, excepting of course Government bonds. Not a single California electric company appears in the entire list.

Hydroelectric securities, as a class, yield a comparatively liberal return. The industry is still in the development stage, and because of this fact, and of the large amounts of new capital required annually in enterprises of this character, interest and dividend rates in the past have been high when considered in conjunction with the relative safety of the investment.

But it is not merely that the securities of these hydroelectric corporations possess the essential features of safety of principal and stability of earning power which every investor desires or that they yield the maximum return commensurate with these requisites. The real strength of these securities lies in the fact that the power companies give an indispensable service in a progressive and rapidly growing section of the country; that they are generally conceded to be largely responsible for the tremendous strides made in the development of the state which they serve; that there is an almost unlimited field for their future expansion; and that the inhabitants of California are fully awake to the necessity of producing more and still more power to keep the wheels of progress moving.

One of the most encouraging things about the financing of these power companies is the unqualified support of the local investing public. Californians believe in their hydroelectric utilities, and are not afraid to back their judgment with their money. Almost eight years ago, the Pacific Gas and Electric Company, under the leadership of A. F. Hockenbeamer, Second Vice President and Treasurer, initiated the policy of local partnership, or direct sale of stock to consumers and residents of the territory served. The plan was an instant success, and has since been adopted by a multitude of utilities throughout the country. The five largest power companies in California now have a combined stockholder's list of over 48,000, of whom almost 42,000, or approximately 88 per cent, reside in the state. These five companies had slightly over $150,000,000 face value of stock outstanding in the hands of the public at December 1, 1921, of which upwards of $108,500,000 was owned by local investors. The Pacific Gas and Electric Company, the pioneer in this movement, still leads all the public service corporations of the country in the amount of stock sold to local investors, and now has 18,800 stockholders, of whom approximately 15,000 are residents of California. The Southern California Edison Company has also been very successful in the distribution of its stock among the residents of its territory and now has over 24,900 names on its stockholders' list, including over 22,400 residents of California. The San Joaquin Light & Power Corporation, Great Western Power Company, and San Diego Consolidated Gas & Electric Company have also sold substantial amounts of their stock to their consumers.

This widespread distribution of ownership among the utilities' consumers is significant not only as an assurance of the confidence and good-will of the local public, but also as indicating to some degree the capacity and willingness of California residents to absorb hydroelectric securities. These figures, of course, apply only to actual participation in ownership through the purchase of stock. The same condition is found when we examine the ownership of bonds of the California power companies. No less than 30,000 of the 50,000 holders of all classes of securities of the Pacific Gas and Electric Company, for example, reside in California, and upwards of $120,000,000 par value of stocks and bonds of this one Company, or approximately 65 per cent of its total outstanding capitalization, is held within the boundaries of the state.

Some idea of the potential power of the local public to absorb investment issues may be realized from the statement that there are in California over 1,600,000 depositors in savings banks, or approximately one-half of the entire population. In the United States, as a whole, only one person in ten is a depositor in a savings bank.

It is apparent, therefore, from a realization of the dependence of California upon electricity in every branch of industry, from the unparalleled increase in the utilization of hydroelectric energy in the past quarter of a century, and the insistent demand for still more power, and from the steadily improving financial position of the power companies and the readiness with which large issues of their securities have been absorbed in the past few years, that no fears need be entertained as to the ability of these companies to find the funds necessary to finance the tremendous task which they have undertaken.

Undoubtedly a large proportion of the necessary funds will be obtained within the state itself. It is not intended, however, to suggest that it will be necessary, or even desirable, to secure from local investors the entire amount of requisite capital for the financing of the power program. The securities of California hydroelectric corporations are held throughout the investment world, and are assured of a ready market anywhere in the United States. Large amounts of investment capital will undoubtedly continue to be attracted from all parts of the country, as has been the case in the past, by the comparatively high yield and unusually bright prospects of these corporations. It is, however, incontrovertible that as California grows in wealth and population, more and more of the securities of the local power corporations will be absorbed by her people, and this progressive "home partnership" is an asset not lightly to be valued by investors, wherever situated, in considering the desirability of the offerings of these companies.

In conclusion, it may not be amiss to suggest that it behooves every member of the electrical fraternity, as a matter of self-interest, to give his unqualified support to the power companies in their undertaking. The utilization of electric current is the basis upon which is built up the entire massive fabric of the electrical industry. It is gratifying to observe an increasing realization of the interdependence of the various branches of the industry, and the evidences of a growing spirit of helpful co-operation among its members. Illustrative of this attitude may be mentioned the work of the San Francisco *Electrical Development League*, which recently organized a campaign to aid the local power companies in the sale of stock. The actual results of this campaign are not yet available, although it is understood that so far they have been very satisfactory. But even if not a single share of stock had been sold, the campaign would still have been well worth while considering merely the educational value of the very interesting literature which was disseminated by the League concerning the construction program of the hydroelectric companies and its intimate relationship with the present and future prosperity of the West.

Synchronous Operation of Alternators Through Capacitance

SYNCHRONIZING EFFECT OF TWO PARALLEL TRANSMISSION LINES

By T. Nishi

Imperial University of Tokyo, Tokyo, Japan

The author of this article discusses a phenomenon which has been observed on a number of power systems but whose true import has not been clearly understood, namely, the mutual synchronizing action of two circuits which are in close parallel. The theory of this action is clearly explained in the article and the conclusion is drawn that of two arrangements of two transmission circuits in physical parallel, that one is the better in which the conductors of the same phase do not occupy the same relative position on the towers, but rather diametrically opposite positions. This conclusion is borne out by experimental results on two systems.—Editor.

Introduction

As far as the author knows, the synchronous effect of two parallel transmission lines was first noticed in Japan on the system of the Inawashiro Hydro-electric Company. The transmission line consists of two 110,000-volt circuits carried by the same towers.

The first observation was made on December 3, 1914, when two generators were independently connected through transformers to each of the two circuits, and were running at no load. It was observed that when the line voltage was raised to about 73,000 volts, and the frequencies of the two systems approached each other, the pointer of the synchroscope showed a tendency to slow down when passing the in-phase point and to swing rapidly past the 180-deg. out-of-phase position. When the frequencies became nearly equal, the pointer would stop near the in-phase position and the operator could quite easily throw in the paralleling switch.

Afterward, another test was carried out by the engineers of the company. In this case, the two generators were synchronized at the substation near Tokyo. When the two generators were running, each connected to one of two circuits as in the foregoing test, the synchroscope at the substation would come to a stop with the pointer near the in-phase position, so that the operator could close the paralleling switch with ease. The effect was not so apparent, however, when the generators were carrying some load.

Another example of the phenomenon was observed in the transmission system of the Southern Sierras Power Company in California, and a report of it was presented by

R. H. Halpenny at the Pacific Coast Convention of the A.I.E.E.* An abstract of his report follows:

"Circuit No. 1 of the tower line of the Southern Sierras Power Company was in use at the time for transmission at 90,000 volts between the generating plants on Bishop Creek and the San Bernardino substation.

"Circuit No. 2 of the tower line was to be used temporarily as an emergency connection between a 10,000-kv-a. generating plant at the northern end of the line and a 55,000-volt transmission line leaving the San Bernardino substation, the reason for this connection being that one of the three-phase, 88,000/55,000-volt, 4,000-kv-a. transformers at the San Bernardino station was out of service and there was insufficient transformer capacity remaining to carry the 55,000-volt load at the station.

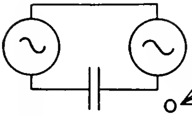

Fig. 1. (Left) Series Operation of Two Single-phase Alternators with Condensive Load

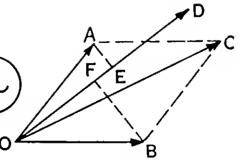

Fig. 2. (Right) Diagram Showing the Relation Between E.M.F's. and Currents in the Series Operation of Alternators

"Circuit No. 2 was energized by the hydroelectric plant and was to be synchronized at the San Bernardino substation with circuit No. 1 through the three-phase transformers mentioned. As the frequency of the incoming plant approached that of the 60-cycle system, it was observed that the pointer of the synchroscope showed a tendency to slow down when passing the 180-deg. out-of-phase position and to swing rapidly past the point denoting phase coincidence. When the frequencies of the two systems became equal, the instrument came to a stop with the pointer 180 deg. away from the in-phase position. It was noticed that the frequency of the incoming circuit remained fixed as though tied in with the remainder of the system.

"After investigation and communication with the incoming hydroelectric plant, the San Bernardino operator came to the conclusion that the phenomenon was due to the mutual action of the two tower-line circuits. He therefore instructed the hydroelectric plant operator to change the speed; after which he succeeded in throwing in the paralleling switch, with a rapidly swinging synchroscope pointer, when the plant again approached the frequency of the system."

Theory

When two alternators are connected in series and are feeding current to a condensive load, as shown in Fig. 1, they can be operated in synchronism with each other, though synchronous running is impossible when the load is inductive.

In the vector diagram in Fig 2, let OA and OB be respectively the electromotive force of the alternators A and B which are connected in series as in Fig. 1; then the resultant electromotive force acting in the whole circuit is OC. When the load is condensive, the current leads the electromotive force OC, such as shown by OD in Fig. 2, and the synchronous operation is in stable equilibrium. The reason is as follows:

Suppose that the two alternators are exactly similar and have the same excitation, and also their prime movers are in the same condition, then the loads carried by A and B are respectively proportional to $OD \times OE$ (AE is perpendicular to OD) and $OD \times OF$ (BF is perpendicular to OD). Since OE is greater than OF in this case, where A happens to lead B, the load carried by A is greater than that carried by B. Therefore, A tends to slow down while B tends to speed up, that is, the two alternators have the tendency to come into phase with each other. Similarly, if B happens to lead A at any instant, B tends to slow down while A tends to speed up, until they are exactly in phase with each other. In other words, the two alternators can be operated synchronously with stable equilibrium. If the alternators are not excited exactly the same amount or their prime movers have different output, stable synchronous operation is still possible provided the differences in electromotive force or in output are not excessive. It is obvious that, in such cases, the electromotive forces of the two alternators are not exactly in phase with each other, but the operation is still stable with a definite angle of phase difference between the electromotive forces. This fact may be readily proved by a similar vector diagram. It is also obvious that the phase relation can be controlled by the governors of the prime movers in all

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* *Electrical World*, February 21, 1920, p. 438.

cases, as is usually the case with alternators in parallel operation.

Though the preceding discussion is based on single-phase alternators, it also applies to polyphase alternators when they are loaded symmetrically. For example, two three-phase alternators are connected as shown in Fig. 3, and their operation is evidently stable. Hence, if a synchroscope is connected to the alternators in an ordinary manner, the pointer of the instrument will stop at a certain position nearly diametrically opposite to the ordinary synchronism point, for the phase relation of the two machines is just opposite to the case of parallel operation. And the position of the pointer may be changed at will by adjusting the governors of the prime movers, so long as synchronism is not destroyed.

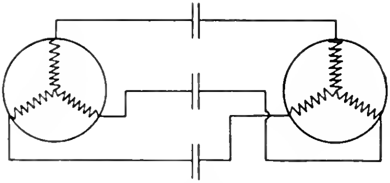


Fig. 3. Series Operation of Two Three-phase Alternators with Condensive Load

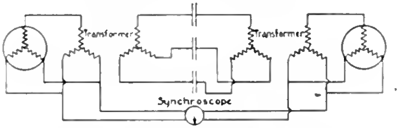


Fig. 4. Series Operation of Two Three-Phase Alternators Connected with Condensive Load Through Transformers

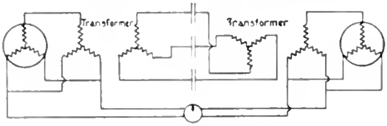


Fig. 5. The Same as Fig. 4, Except Transformer Connection on One Side is Reversed

Next suppose the case in which transformers are inserted between the load and each alternator as shown in Fig. 4. In this case, the result is obviously the same as has been described.

If the connections of the transformer bank on one side are changed as shown in Fig. 5, what will happen? Obviously, the phase relation of one alternator to the other becomes just opposite to the preceding case, and the other factors are unchanged. Hence, if a synchroscope be connected in an ordinary manner, the pointer will stop at or about the in-phase position because, in this case, the two machines are in the same phase relation as when they are operated in parallel in ordinary cases.

When two alternators are operated in such a manner that each is connected to one circuit of a long transmission line which consists of two independent circuits suspended on the same tower, the conditions may be electrically represented by the diagram in Fig. 6, where the distributed capacitance between the conductors of the two circuits is represented by a concentrated capacitance C and the capacitances to ground and between phases are not shown because of minor importance here.

First suppose that

$$C_{11}=C_{12}=C_{13}=C_{21}=C_{22}=C_{23}=C_{31}=C_{32}=C_{33}$$

then the interaction between the two circuits will be zero, and the two machines will run independently of each other; because the effect on any phase of one circuit from each phase of the other circuit will be cancelled out at any moment.

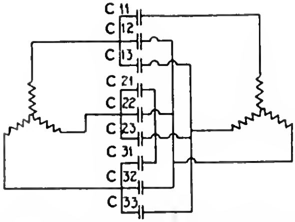


Fig. 6. Diagram Showing Two Alternators Feeding Each of Two Circuits on the Same Tower Line

Next suppose the case in which C_{11}, C_{22}, and C_{33} are greater than the others, i.e., for simplicity, let

$$C_{11}=C_{22}=C_{33}=C_0$$

$$C_{12}=C_{13}=C_{21}=C_{23}=C_{31}=C_{32}=C \text{ and } C_0>C$$

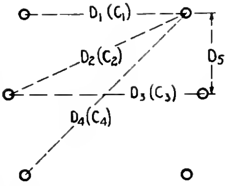
i.e., $C_0-C'=C$

or $C_0=C+C'$

then the conditions may be represented by the diagram in Fig. 8 where we suppose tertiary windings in the transformers which are connected to the capacitances C' while the secondary windings are connected to the capacitances C. In this case, there is evidently no interaction through the secondary windings but we have an interaction through the tertiary windings. The conditions are, therefore, the same as in Fig. 4. Hence, if C' is sufficiently large, the two alternators will tend to synchronize with each other and the pointer of the synchroscope will stop near the diametrically opposite point to the in-phase position; in other words, the phase difference between the two machines is nearly 180 deg.

Now suppose the third case in which C_0 is less than C, and let $C_0 = C - C''$.

A little consideration will show that, in this case, the conditions may be represented electrically by the diagram in Fig. 9 where the tertiary windings of the transformers on the right hand side are connected with opposite polarity to the secondary windings. It goes without saying that this system is quite equivalent to the case represented by Fig. 5. Hence, if C'' is sufficiently large, the machines will tend to synchronize with each other and the pointer of the synchroscope will stop at a point near the in-phase position.



Dia. of Conductors - 2r = 0.51"	
D_1 = 20 ft.	C_1 = .006525 μF/mile
D_2 = 24.2 ft.	C_2 = .00635 μF/mile
D_3 = 24 ft.	C_3 = 00636 μF/mile
D_4 = 28.3 ft.	C_4 = 00621 μF/mile
D_5 = 10 ft.	

Fig. 7. The Arrangement of the Conductors on the Tower in the Inawashiro System

From this discussion, it is clear that the Inawashiro transmission system corresponds to the case represented by Fig. 9, and the Southern Sierras Power system to the case represented by Fig. 8.

The transmission line of the Inawashiro Hydroelectric Company consists of two circuits, each arranged in nearly a vertical plane on each side of the tower as shown in Fig. 7. There are three sectionalizing stations dividing the line into four sections, and transpositions of the conductors are made in each circuit at each of these stations. The relative position of conductors in each section and the length of each section are shown in Fig. 11 and the capacitances are calculated as follows:*

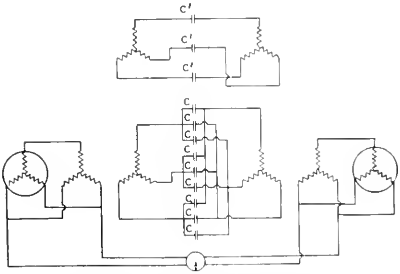


Fig. 8. Diagram, Equivalent of Fig. 6, When Two Alternators Feed Each of Two Circuits on the Same Tower Line and When $C_0 > C$

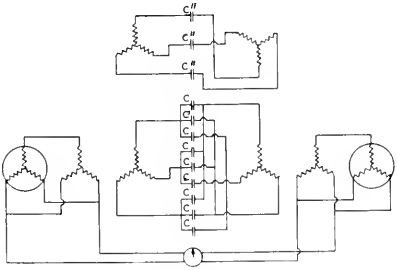


Fig. 9. Diagram, Equivalent of Fig. 8, When Two Alternators Feed Each of Two Circuits on the Same Tower Line and When $C_0 < C$

$$C_{11} = l_1C_4 + l_2C_3 + l_3C_4 + l_4C_4 = 0.8831\ \mu F\dagger$$
$$C_{22} = l_1C_3 + l_2C_4 + l_3C_4 + l_4C_3 = 0.8864\ \mu F$$
$$C_{33} = l_1C_4 + l_2C_4 + l_3C_3 + l_4C_4 = 0.8805\ \mu F$$
$$C_{12} = C_{21} = l_1C_2 + l_2C_2 + l_3C_1 + l_4C_2 = 0.9009\ \mu F$$
$$C_{23} = C_{32} = l_1C_2 + 1_2C_1 + l_3C_2 + l_4C_2 = 0.9042\ \mu F$$
$$C_{31} = C_{13} = l_1C_1 + l_2C_2 + l_3C_2 + l_4C_1 = 0.9082\ \mu F$$

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* In the calculation of capacitance, the simplest formula $C = \frac{0.01941}{\log_{10}\frac{D}{r}}$ μF per mile was used and the effect of ground was neglected.

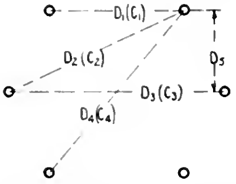
† μF is here used as the symbol of micro-farads in accordance with the recommendation of the International Electro-technical Commission.

The capacitances between corresponding phases in the two circuits, as denoted by C_{11}, C_{22}, C_{33}, are less than the others, and this fact would account for the stopping of the synchroscope pointer at nearly the in-phase position.

The arrangement of the conductors in the Southern Sierras Power transmission line is shown in Fig. 10. The line is approximately 240 miles in length and three complete transpositions are made in each circuit of the line. The transposition towers are located so that the sections between transpositions are of equal length. In other words, there are nine sections of equal length, 26.6 miles, between the two terminal stations. The relative position of the conductors in each section is shown in Fig. 12 and the capacitances are calculated as follows:

$$C_{11} = C_{22} = C_{33} = (6\,C_1 + 3\,C_3)\,l = 1.5828\,\mu F$$

$$C_{12} = C_{21} = C_{23} = C_{32} = C_{31} = C_{13} = (6\,C_2 + 3\,C_4)\,l = 1.5375\,\mu F$$



Dia of Conductors • 2r • .5622"	
D₁ • 16.5 ft.	C₁ • .00680 μF/miles
D₂ • 23.71 ft	C₂ • .00645 μF/miles
D₃ • 26.5 ft.	C₃ • .006356 μF/miles
D₄ • 25.93 ft.	C₄ • .006375 μF/miles
D₅ • 10 ft.	

Fig. 10. The Arrangement of the Conductors on the Tower in the Southern Sierras System

In this case, the capacitances C_{11}, C_{22} and C_{33} are greater than the others and this condition accounts for the observed phenomenon.

In the laboratory of the Tokyo Imperial University, the writer succeeded in the synchronous operation of two small alternators, each of about 5 kv-a., through six 2 μF telephone condensers which were used as C_{12} C_{13} C_{23} C_{32} C_{31} and C_{13} while C_{11} C_{22} and C_{33} were zero. This result also supports the foregoing theory.

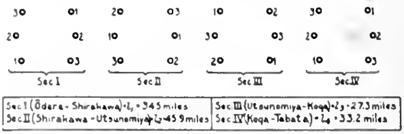


Fig. 11. The Relative Position of the Conductors in Each Section of the Inawashiro System

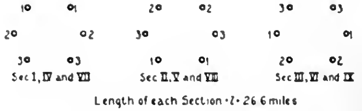


Fig. 12. The Relative Position of the Conductors in Each Section of the Southern Sierras System

Conclusion

It would be concluded that the arrangement of the conductors shown in Fig. 11 is more desirable than that in Fig. 12, because it does not cause any trouble due to the synchronizing effect and would facilitate synchronizing at the receiving station.

Inawashiro Tower Line Near Utsunomiya

The General Electric Company's Contribution to the New Merchant Marine

By J. Livingston Booth

Marine Engineering Department, General Electric Company

America's industrial activity during the late war has left it with a merchant marine which begins to be comparable with its future needs. Because in the building of these ships radical departures were made from former shipbuilding practice, much controversy has arisen concerning the merit of the innovations—notably the use of geared turbines in place of reciprocating engines. The following article is timely in this respect, in that its review of the service of the Hog Island type of turbine-gear driven ships furnishes convincing testimony as to the quality of their performance. The article also outlines other contributions of the Company to the new merchant marine, such as its inspection service, its School of Marine Engineering, and its design and production of electric drive equipment.—Editor.

At the time of the great national crisis in 1917, when "Ships and more ships" seemed to be the greatest factor for winning the war, the General Electric Company was experimenting with turbines and double-reduction gears for driving cargo vessels.

In all, fifteen vessels had been so equipped up to April, 1917, representing five or six different designs of reduction gears. No serious troubles had been experienced on any, and sufficient experience had not been obtained to show which of the various designs would prove to be the most successful in prolonged service.

With the entry of this country into the war, however, the whole situation was changed. The enormous program of cargo vessels laid down by the Government, which was far beyond the capacity of the then existing manufacturers of marine propulsion machinery, necessitated production being undertaken on a very large scale without the preliminary development work which is customary before undertaking quantity production.

Orders were placed with the General Electric Company by the Government for propelling machinery which finally amounted to the equipments for 500 cargo vessels, a total which was nearly equal to the entire fleet of steel ocean-going cargo boats owned in the United States in 1915. It was also intimated that the schedule of production of hulls would necessitate the completion of machinery at an ever-increasing rate, which in a year's time, or by the fall of 1918, was to amount to one complete equipment per working day.

This schedule was actually lived up to; and when the Armistice was signed in November, 1918, one complete set of machinery for a cargo vessel was leaving the Schenectady Works every day, and a number of equipments were awaiting hulls at the shipyards. The curves shown in Fig. 1 give the production and number of cargo boat equipments placed in service up to April, 1920.

This tremendous production was accomplished only by extraordinary means and, apart from the erection and equipping of new buildings, necessitated the adoption of the simplest design in which the amount of material, machining processes, etc., were cut down to the minimum consistent with its ability to meet the war emergency.

When production conditions allowed, changes in design were incorporated, wider gears being used to give longer life, and other changes being made as a result of increased experience under actual service conditions.

Performance

The 500 equipments originally ordered were reduced considerably at the end of the war by cancellations, but up to the end of 1921, 310 cargo vessels had been placed in service. This number includes 24 tankers, but is exclusive of army transports and naval vessels also equipped with marine geared turbines.

In spite of the existing shipping depression, these ships have steamed a total of approximately 18,000,000 miles, which, when deducting eleven which were sunk, gives a total of 60,000 miles per ship, though some have made over 200,000 miles.

In view of the great amount of discussion which has centered around Hog Island and the Hog Island type of ship, it is of special interest to examine the service record of these ships, all of them having been equipped with General Electric marine geared turbines of the later war emergency type.

The *Daily Marine Record*, of November 12, 1921, in commenting on the performance of these vessels, says the Hog Island ships are the best we have and that of the 122 built (which includes 12 transports) 102 were reported to be in service at that time.

At that date the total number of cargo vessels in operation under the control of the U. S. Shipping Board was reported to be only

456, so that of all these running, 22 per cent were Hog Island vessels, and 84 per cent of all Hog Island ships built had been retained in service. The fact that ships of the Hog Island type have been about the last to be laid up is due, not only to their being economical to operate, but also because their maintenance cost has been extremely low, many not having required any expenditure for machinery repairs beyond the usual voyage work sheet.

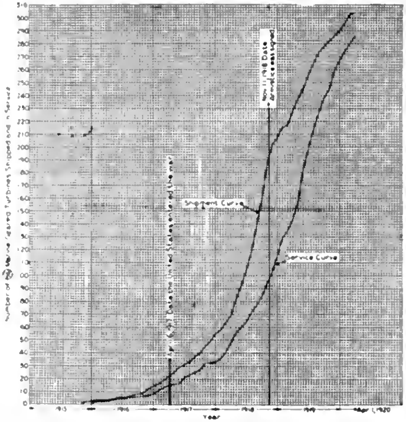


Fig. 1. Curve Showing Production of Equipments for Merchant Ships by the General Electric Company During the War Period

The chart reproduced in Fig. 2 shows the performance record of the Hog Island type of equipment. It should be noted that the chart includes the results obtained from 164 vessels, 54 additional equipments of the Hog Island type having been built and installed in hulls built by other shipbuilders. The figures given are as of April 20, 1921; the total mileage up to the end of 1921 is 9,578,581 miles. The *Quistconck*, the first ship to go into service, had made 119,589 miles to that date, and four additional ships had made over 100,000 miles.

The only replacement which has been made since the chart was compiled is one low-speed element which was damaged by some bolts having dropped in and passed through the gears.

Fuel Consumption

Many of the ships are running on a consumption of fuel oil of about one pound per shaft horse power hour. Some are slightly under this and others over. Many of the ships are not running under the best conditions owing to some engineers, who have had mostly reciprocating engine experience, not yet fully appreciating the greater importance of high vacuum to turbine machinery than to reciprocating engines. The consumption given is the fuel used for all purposes and includes the consumption of the steam driven auxiliaries, with which most of these vessels are equipped.

A further saving in fuel consumption could be made on these vessels by driving the deck and engine room auxiliaries electrically, due to the lower water rate that could be obtained from a generator set of sufficient capacity to handle the entire auxiliary load.

Due to the lessened steam consumption needed to carry the auxiliary load, and also to a reduction in the load on the auxiliaries, the amount of exhaust steam available is more nearly equal to the quantity required for heating the feed water, and a better heat balance is effected.

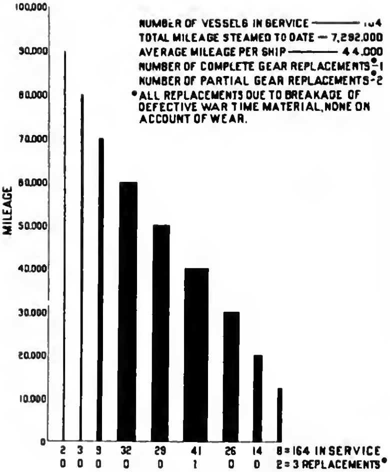


Fig. 2. Performance Record of the Hog Island Type of War Emergency Gears

Turbine Troubles

It was inevitable that with equipments built under rushed war time conditions certain troubles should have been experienced, but these have been confined almost entirely to the early war emergency gears.

The impulse type of turbine, with its comparatively large running clearances and substantial design of buckets, is especially well fitted for marine use; and the short, substantial design of turbine produced for the purpose by the General Electric Company has gained an almost perfect record for reliability and freedom from breakdowns under all conditions of service. No replacements have been made due to turbine failure; and on the vessels on which turbine repairs have been made, these have in most cases been caused by improper operating conditions. One or two cases of a loose turbine wheel or shroud band occurred during the war, but in no case did this prevent the ship running under her own steam.

Fig. 3. Typical Cargo Vessel of Approximately 14,000 Tons Displacement Equipped with G-E Marine Geared Turbine. Nearly 300 have been placed in service

Fig. 4. Typical Tanker, Carrying Approximately 10,000 Tons of Oil. Twenty-four of these have been equipped with G-E Marine Geared Turbines

Gear Troubles

The troubles experienced with double-reduction gears were confined to the early types of war emergency gears only, of which 110 were placed in service. These failures have been due to a variety of causes: faulty wartime materials, overloading of a portion of the length of a tooth due to improper installation or to misalignment, ignorance of operators, inadequate lubrication, etc.

The early war emergency gears, however, in which high tooth pressures were employed in order to reduce their size, weight, and the amount of machining necessary, were capable of giving about three years' service and were, therefore, not comparable as regards maintenance costs, from an owner's point of view, with a reciprocating engine. Except in cases where their life has been shortened by weak foundations, improper installation, inadequate lubrication, etc., these gears have given all the life that could be expected from them, but the necessity for their replacement has given rise to the erroneous impression in the minds of those unacquainted with the facts that double-reduction gears have been a failure and are unsuited for marine use.

Inspection Service

It was soon found when vessels began to go into service in greater numbers that very different results were being obtained from gears of the same design. Gears made from the same drawings, of the same material, cut on the same machine, showed heavy wear after six months' service on one vessel, while on another their condition was such that their predicted life could be expected and was ultimately obtained.

This variation was due to differences in design of the foundations provided by various shipbuilders, to the methods of installation used, to the quality of workmanship, to the adequacy or otherwise of the lubricating system provided, and also to the fact that many of the ships were being taken to sea by men who were almost totally inexperienced in the operation and maintenance of turbines and gears.

To prevent these conditions causing the disablement of a vessel with its possible loss during the submarine campaign, a system of inspection was instituted by the Company to inspect all vessels equipped with its machinery practically every time in port. While this was confined mostly to the New York and Philadelphia Districts during the time the convoy system was in force, inspections were afterwards made in all the principal ports of the east and west coast by men specially trained for the purpose. This also necessitated the establishment at Schenectady of a central office to direct the inspection system, to analyze reports, and to

Fig. 5. Marine Geared Turbine of 2500 h.p. of the One-plane War Emergency Type

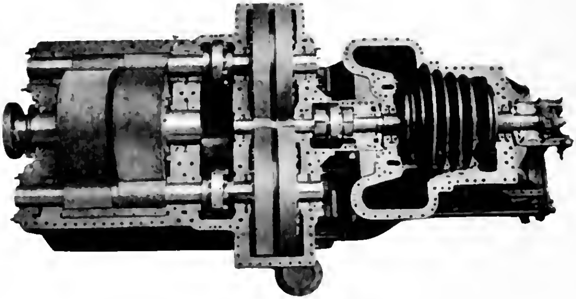


Fig. 6. One-plane War Emergency Type Geared Turbine with Casing Removed

keep the designing engineers informed of results obtained with different types and designs of apparatus in service.

Much was also done in co-operation with the Shipping Board to eliminate conditions found on ships which were likely to cause delays or an interruption in service. No charge was made by the Company for these inspections and much work was done without any question of responsibility being raised, which would ordinarily be performed by the shipowners or the ship's engineers. It resulted, however, in a complete freedom from serious breakdowns; and although over 80 per cent of the new turbine driven ships running up to the end of the war were equipped with General Electric marine geared turbines none of these had ever been towed into port on account of a breakdown of the turbine or gears and no vessel was lost due to failure of the machinery.

While the inspection system was first undertaken in the protection of national and also of the Company's interests, it has enabled an enormous amount of valuable information to be compiled on the performance of various types of apparatus and devices under actual service conditions, and on developments in marine apparatus throughout the world, without which the great progress which has been made in the design of General Electric marine geared turbines during the last five years would have been impossible.

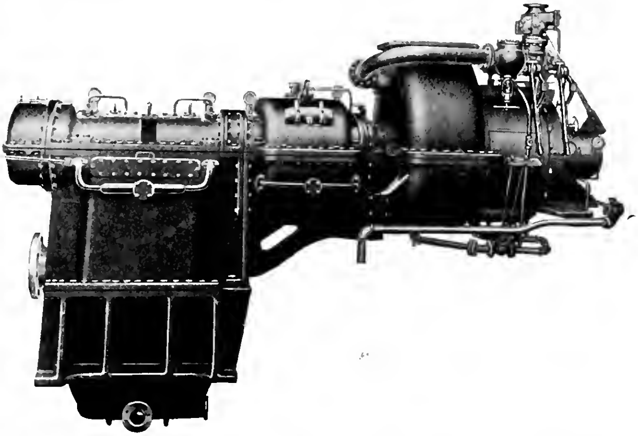


Fig. 7. Latest Type of G-E Marine Geared Turbine with Two-plane Type Reduction Gears

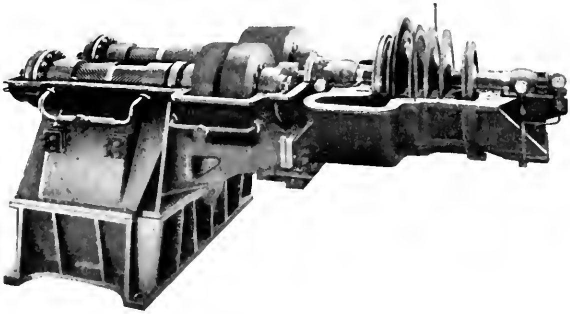


Fig. 8. Two-plane Type of Marine Geared Turbine with Casing Removed Showing Turbine Rotor, High-speed Gears and Low-speed Pinions

School of Marine Engineering

To assist in removing some of the disadvantages under which ships were being operated due to inexperienced engineers, a school of Marine Engineering was opened in 1918 by the Company to train engineers in the operation and care of turbines and reduction gears. Special attention was also given to methods of obtaining the maximum overall economy in ship operation.

Fig 9 Replacing a Set of One-plane Reduction Gears by the Two-plane Type in the Record Time of Ten Days

A short course of intensive training was given which was attended by approximately 500 officers of the Naval Reserve and over 1000 chief and first assistant engineers from the U. S. Shipping Board. A number of engineers from the Army Transport Service, port and superintendent engineers, and others have also taken the course. The beneficial results of a larger number of trained engineers being available has been shown very clearly through the inspection service.

Replacement Program

During 1920 it became necessary to consider the replacement of some of the early war emergency gears which had reached the end of their life; and gears and other propulsion machinery remaining from the building program were used by the Shipping Board for this purpose. Some reciprocating engines for which the hulls had been cancelled were also installed, but this was soon recognized as a backward step and discontinued.

Electric Drive

A number of electric drive equipments which were originally ordered from the Company for new hulls are also being used for replacement purposes, the first equipment having been installed on the S. S. *Eclipse*. This vessel has attracted a great deal of attention on account of being the first electrically driven cargo vessel. However, it does not seem to be generally recognized that she is not a new vessel, but that her turbine and gears have merely been replaced by a turbine-generator and motor, all her original steam driven deck and engine room auxiliaries being retained. Therefore, with regard both to economy and arrangement of machinery, she is not representative of the best which could be obtained on an all electric ship.

With an electric drive installation of this capacity no claim is made for a greatly decreased fuel consumption, as the turbine-generator and motor losses about balance the turbine and gear losses of the marine geared turbine.

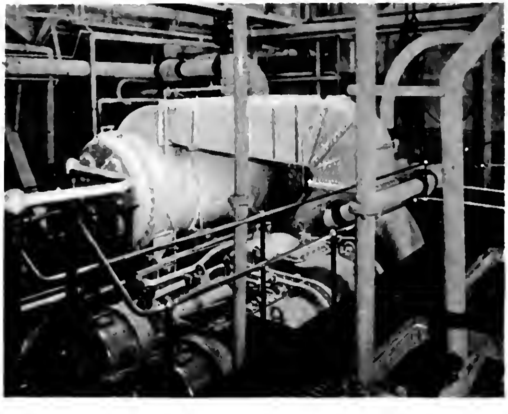


Fig. 10. Replacement of One-plane War Emergency Gears by the Two-plane Type. Installation completed

In addition to the advantages of superior maneuvering qualities and full astern power possessed by the electric drive, it is anticipated that maintenance cost and delays due to machinery troubles will be small. The excellent condition of the electric machinery on the *Eclipse* after her first voyage of seven months, during which she steamed 26,500 miles, promises to justify the belief that the low maintenance cost of electric drive equipments in naval vessels will also be realized on cargo ships.

Improvements in Reduction Gears

At the conclusion of the war a great deal of research work was undertaken by the Company to determine the best shape of tooth and material for reduction gears. Complete tests were made in the factory and a number of test gears built and placed in service on ships. Very great progress has been made as a result of this investigation, and, by the use of the improved shape of tooth and material, it has been possible to build replacement gears which go into the original gear casing of the war emergency equipments and which are giving a very greatly extended life.

With the end of the war building program, the General Electric Company revised the two-plane type of gear originated before the war. The tremendous experience, and almost unlimited opportunity afforded for gaining engineering knowledge from observing gears of all types and makes in service, indicated that certain modifications should be incorporated in the design. Equipments of this later design which have been put in service since the conclusion of the war are all in such an excellent condition after approximately two years' service that it is impossible at the present time to estimate the ultimate life of the gears. The maintenance cost has been practically nothing.

In the two-plane type the turbine and high-speed gears are on a plane considerably above the center line of the propeller shaft and low-speed gears, instead of the turbine and the high and low-speed gears being on the same horizontal plane as in the war emergency design. This arrangement gives the minimum casing area to be supported in the ship, and the casing is therefore much more free from distortion caused by the working of the hull. Also the low-speed pinions engage at points on the circumference of the low-speed gear where the teeth are much less affected by shafting and propeller vibrations. In most ships, the two-plane type may be installed in place of the single-plane war emergency design with only slight alterations being necessary to the machinery foundations, and the change has been made at small expense in as short a time as ten days.

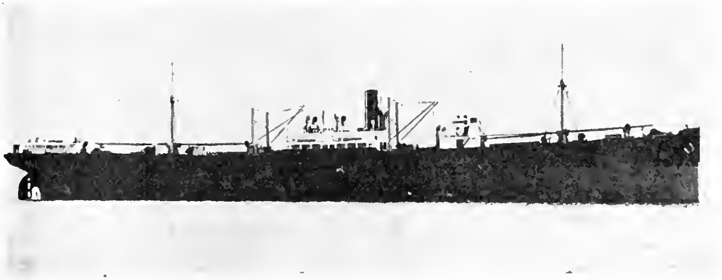


Fig. 11. S. S. *Eclipse*, 15,000 Tons Displacement, the First Electrically Driven Cargo Vessel, Her War Emergency Gears Having Been Replaced by General Electric, Electric Drive Machinery

The two-plane type of marine geared turbine, when used in conjunction with electrically driven auxiliaries which have been especially developed to meet sea conditions, is a most economical equipment for the average merchant ship application.

Heavy Duty Electrically Heated Apparatus for Hotels, Restaurants, Bakeries, Etc.

By J. L. Shroyer

Edison Electric Appliance Company, Inc.

The successful development of the smaller variety of electrically heated appliances long ago established universal recognition of electricity as a superior heating agent to coal, oil, or gas for these purposes. The same theoretical economics apply to heavy duty culinary apparatus as well, but the development of these devices had to await the production of a type of heating element sufficiently substantial to withstand the far more severe electrical, mechanical, and thermal conditions to which this calibre of apparatus is subjected. How well the comparatively recent invention of sheathed wire fills the requirements is evidenced by the fact that about 5,000 heavy duty kitchen appliances are in use today. The following article outlines the many advantages of electrically heated apparatus and shows that they outweigh its single disadvantage. The development of heavy duty culinary apparatus is reviewed, and descriptions and photographs are given of each.—Editor.

Preface

A few years ago the writer was one of the four or five hundred college graduates taking the General Electric Student Engineering Course. The most promising lines in the electrical field were frequently discussed by the students and each made a special effort to get construction of a 500-watt toaster when others were building 10,000-kw. generators, transformers, etc. The heating device department was looked upon by the students as a sort of refuge for those not capable of "holding their own" in the larger and more technical branches of the electrical industry.

Fig. 1 A Typical Bank of Two Hotel Ranges. Separate cutouts for each unit are mounted below the switches. The cover over the cutouts is open at the bottom to permit air from the floor to circulate about the cutouts, up through the switches, and out through perforations at the top of the switchbox cover

experience in the department handling apparatus for which he felt there was the best future. Most departments had a waiting list—except one, the heating device. No one cared to waste a college education on that line. Anyone could wind a wire on a piece of mica and make a heater. The flatiron and toaster were about the only devices in demand. It was hard to arouse interest in the

Today many kinds of electrically heated appliances are to be seen in the store windows. Power companies have organized appliance sales departments—and the officials consider the conduct of these departments as one of the vital elements in the future development of their companies. In many communities the appliance load exceeds the lighting load and in a few more years this will be true of the loads on the lines of all progressive central stations.

Four years ago there was no demand for electrically heated heavy duty kitchen apparatus. Today there are probably 5,000 installations of the larger heavy duty apparatus such as ranges, bread or pastry ovens, and many thousands of installations of the smaller pieces such as toasters, griddles, waffle irons, etc.

Practicability Established

There are more than a hundred installations of large electrically heated heavy duty apparatus in and about Chicago. These are located in many of the most prominent and popular hotels, such as the Drake and Edgewater Beach; clubs, such as the Illinois Athletic and Union League; department stores, such as Marshall Field's and Rothschild's; restaurants, such as Henrici's and the Blackhawk; cafeterias, such as the North American and the Ontras'; hospitals, such as the Mercy andPresbyterian; bakeries, such as the Keep Fresh and Electric.

There are 56 large electric bread or pastry ovens in use in Portland, Ore., and at least 75 in the vicinity of Salt Lake City. There are many installations of heavy duty cooking and baking apparatus in New England, such as those at the Congress Square Hotel, Portland; Penobscot Exchange, Bangor, Maine; Copley Plaza, Boston; and in other territories where power companies

Fig. 2. 30-loaf Electric Bake Oven for Small Restaurants with Switch Panel Removed to Show Interior Switchbox Construction

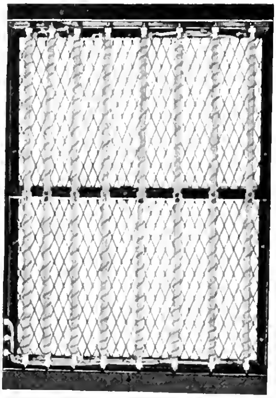


Fig. 3. Heating Unit of the Type of Bake Oven in Fig. 4, Showing the Large Amount of Heating Wire Used and the Method of Distributing the Heat Over the Entire Area

Fig. 4. Four-compartment 11-kw. Electric Bake Oven Having Four Tile Decks with Heating Unit Below Each Deck and One in the Top of the Upper Compartment. Each unit is controlled by a separate three-heat switch and is protected by an individual cutout

have taken an interest in the development of a revenue from this field.

The U. S. Navy Department, after using a large brick oven for several years at the Great Lakes Training Station, installed two similar large brick ovens at the Marine Aviation Base, San Diego, Calif. Several large battleships are equipped with electric ranges in their galleys and many are using electric bread and pastry ovens in their bakeries.

Several of the largest oil tankers are equipped with electric ranges and ovens.

The U. S. Treasury Department, Washington, D. C., after having used a complete installation in the cafeteria of the Bureau of Engraving and Printing for more than a year, recently purchased an additional complete cafeteria equipment.

TABLE I

SCOPE OF THE FIELD FOR ELECTRICALLY HEATED HEAVY DUTY KITCHEN APPARATUS

Number	United States Institutions	Estimated Kilowatts of Apparatus to Replace Fuel Equipment	Value of Electric Apparatus to Replace Fuel Equipment
4,600	Hotels	150,000	$6,225,000
8,946	Restaurants	330,000	8,650,000
12,314	Cafeterias	455,000	12,000,000
18,734	Lunch Rooms	225,000	4,750,000
2,556	Tea Rooms	30,700	640,000
29,000	Luncheonettes	87,000	1,595,000
7,667	Hospitals	130,000	5,050,000
1,804	Homes	39,500	1,550,000
30,000	Schools	132,000	5,000,000
30,000	Industrial Plants	132,000	5,000,000
200	Penal Institutions	10,600	465,000
300	U. S. Government Posts	16,000	695,000
100	Apartment Hotels	3,900	167,000
500	Clubs	19,500	835,000
1,000	Ships	50,000	2,115,000
2,500	Y. M. and Y. W. C. A.	15,000	356,000
30,000	Bakeries	750,000	45,000,000
		2,576,200	$100,093,000

Numerous bakeries have ordered additional electric ovens after having used their original electric installation for more than a year.

One of the largest and most popular restaurants in Chicago is using eight large bread and pastry ovens in its bakery and has been using electrically heated ranges and other heavy duty apparatus exclusively in its kitchen for the past six months. This restaurant recently placed an order for additional complete electric equipment for a new auxiliary kitchen.

Some of the most popular and best known chain restaurant companies have recently ordered complete electric kitchen equipment for some of their restaurants. These orders were placed after a very thorough study had been made of similar apparatus now in use.

Why Bakers Are Selecting Electric Ovens

Large bread or pastry ovens are used in the wholesale production of a commercial commodity for which there is a general steady demand but unlimited competition. The success of any individual bakery depends primarily on the quality of the product and the cost of operation.

The oven is the most important single piece of apparatus in a bakery and it is largely responsible for the quality of the product. Therefore the oven is given prime consideration.

As in the selection of any important apparatus, the advantages and disadvantages of the various types are weighed against each other. The following comparison shows why the electric oven has so rapidly gained general favor.

Advantages

(1) Better and more uniform quality of product.

(2) Lower percentage of the product spoiled during baking.

(3) Goods baked electrically retain their freshness for a longer period, thereby reducing losses due to stale product.

(4) Saves ⅓ to ½ the floor space required for a fuel-fired oven.

(5) Eliminates the often difficult and expensive problem of providing a furnace chimney.

(6) No labor to handle fuel or ashes.

(7) Eliminates constant provision for fuel.

(8) No dirt or dust from fuel.

(9) Can be installed on any floor of a building without bringing up the fuel handling problem.

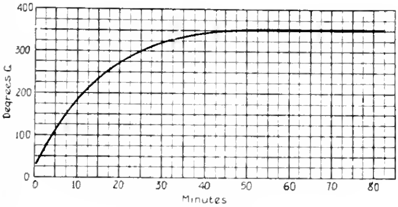


Fig. 5. Heating Characteristic Curve of 9 by 24-in., 4-kw. Hotplate

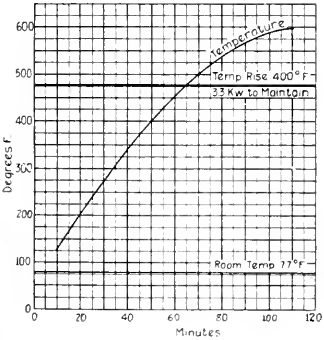


Fig. 6. Heating Characteristic Curve of 11-kw. Oven with 3-in. Rock Wool Insulation

(10) More uniform deck temperature.

(11) More accurate and flexible control of temperature.

Disadvantages

In some communities power companies find it necessary to maintain a rate for electricity which makes the monthly energy bill for electric apparatus higher than the fuel bill when fuel-fired apparatus is used. This difference, however, is usually offset by the advantages resulting from the use of electric equipment.

Comparison

Advantage (1) is probably the most important as it has a direct bearing on holding trade and the growth of a business. With local competition it often determines success or failure.

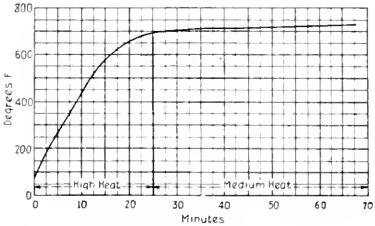


Fig. 7. Heating Characteristic Curve of 18 by 36-in., 6-kw., 3-heat Griddle

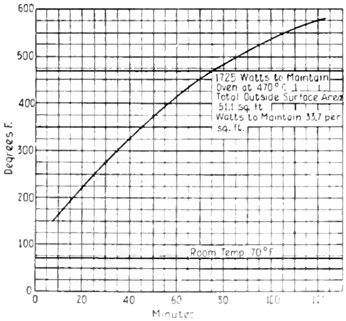


Fig. 8. Heating Characteristic Curve of 5-kw. Bake Oven with 3-in. Rock Wool Insulation

Advantage (2) can be readily estimated in dollars and cents. This one advantage often results in saving more than the additional cost of electricity over coal; for example, there are practically no culls when electric ovens are used. Assuming a saving of 2 per cent of the product on a total output of 10,000 pounds, we have:

200 pounds saved at five cents per pound .	$10.00
Total cost of electricity for baking 10,000 pounds at one cent per kw-hr	10.00

Each of the other advantages enumerated requires separate consideration of each installation. Often a single one determines the selection of an electric oven. Collectively they invariably offset the one disadvantage when a rate of three cents or less per kilowatt-hour can be obtained.

The electric oven is even more suitable for pastry work as the goods have a higher value per pound and quality is a paramount requirement. For such work the cost of electricity is a minor item compared with the advantages gained from the use of the electric oven.

Fig. 9. Four-foot Hotplate Section Heavy Duty Cooking Top with Removable Clean-out Pan

Scope of the Field for Electrically Heated Heavy Duty Kitchen Apparatus

The extent of the field for heavy duty electric kitchen equipment is outlined in Table I. Concerning some of these institutions, the following facts are of interest:

There are approximately 4,600 first-class hotels and 15,000 second-class hotels in the United States.

There are now over 6,000 industrial plants operating their own cafeterias. They serve more tons of food than the hotels.

There are 9,000 textile mills in this country and many are beginning to operate their own cafeterias.

The American Telephone and Telegraph Company already operates 600 lunch rooms for employees.

An up-to-date passenger liner is provided with sufficient kitchen equipment for serving two million meals to individuals per year.

Eight million people spend an average of seventeen days in the hospitals of the United States each year. Hospitals serve more food than all the hotels. Hospitals and allied institutions have a capacity of over 900,000 beds. The hospitals alone purchase more than one and one-quarter million dollars worth of kitchen equipment annually.

Eighty per cent of the city high schools in the process of building are equipped with cafeterias. There are about 20,000 high schools in the United States. Nearly 5,000 have lunch rooms. Chicago now has more than 70 school lunch rooms. Ninety per cent of the 500 normal schools in the United States operate their own dining rooms.

Immediate Field

Coal and gas equipment has an average life of five to ten years. At least $10,000,000 worth of electric apparatus would be required per year for replacements.

Considering the general interest in electric apparatus by leading men in the hotel, restaurant and bakery field, it seems safe to estimate that after five years at least 15 per cent of the field will be using electrically heated apparatus. On this basis, after 1926 at least $5,000,000 worth of electric apparatus will be purchased each year. Considering the tendency of many institutions to discard fuel apparatus for electric before it is worn out, to secure quickly the advantages of the electric, this estimate seems conservative.

Fig. 10. 180-loaf, 25-kw. Electric Oven with White Enamel and Nickel Trim Finish

Effect on Expansion of Power Companies

If the fuel equipment now in use in the United States were replaced with electrically heated apparatus, the power companies would be called upon to furnish approximately 12,500,000 additional kilowatt-hours per day. Assuming that 15 per cent of the field will be using electricity in five years, there must be provided during this time generating and distributing equipment for supplying approximately 1,875,000 kw-hr. per day.

Desirable Central Station Load

In the average installation the ovens make up one-half the total connected load. They are ordinarily pre-heated on high heat prior to 7:00 a.m. and operated on medium heat (½ maximum) during the baking period which ends in the early afternoon. They are seldom used in the evening when the peak load occurs. The range top, broilers, and other miscellaneous pieces draw a fairly steady load from 6:00 a.m. to 7:00 p.m. with moderate valleys from 1:00 to 4:00 p.m. It is a seven-day load, fifty-two weeks per year, with the heaviest load on holidays and Sundays when other loads are nil.


Fig. 11. 18 by 36-in., 6-kw. Electric Griddle. The heating unit is divided into a right and a left-hand section, each controlled by a separate three-heat switch and protected by individual cutouts mounted at the front of the device in a readily accessible box

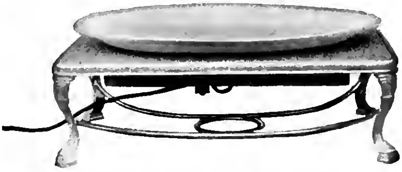


Fig. 12. Serving Platter Warmer. This is a popular device among the high class hotels

Data from an average installation of three hotel range tops, one meat roasting oven, and one combination bread and pastry oven, having a total connected load of 73.5 kw. (maximum demand approximately 75 per cent of the total connected load), show a consumption of 9,000 kw-hr. per month.

Development of Heavy Duty Apparatus

Designing engineers gave considerable time to heavy duty apparatus during the early development of household appliances. Most of their efforts to build apparatus sufficiently rugged to withstand the heavy service proved futile and the development suffered a relapse for several years.

Heavy duty electrically heated kitchen and bakery apparatus is used in the wholesale production of goods for which there is keen commercial competition. The efficiency and practicability of such apparatus is therefore of prime importance; but the general scope of this article prevents a detailed technical analysis of designs.


Fig. 13. 6-kw. Doughnut Stove. This device is intended to heat a 24-in. grease kettle and has a capacity of approximately 100 dozen doughnuts per hour

Electrically heated equipment for large kitchens really centers about the range. The cooking surface of such a range must often be operated at a dull red heat eighteen hours out of twenty-four, supporting kettles weighing hundreds of pounds and must not be put out of commission if by chance a ten-gallon soup kettle is overturned on it. Imagine a transformer, generator or any other kind of electric apparatus standing up under such treatment.

The temperature in a kitchen and the nature of the work naturally tends to make the help nervous and high strung. Proper equipment to produce food when wanted and in the manner wanted is a matter of prime importance to their reputation as chef or cook. There is probably no other class of workmen who subject the machinery with which they work to such rough treatment and who demand greater practicability and continuity of operation.

Sheathed wire heating elements developed by the General Electric Company gave the heavy duty heating engineers new possibilities. These elements could be cast in rugged top plates and the protected terminals brought out to a point beyond danger of exposure. Likewise, the range oven elements and terminals could be fully protected against contact with spilled foods, condensation of vapors, etc. A range of this kind constructed about 1918 was the first to prove itself equal to the service demanded. In fact it is today the only type with a proven record.

With the range problem solved the development of auxiliary apparatus such as meat broilers, griddles, toasters, steam tables, etc., progressed rapidly. Today, complete, thoroughly developed electrical apparatus of proven reliability can be had to replace any type of fuel apparatus used in the kitchen.

The electric bread and pastry oven is another very important and practical apparatus. The patented multiple deck oven having air tight compartments with tile decks and heating units beneath each deck and one element in the top of the upper compartment, and each element separately controlled with a three-heat snap switch, has received universal approval of the bakers. Thousands of these ovens

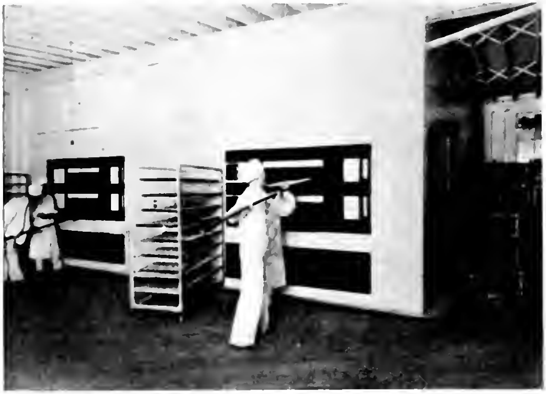


Fig. 14. A Typical Installation of Electric Brick Ovens. This bank has a total capacity of approximately 1200 one-pound loaves per hour

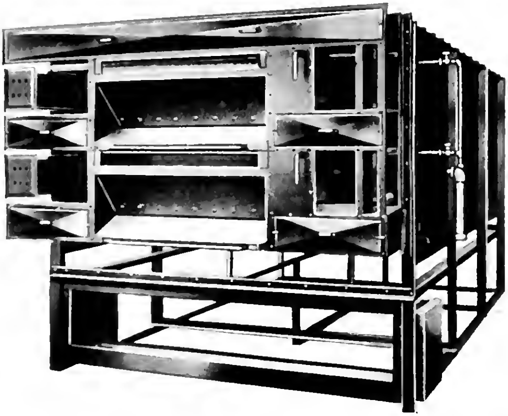


Fig. 15. Metal Frame Work (Less Switchbox) for the Type of Electric Bake Oven Shown in Fig. 14

Fig 16. Switchbox for Brick Oven, Showing Individual Cutouts and Three-heat Switches for Each Unit

have been put in use within the last few years. Flour, yeast and other allied industries are fast becoming interested in putting the baking industry on a scientific basis. Milling companies are installing large electric ovens in their model bakeries. Bakery schools are using electric ovens. The ignorant baker who insists on baking the same way his grandfather did is now practically a thing of the past, and one of the early obstacles to the general introduction of electric ovens is overcome. Bakers are no longer skeptical of the electric oven but are demanding it.

Fundamental Features in Design

Careful consideration must be given to the following design features:

(1) The apparatus must be capable of producing results equal to or better than similar fuel-heated equipment. (Time, quality, and ease of operating are important elements.)

(2) The design must be substantial and capable of withstanding the most severe handling. The parts must stand up, although subject to intensive heat, mechanical wear, contact with grease, liquids, and fumes, and electrical strains.

(3) The construction must be such as to permit of quickly replacing the heating elements, switches, etc., without moving the apparatus or allowing it to delay production.

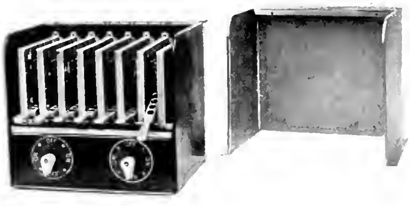


Fig. 17. Seven-slice Toaster for Individual Order Service. The heating units are of the sheath wire type with the terminals brought out at the back

Hotel Range

The size of electric hotel range most commonly used is a 4-ft. section with four 50-lb., 9 by 24-in., 4-kw. cast-in element hotplates and a large oven with 3-kw. sheathed wire heaters in the top and bottom. Each unit is controlled by a separate three-heat switch and protected by separate fuses. This size is particularly suitable where a number of sections are banked end to end or where an installation of fuel-fired apparatus is gradually replaced with electric as the individual pieces wear out.

To secure the advantage that results from segregating the oven and surface work, usually done by different cooks, there is a recent tendency toward eliminating the oven in the range and using separate roasting and baking ovens of the multiple deck type. This combination has the additional advantage of greater economy in the use of energy due to the better efficiency of the multiple deck oven.

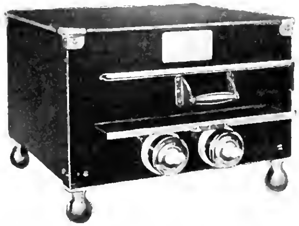


Fig. 18. This Toaster Has a Capacity of 16 Slices per Minute, Both Sides of the Bread Being Toasted at the Same Time

Bake Ovens

The large, multiple deck, box type oven with heaters under each deck and one heater in the top of the upper compartment has proved pre-eminently popular. The uniform distribution of heat and the close and more or less independent control of the temperature of each compartment make it particularly suitable for average requirements where it is often necessary to bake goods of different character on the various decks at the same time.

Box type ovens of this design are made in six standard sizes from the 30-loaf, 5-kw. to the 180-loaf, 25-kw. They have an average operating efficiency of approximately 90 watts per pound. By skillful operation, efficiencies as low as 60 watts per pound can be obtained.

The electrically heated brick oven is fast gaining general favor for places where a production of 200 lb. per hour or more is required. Fig. 14 shows a typical bank of two 400-lb. ovens having a total deck capacity of 800 one-pound loaves and a total rating of 108 kw. There are six heating units per oven, each unit having three sections and each section being controlled by individual three-heat switches and protected by separate fuses. Automatic door lights are provided for each deck. Steam spray pipes are located in the top of each compartment for charging the oven with steam, as this is required for certain kinds of bread. An open ventilating duct extends across the top of each door opening, inside the brick work, to carry off excess steam and vapors.

The body of this oven consists of a heavy sheet-iron shell surrounded with heavy heat storage brick, light heat insulating brick, an expansion space packed with mineral wool, a course of ordinary building brick, and an outside course of white enameled brick, making a total thickness of approximately 24 inches.

Toasters

There is a specific demand for two distinct types of toasters, the smaller one (Fig. 17) for individual order service and the larger size (Fig. 18) for quantity production. No one disputes the superiority of the electric toaster. However it must operate at an extremely high temperature over long periods and must be dependable. This necessitates very careful design. The seven-slice toaster (Fig. 17) designed for quick order service illustrates the more important features. This toaster is equipped with eight identical, inexpensive and readily removable sheathed wire heating units, each unit being rated 55 volts. They are connected two in series for 110 volts and four in series for 220 volts. The design is such that there is no space for crumbs to lodge except in a readily removable crumb tray underneath the heating units. All terminals are brought out at the back so as to eliminate the possibility of contact with crumbs or foreign matter. For fancy counter service an ornamental highly finished casing can be used.

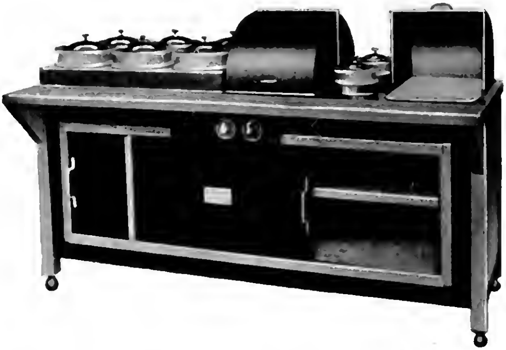


Fig. 19. A Typical Steam Table with Plate Warming Compartment, 6-kw.

Steam Table

The steam table shown in Fig. 19 is approximately six feet long. There are three 1500-watt sheathed wire heating elements beneath the water tank and one 1500-watt element mounted vertically in the center of the plate warmer compartment. Circulation of air in the plate warmer compartment is upward through the chamber containing the heating element and outward to the right and left between the shelves and returning underneath the shelves to the heating chamber. This method tends to heat all the plates in a stack uniformly and eliminates the tendency of overheating the bottom plates (when heaters are placed under shelves) and not properly heating the top plates which are the first to be taken off.

Broiler

The radiant broiler is often more constantly and severely used than any other device. It is not only used for broiling fish and meats, but for all sorts of miscellaneous purposes such as toasting, browning, warming and the like. In many places the broiler is turned on high at 6 a.m. and not turned off until midnight. The heating elements must operate at a higher temperature than those of any other kitchen apparatus.

The mechanism for raising and lowering the grid must be simple, rugged, and convenient for the chef to operate.

Waffle Iron

The heavy duty electric waffle iron is a rather new device for which there has been a sudden and rapidly growing demand. Individual round waffles about 8½ inches in diameter are by far the most popular shape and size. A three-section iron of this type has a capacity of approximately 120 waffles per hour.

The upper and lower irons are each heated with separate helical core sheathed wire elements in which the terminals are brought out at the back so as to be fully protected against grease and the like. A two-heat switch is provided for each iron, the low heat being just sufficient to maintain the iron at operating temperature when not being used.

Clocks and Watches

A SHORT REVIEW OF THE HISTORY, PRINCIPLES AND DEVICES OF TIME KEEPING

By Chester I. Hall

Experimental Laboratory, General Electric Company

Time of day is of intimate concern to all of us from the age of a few years, and it is not surprising that devices to record the passing of the day were in existence hundreds of years before the birth of Christ. The oldest and the principal timepiece for centuries was the sun dial; but this was useless on cloudy days and after the setting of the sun. This deficiency started the long series of inventions and refinements which has culminated in the marvelously accurate pendulum clocks and chronometers of today. Mr. Hall believes that future development, instead of attempting to improve what is already a wonder of scientific attainment, should aim at some system of automatically setting to correct time every twenty-four hours from a station such as the Naval Observatory at Washington.—Editor.

In our modern high speed life, time is becoming always more important to us and more a part of our activity, conversation and thought. In spite of this fact the average man knows little of the wonders of present-day time-keeping devices. His watch either runs or does not run, it either keeps time or does not keep time, and that is the end of his interest. And yet the desire for accurate time-keeping is as old as history itself, and horology was an established science when B.C. became A.D. The ancient Egyptian astronomers had selected certain stars which crossed the meridian at approximately equal intervals during the night, and so divided it into units corresponding to hours, and these periods were numbered in an orderly fashion.

Man is largely concerned with the change from day into night and night into day, so it would seem logical to take this cycle as a fundamental unit in our measure of time. Fortunately the average rotation of the earth about its axis is, within the limits of accuracy of our measurements, at an absolutely constant rate. Astronomers have given us positive proof that the time required for one revolution is the same today as it was in the time of Hipparchus, an Alexandrian who lived about 2000 B.C. Calculations of the eclipses show a variation of less than 1/200 of a second from his day to ours.

In order to determine the speed of rotation of the earth, it is necessary to refer to some fixed point outside the earth. Such a point may be the sun or a fixed star. If the revolution is measured with reference to the sun it is called a solar day, and with reference to a fixed star a siderial day. These two differ in length because the earth makes one revolution about the sun during a year, thus making one more solar than siderial day during the year. But the rate of travel of the earth around the sun is not uniform, being faster when nearest the sun, so the variation of the length of a solar day may be as much as 30 seconds plus or minus. In order to correct for these variations, we have established an average or mean solar day that forms the fundamental unit of our present time system. The division of the mean solar day into its fractional parts was made at a time before the adoption of the decimal system and during the vogue of the sexagesimal system, so that we have twenty-four hours per day, sixty minutes per hour and sixty seconds per minute. Lengths of time shorter than one second are given in the decimal notation.

The problem before the ancient horologist was the construction of a device which would measure off not only the mean solar day but its fractional parts with sufficient accuracy to be useful.

The first attempts were undoubtedly in the direction of crude sun dials, for as early as 725 B.C. we have a record of the use of such an instrument. "And Isaiah, the prophet, cried unto the Lord; and he brought the shadow ten degrees backward, by which it had gone down in the dial of Ahaz."

For century after century the sun-dial continued as the principal time piece, practically unchanged except in refinements of construction. It was largely intended for permanent mounting in the garden or on the roofs of houses, but there are records of pocket dials (Fig. 1) that were small enough to be carried about but which could not be used until a meridian had been established, so that a time reading was laborious and could only be done by the educated. However, the most refined of sun-dials was useless on cloudy days and at night. This led to the development of devices that would measure out equal intervals of time without reference to the sun.

The earliest form of record was the clepsydra or water clock, in its simplest form an earthern-ware vessel with a small hole at the bottom which would empty itself at a fairly uniform rate. This was first used in the Grecian era to set a limit to the speeches in the courts of justice. Apparently the modern lawyer has a very ancient and honorable precedent for love of the sound of his own voice.

Fig. 1. Chinese Pocket Sun Dial

Indicating mechanisms were added later (Fig. 2), Plato being credited with the invention of a clepsydra that would indicate the hours of both the day and night. A water clock made in Alexandria about 135 B.C. consisted of a series of wheels which upon rotation by a stream of water caused the gradual rise of a little figure which pointed out the hours on a graduated scale with a tiny wand. In the time of the Cæsars one of the favorite forms consisted of a large copper vessel containing holes at the bottom, which was floated in a fountain and would gradually sink as it filled, and as it submerged would automatically ring a gong, upon which a servant would empty the vessel, reset the gong and await the completion of the next cycle. Man power was cheap in the good old days.

Various other devices were used in the home for the marking of time intervals, such as the hour glass using the flow of sand, which has descended to us as an egg timer, and the marked candle and lamp. The candle of standard diameter and wick size was marked with rings at equal distances, the spaces being sometimes numbered with the hours of the night; and the lamp containing a float and indicating rod in the fuel chamber showing roughly the passage of time.

No change took place in the fundamentals of the timing mechanisms until about the thirteenth century. The invention and development of balance clocks corresponding very closely in form to those of today, are ascribed on rather poor authority to Pope Silvester II, in about 996 A.D. It is recorded, however, that a balance clock was installed in one of the towns of Westminster in 1288.

The clock of this period consisted of weights as the power source, and a train of gear wheels terminating in a verge escapement driving a balance wheel. A verge escapement is shown in Fig. 3.

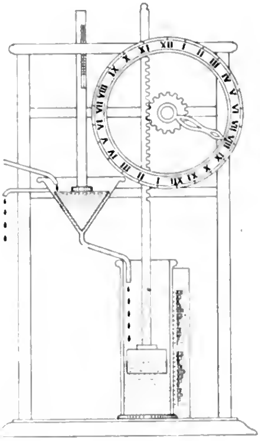


Fig. 2. Clepsydra or Water Clock

The first great step in the improvement of the clock is due to the great inventor and physicist Galileo in the 17th century. The story has it that sitting in church, apparently thinking of anything but the service, he suddenly noticed that a censer swinging from the ceiling synchronized with his pulse beat, and even upon a greatly decreased swing, when almost stopped, maintained its rate of oscillation. Further tests brought out the true isochronism of a free pendulum. Galileo himself, however, made no practical application of his discovery except to construct some portable pendulums that physicians of the day used in taking the pulse of their patients.

The germ of the idea of a modern timepiece was due to Galileo's son, who built an entirely practicable mechanism which not only connected the pendulum to an indicating train to show the time of day, but also gave it an impulse at the beginning of each stroke to maintain it in oscillation. A clock of this type said to be the original model is now on exhibition in the Victoria and Albert Museum in England. The type of escapement used is shown in Fig. 4.

Most of the development in pendulum clocks since the time of Galileo has been concerned chiefly with improvement in the escapement and impulse mechanisms and in the compensation for the various slight errors due to changes of length of stroke, temperature, barometric pressure and humidity.

These refinements have made the modern astronomical clock one of the wonders of the world.

A completely compensated clock installed in the Swiss Observatory at Neuchatel has been very carefully rated for a period of five years, and during that time its maximum deviation from absolute accuracy has been .033 seconds. It is of course calibrated and adjusted every night, the regulation in this case being obtained by means of a variation of barometric pressure inside the clock case.

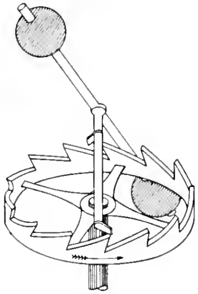


Fig. 3. Verge Escapement

What are the refinements of design necessary to maintain such extreme accuracy?

The fundamental equation of a simple pendulum is

$$T = \pi \sqrt{\frac{L}{G}}$$

in which T is the time of a complete oscillation, L is the distance from the point of support to the center of mass of the pendulum and G is the acceleration of gravity for the point at which the pendulum is mounted. Substitution in this formula will give a length of approximately 39 inches for a pendulum of one second per oscillation. The determination of the exact length required is usually by trial. Theoretical isochronism of a pendulum having a variation of amplitude of arc cannot be obtained unless the curve generated by the center of mass is a cycloid. But the circular arc and the cycloid so nearly coincide for 2 degrees on each side of dead center that the usual pendulum is accurate for practical purposes. If, however, the arc of travel is increased from 4 degrees to 4.2 degrees, a clock will lose 0.66 seconds per day. It is apparent, therefore, that the pendulum must maintain a constant arc of swing. This is obtained, first, by the use of a gravity escapement in which the impulse given to the pendulum is absolutely constant, and second, by the maintenance of a constant barometric pressure so that the resistance to motion is constant.

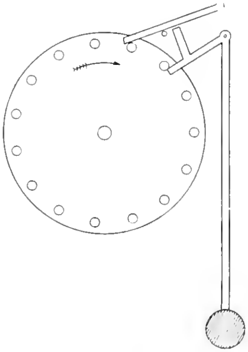


Fig. 4. Pin Wheel Escapement (Galileo)

To prevent the effects of temperature (due to the increase and decrease of the length of the pendulum bar) the bar is usually made of

Invar, a nickel-iron alloy having a temperature coefficient of expansion of approximately 0.000001 per degree C. This slight expansion is compensated for by the use of a bob supported at the bottom and made of a metal having a high coefficient of expansion, so that the center of gravity of the mass is moved as the bar changes length. As a further assurance the entire mechanism is kept at constant temperature.

The effect of variations of atmospheric pressure on the rate of a pendulum are large enough to cause considerable errors due to two different effects. First, since the bob is immersed in air the buoyant effect of the air will vary with its density, and while the mass remains the same the acceleration of gravity acting upon it will be decreased with an increase of density, so that the clock will lose about 0.15 seconds per day for each inch (mercury) rise of pressure.

Second, the mass of air carried with the bob will increase with an increase of density of the air causing a slowing of the clock of about 0.33 seconds per day for each inch (mercury) rise of pressure or a total of 0.45 seconds per day per inch rise (mercury). This effect is eliminated by maintaining constant pressure inside a sealed case usually slightly below the atmosphere.

Even changes of humidity will cause variations in the rate of a pendulum clock due to two factors: first, the air carried with the bob will be of different weight due to the variation of water vapor, and second, the arc of travel will change due to changes of air friction.

It is interesting to find that the development and perfection of this wonderful instrument, the observatory clock, is not due to any one genius, but is a combination of the ideas of hundreds of inventors, designers and scientists over a period of about ten centuries.

But a pendulum clock is not portable and cannot be carried in the pocket. One of the early ancestors of the modern watch was built by a blacksmith of Neurenburg about 1500 and was known as the "Neurenburg Egg." It was constructed entirely of iron, was about the size of a large goose egg and weighed about four pounds. It had a spring for the power source, a gear train to transmit the power, an escapement to regulate the rate of unwinding of the spring and hands and dial to indicate the time of day. It was not a good time-keeper but it contained all the fundamentals of the modern watch. The verge was the only escapement available at the time and had to be used in spite of its erudity. But during the middle ages extreme accuracy in a pocket timepiece was not of very great importance. There were no trains to be caught; so the watch became an ornamental jewel, the insignia of the aristocrat.

The improvement in accuracy was largely due to the needs of navigation. Time of day was essential in getting a "dead reckoning" and a pendulum clock could not be used on a rolling vessel. So by gradual development the ship chronometer came into being, permitting the improvement of the watch until today we are all able to carry timepieces of better accuracy than most scientific laboratory apparatus. A few little pieces of brass and steel combined with the brains of countless inventors of present and past ages, and we have a watch.

Improvements in both clocks and watches are still going forward, but they are very detailed in nature and the result on the time keeping qualities can usually be determined only by careful scientific tests.

Development for the future, instead of being an attempt to increase the accuracy of a device that is now one of the wonders of scientific attainment, should be in the direction of automatically resetting to correct time every twenty-four hours with reference to some time standard such as may be obtained from the Naval Observatory at Washington. The entire world could then be put into step and automatically synchronized every day.

Method of Selecting Gearing for Motor-driven Cargo Hoists and Winches

By J. A. Jackson

Power and Mining Engineering Department, General Electric Company

In determining the gearing for motor-driven hoists and winches it is best practice to base calculations on the average load to be handled, making the rope speed for this load the maximum that is consistent with safety and accurate control. The speed at rated load and overload will then depend upon the speed characteristics of the motor. The author shows how to calculate the proper gearing for hoists and winches when driven by constant speed motors and variable speed motors, the latter classification including compound wound motors.—Editor.

Specifications for winches and hoists used on cargo handling work usually specify the rated load with rope speed at that load, and also specify the maximum load which the equipment must be guaranteed to handle. It is questionable whether this is the best way to compile the specifications, as the load handled by the hoist most of the time is far below (often less than half) the rated load, and the important thing to know is how fast will the hoist handle this average load. The rated load is generally of such a weight that it must of necessity be handled carefully and moderately slowly, while the average load can be conveniently and safely handled at a much higher speed. For the purpose of this article then, the average load and corresponding rope speed will be specified, allowing the rated load speed and the overload speed to come what they will as determined from the speed characteristics of the motor.

Constant Speed Motors

The selection of the correct gear ratio for a hoist driven by a constant speed motor, such as a d-c. shunt or an a-c. induction motor, is not at all difficult. Knowing the rated *full load* speed of the motor, the rope speed in f.p.m. and the diameter of the hoist drum to the rope center, it is a simple matter to determine the gear ratio by the formula

$$\text{Gear ratio} = \frac{R \times \pi \times D}{S} \qquad (1)$$

where R = full load speed of motor in r.p.m.
D = diameter of drum to rope center in feet
S = speed of rope in feet per minute.

The rope speed on a hoist driven by a constant speed motor varies only a few per cent (usually not over 5 per cent) between full load and no load on the hook; hence the horse power required for hoisting various loads is directly proportional to the load with a maximum possible error of about 5 per cent.

Variable Speed Motors

When a hoist is driven by a variable speed motor, such as a d-c. series or compound wound motor or a single-phase variable speed a-c. motor, the determination of the correct gear ratio and the horse power requirements can not be obtained as simply as for constant speed motors. While variable speed motors are always given a rated horse power and speed by their makers, these values are nominal only and merely show what the motor can stand for a short run (usually ½ or 1 hour) with a definite temperature rise. It is only a rare coincidence if the rated speed has any relation to the gearing necessary to meet the required conditions. To determine the gearing when using variable speed motors it is necessary to know

(1) The rope speed in feet per min. at which a definite load in pounds must be hoisted.

(2) The mechanical efficiency of the hoist or winch when handling this load.

(3) The diameter of the drum to the rope center.

For example, a cargo winch has a rated full load capacity of 4000 lb., must be able to handle 6000 lb. occasionally, and its average load is 2000 lb. Since most of the winch work is performed at average loads, the speed at this load is the most important speed and is the speed which should be specified. Assume then that a 2000-lb. load must be hoisted at 200 f.p.m. on a drum 1.887 ft. in diameter to the rope center. The mechanical efficiency of the winch from the load to the motor pinion must be assumed, and since this efficiency varies with the load it is advisable to plot an efficiency curve. As a starting point, it is necessary to assume the efficiency at the rated full load of 4000 lb., and this efficiency will be taken as 80 per cent. The equivalent rope pull at the motor pinion to hoist a 4000-lb. load will then be

$\frac{4000}{0.80} = 5000$ lb., or the losses between the load and motor pinion will be represented by a rope pull of $5000 - 4000 = 1000$ lb. Tests made on several hoists operating at moderate rope speeds showed that the losses when hoisting a light hook are roughly one-half the losses when hoisting rated load. Applying this rule in this case, the no-load loss would be represented by $\frac{1000}{2} = 500$ lb. rope pull. Assuming that the losses are proportional to the load on the hook, a straight line loss curve (See Fig. 1) can be plotted starting at 500 lb. for no load and passing through 1000 lb. loss at 4000 lb. load. The efficiency curve shown in the same illustration can then be readily calculated as follows:

Efficiency =

$$\frac{\text{Hook load}}{\text{Hook load} + \text{loss in equivalent rope pull}} \quad (2)$$

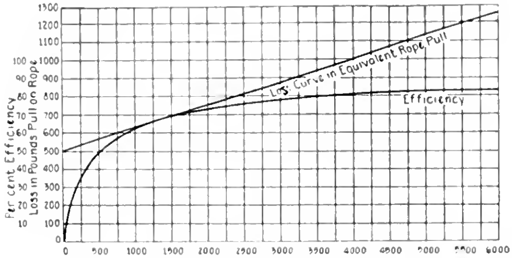


Fig. 1. Loss and Efficiency Curves for Determining the Correct Gearing of Hoists Driven by Variable Speed Motors

The efficiency curve shows the efficiency at 2000-lb. load to be 73 per cent; hence the horse power when hoisting this load at 200 f.p.m. is

$$\frac{3000 \times 200}{33000 \times 0.73} = 16.5 \text{ h.p.}$$

A motor rated at 16.5 h.p. would, however, not be large enough since the rated load of the winch is 4000 lb. and an overload of 6000 lb. must be handled occasionally; and further, the motor must have sufficient capacity to stand the heating when operating on a rapidly recurring cycle.

The next step then is to *assume* a definite motor and see if it will meet all conditions. Assume that a 25-h.p., 550-r.p.m., 230-volt d-c. series wound motor will be about what is required and obtain from the manufacturer the speed-torque characteristics of this particular 25-h.p., 550-r.p.m. motor (Fig. 2). From these curves it will be found that the speed of this motor at 16.5 h.p. is 720 r.p.m., and the torque in pounds at one foot radius is 120. The gear ratio can then be found by substituting in formula (1), using 720 as the full load speed of the motor. It is found to be $\frac{720 \times 3.14 \times 1.887}{200} = 21.32$ to 1 total gear ratio.

If the rated speed of the motor (550 r.p.m.) was used to determine the gear ratio (a mistake which is commonly made) the ratio would be

$$\frac{550 \times 3.14 \times 1.887}{200} = 16.28 \text{ to } 1.$$

The actual rope speed when hoisting a 2000-lb. load would be 236 f.p.m. instead of 200 as required, and the duty on the motor would be much more severe.

Reverting to the correct gear ratio of 21.32 to 1, the next step is to check the torque on the motor when hoisting the maximum load for which the winch is designed to see whether it is within the range of the motor. The winch efficiency for 6000 lb. is 82.5 per cent as read from the curve. The torque in foot-pounds at the motor pinion can then be calculated by the formula

$$T = \frac{P \times r}{g \times e} \quad (3)$$

Where T = torque in pounds at 1 ft. radius at motor pinion,
P = pounds load on hook,
r = radius of hoist drum to rope center in feet,
g = total gear ratio,
e = mechanical efficiency from load to motor pinion.

Substituting, the torque for a 6000-lb. load is found to be

$$T = \frac{6000 \times 0.943}{21.35 \times 0.825} = 321 \text{ lb. at 1 ft. radius.}$$

An inspection of the motor curve shows that this torque is well within the range of the motor; hence from a torque standpoint the motor is large enough. The speed of the motor at 321 lb. torque is 495 r.p.m., which corresponds to $\frac{495 \times 3.14 \times 1.887}{21.35} = 137$ f.p.m. rope speed for a 6000-lb. load. By the same method the rope speed with a 4000-lb. load is found to be 167 f.p.m.

The 25-h.p. motor is therefore satisfactory from a torque standpoint and must be checked to see if it will stand the heating on rapid duty cycle work. The calculations to determine this are beyond the scope of the article.

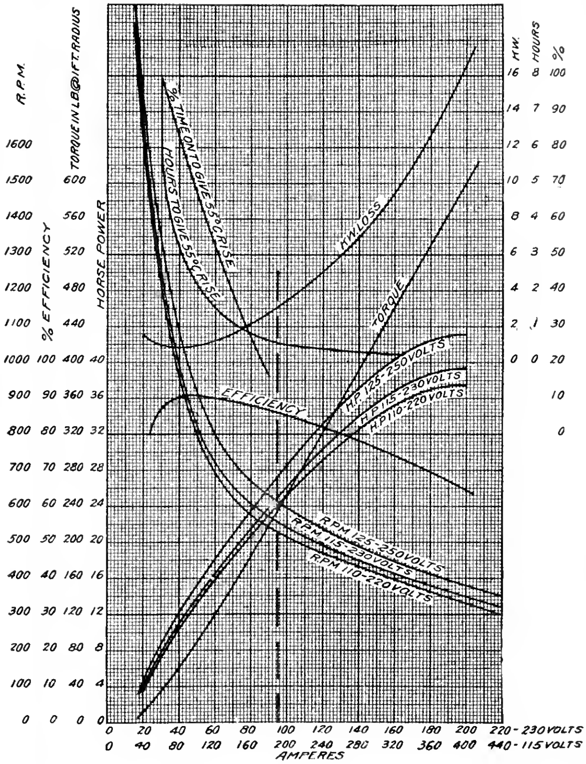


Fig. 2. Characteristic Curves of a 25-h.p., 550-r.p.m., 230-volt, Direct-current Series-wound Motor

Compound Wound Direct-current Motors

The correct gearing to use with compound wound motors is determined by the same method as that given above for other variable speed motors, taking particular care, however, to use the correct curves for the compound wound motor. A mistake is sometimes made in using the speed curve of a series motor to determine the gearing when a compound wound motor is to be used. This, of course, gives an incorrect gearing.

Compound-wound motors are generally used on winches which have both nigger heads and a drum in order to hold down the rope speed when handling light loads on the nigger head. To meet this load condition an intermittent rated motor is ample just as it is on a winch with a drum and no nigger heads, since the load is of an intermittent character. However, when operating with the nigger heads it is the practice of stevedores to allow the motor to run continuously and handle the load entirely by throwing the rope on and off the nigger heads. Thus the shunt field winding remains on the line continuously at its full strength, for which reason it is necessary to design the shunt winding for continuous duty. This means larger copper than would be used for an intermittent field, and in order to get this larger wire into the available space it is necessary to take off more of the series field turns than would be removed if an intermittent shunt field could be used. The effect of this is to reduce the field strength at normal rated load, and thus increase the rated speed of the motor. This increase is usually from 25 per cent to 35 per cent, making the rating of a 25-h.p., 550-r.p.m. series motor, 25 h.p. at about 725 r.p.m. when compound wound with a continuous rated shunt field. This change in speed makes it very important to get a correct speed curve to determine the required gearing.

Control Equipment of Paulista Locomotives

By P. W. Forsberg

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The principal features in the electrification of the Paulista Railway of Brazil were outlined in an illustrated article in the General Electric Review for July, 1921. The freight and passenger locomotives were described, as were also the substations, high tension transmission line and secondary distribution. Brief reference was also made to the form of locomotive control; but as the performance of the locomotives is directly dependent upon the design and functioning of the control equipment, and as the control for the Paulista locomotives differs in some respects from anything that has been developed before, Mr. Forsberg has prepared a separate article on this part of the equipment.—Editor.

Work is nearing completion on the new electrified section of the Paulista Railway of Brazil, and it is expected that electric operation will be in full swing within a very short time. The electrification of this line has been of particular interest, as it marks the inauguration of electrification of the main lines of South America, where wood has been used extensively for locomotive fuel, and the problem of cutting and transporting this fuel from the gradually receding forests has brought the electrification question abruptly to a head. In steam road electrification the locomotive is always of particular interest; for after all the sole purpose of a railroad is to get the tonnage over the road, and the power, reliability and performance of the locomotive determine, possibly to a greater extent than anything else, the success and sufficiency of the whole project.

It should therefore be of interest in connection with the general information that has already been published on this electrification, to give a detailed description of the locomotive control and its functioning.

The Locomotive

As the control is determined by the weight and required performance of the locomotive, a brief description of the locomotive will be given. Fig. 1 shows the profile of the road over which the locomotives are to operate with freight trains of 700 metric tons and passenger trains of 400 metric tons trailing. The rolling profile of the road, characteristic of so many railroads of South America, stands out in striking contrast to our American roads, and has a particular bearing on the selection of control and especially the regenerative braking control. The present electrification extends only from Jundiahy to Campinas, 44 kilometers of double track, but the plans involve a future extension to the entire broad gauge section of the line shown in the profile.

TABLE I

DATA ON ELECTRIC LOCOMOTIVES FOR PAULISTA RAILWAY

	Freight	Passenger
Length overall	39 ft., 2 in.	55 ft.
Width	10 ft., 1¼ in.	10 ft., 1¼ in.
Height over 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 equipment	118,800 lb.	158,900 lb.
Weight of electrical and brake equipment	81,200 lb.	81,100 lb.
Diameter of drivers	42 in.	42 in.
Diameter of guiding wheel	......	36 in.
Number of motors	4	4
Gear ratio	82/18	70/30
Total continuous rating, h.p.	1,600	1,600
Total (1-hour rating) h.p.	1,680	1,680
Tractive effort, continuous	27,300 lb.	13,900 lb.
Tractive effort, one hour	28,900 lb.	14,750 lb.
Speed, continuous rating, m.p.h.	22.1 (35.6 km.)	43.4 (69.8 km.)
Speed, one hour rating, m.p.h.	21.8 (35.1 km.)	42.8 (68.8 km.)
Maximum safe speed	30.5 (50 km.)	55 (90 km.)
Tractive effort, 30 per cent coef. adh.	60,000 lb.	48,000 lb.

Power for the locomotive is obtained at 3000 volts from an overhead of twin catenary construction, and is supplied to the trolley by three 1500-kw. motor-generator sets from a single substation located at Louveira.

The passenger and freight locomotives differ in construction and gear ratio, but the same control is used on both types. The locomotives are equipped with four GE-267 self-ventilated motors. The general data are given in Table I.

The train is equipped with vacuum brakes, while the locomotive is equipped with compressed air brakes. Air and vacuum are furnished by a combined compressor-exhauster set operated by a 3000-volt motor running continuously. A control generator geared to the compressor-exhauster shaft furnishes control power at 65 volts and charges an auxiliary storage battery which may be used to supply current for control in an emergency, and for lights and testing when the compressor-exhauster is shut down.

Current Collection

The system of current collection is the same as that used on the C., M. & St. Paul locomotives. The pantagraph is of the sliding type with two independent contact pans, each of which has four copper contact strips with a groove for lubrication. The pans are equipped with long horns to prevent fouling with the overhead when the pan runs off the wire. The range in working height is about 9 ft., and throughout this entire range the pressure against the wire is approximately constant.

The pantagraph is air raised and gravity lowered. This assures that the pantagraph cannot rise accidentally. This is very important from the standpoint of safety. The pantagraph is shown in Fig. 2.

To provide for raising the pantagraph when there is no air on the locomotive, a hand pump is used by which air may be pumped either directly into the air cylinders of the pantagraph, or into a trolley reservoir from which the pantagraph may be raised later. The trolley reservoir is equipped with a globe valve which may be closed after shutting down the compressor when the locomotive is to be out of service for some time. By this means sufficient air can be held in the reservoir to raise the pantagraph after a period of eight or ten hours or more. It will therefore seldom be necessary to operate the hand pump.

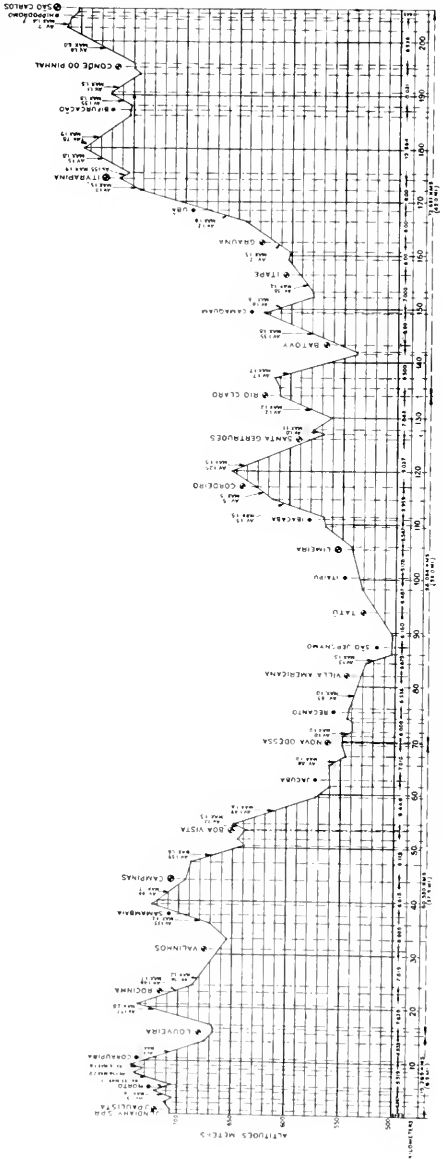

Fig. 1. Condensed Profile Showing Maximum and Average Grades. Gauge 1 M, 60

Accelerating and Motoring

There are two combinations of motors, viz., series with all four motors in series, and series-parallel with two groups of two motors in series. The control provides for 14 accelerating steps in series and 10 in series-parallel.

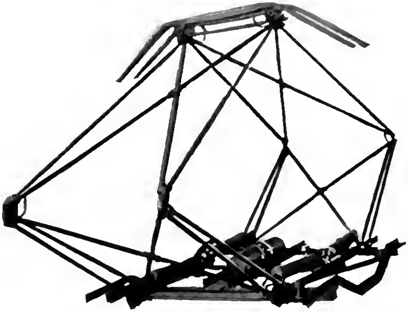

Fig. 2. 3000-volt Pantagraph Trolley Shown in Raised Position

The 14th step series and the 10th step series-parallel are running steps with all resistance cut out. Two additional running steps are provided by shunting the motor fields either in the full series position or in the full series-parallel position. Figs. 3 and 4 show the accelerating and running characteristics of the freight and passenger locomotives. These curves show the even distribution of steps for acceleration, and especially the small torque steps between 10 and 25 per cent tractive effort with the locomotive at rest. This is a very important point in the starting of heavy freight trains, for if the steps in this area were large the train might not be able to start on one point but might slip on the next, which would lead to difficulty in starting a heavy drag.

Transfer from series to series-parallel is accomplished by merely moving the main controller handle from full series to the 1st step series-parallel, or one notch on a progressive dial. When passing from the full series position to the 1st parallel position on the master controller, the series resistance is automatically cut in and then an air-operated cam switch throws, which short circuits a pair of motors and disconnects them from the line, leaving the other pair with their torque maintained, after which the disconnected pair are connected in parallel with the other pair. This allows a smooth transfer, as the timing of the insertion of resistance and the throwing of the switch is always the same, and is out of the control of the operator. The sequence of the cams on the transfer switch insures against any false connections during transfer. Torque is maintained during transfer in going back from series-parallel to series as well as from series to series-parallel, which insures against a sudden loss of torque when turning back, and reduces the chances of pulling draw bars or causing severe strains on the train, by allowing a gradual decrease in torque.

At each of the full running positions the fields may be shunted by throwing a separate selective handle to the shunting position.

Regenerative Braking

Regenerative braking as applied to the Paulista locomotives is of particular interest as it involves a radical departure from any system used heretofore, and the small increase in cost, weight and complications required over simply a motoring locomotive has opened a field for the use of regeneration on locomotives where it has hitherto been

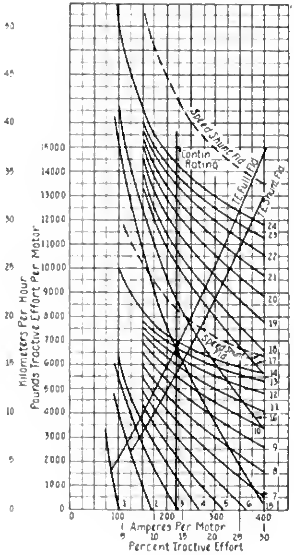

Fig. 3. Accelerating Characteristics of Freight Locomotive

impractical to apply it on account of the limitations in space, cost and weight per axle.

When deciding upon the system of regeneration to be used, the characteristic of the profile and the method of train handling were considered. The profile is very broken with numerous short grades, and it was possible to take advantage of this condition to furnish a regenerative system which is very simple and reliable, and yet fully adequate for the service. No system of regeneration is justified for this service that does not fulfill the following requirements:

(a) No reduction in reliability of operation.
(b) Low additional cost and weight.
(c) Ruggedness and reliability of apparatus.

It was with these points in view that this system of regeneration was adopted. The particular feature of the regenerative system is that the same apparatus is used for controlling the regeneration as is used for acceleration. One of the motors is used to excite its own field and the field of the other three, and the regeneration is controlled by the same controller, contactors and resistors as are used for acceleration. By this means the maximum economy in the use of apparatus is obtained, together with the additional advantage of using the same rugged and reliable apparatus for regeneration as for acceleration and motoring. Thus the necessity of using extra relays, contactors, controllers and motor-generator exciter sets, all of which involve added complications, is eliminated, maintenance costs lowered and reliability of operation increased.

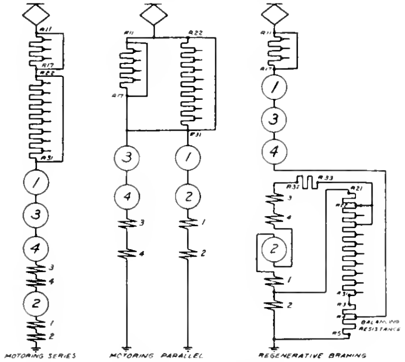

Fig. 5. Simplified Diagram Motoring and Regenerative Braking

Fig. 5 shows in a simplified form the connections for motoring, series and series-parallel, and for regenerative braking. This diagram shows the simple changes that are necessary in the series motoring connection to give the braking connection. The balancing resistance, which is used to stabilize the excitation and compensate for line voltage fluctuations, is connected in a particularly advantageous location with respect to the exciting motor field, so as to give the maximum protection to the motors against disturbances on the line. A heavy surge of regenerated current may entirely kill, or even reverse the field of the exciter, thereby lowering the voltage and reducing the surge before excessive currents are reached. Figs. 6 and 7 show the regenerative characteristic of the freight and passenger locomotives, giving the range of regeneration in tractive effort and speed.

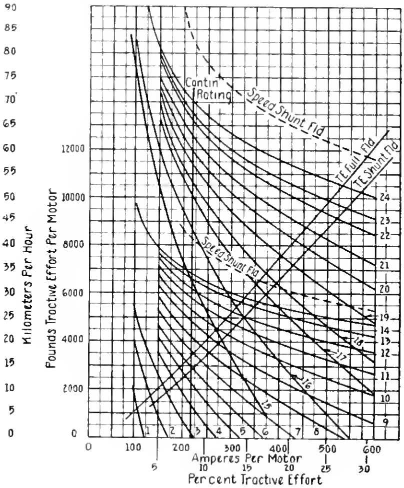

Fig. 4. Accelerating Characteristics of Passenger Locomotive

Operation and Connections

The schematic diagram of the main and control connections is shown in Fig. 8, which indicates the extreme simplicity of the control. The master controller, the development of which is given in the diagram, is shown in Fig. 9. The contact segments are screwed on a sheet iron cylinder making a particularly rigid but light construction. The mechanical interlocking is contained in the upper section.

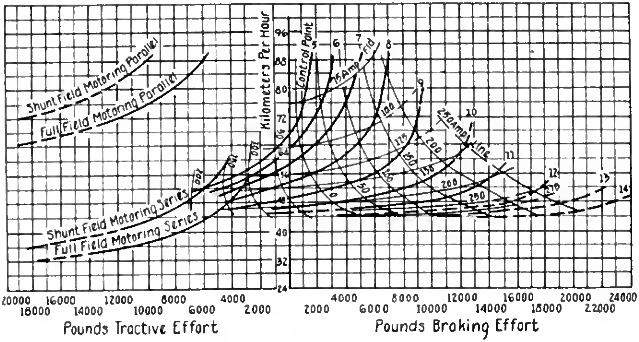

Fig. 6. Regenerative Braking Characteristics Freight Locomotive

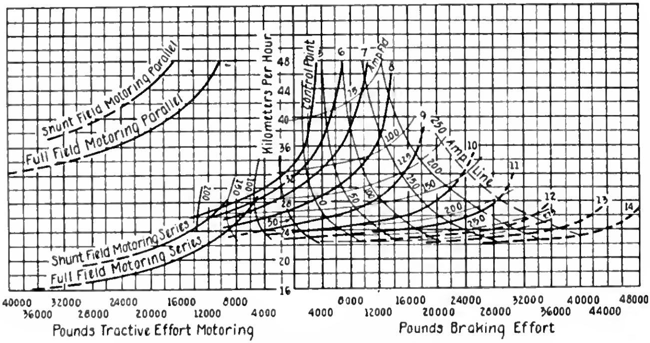

Fig. 7. Regenerative Braking Characteristics Passenger Locomotive

The locomotive is controlled from the operator's position shown in Fig. 10. The controller is shown at the left, the ammeters and air gauges in the center, and the brake valves to the right. At the left is also the pantagraph operating valve for raising or lowering the pantagraph. The controller has three handles, viz., reverse handle (top), selective handle by which motoring, braking or field shunting may be selected (middle), and the main handle (bottom) for controlling the acceleration and regenerative braking. To accelerate the locomotive the main handle is notched up on the dial. At each of the full running positions the selective handle may be thrown to shunt the field. If regeneration is desired it is simply necessary to move the main handle back to the 1st notch and throw the selective handle to the braking position, and then notch up on the main handle until the desired braking effort is obtained. The manipulation is very simple, and always assures a smooth transfer from motoring to regeneration by a gradual decrease of motoring torque to a very low value and then a gradually increasing braking torque. The controller is mechanically interlocked so that no false manipulation is possible.

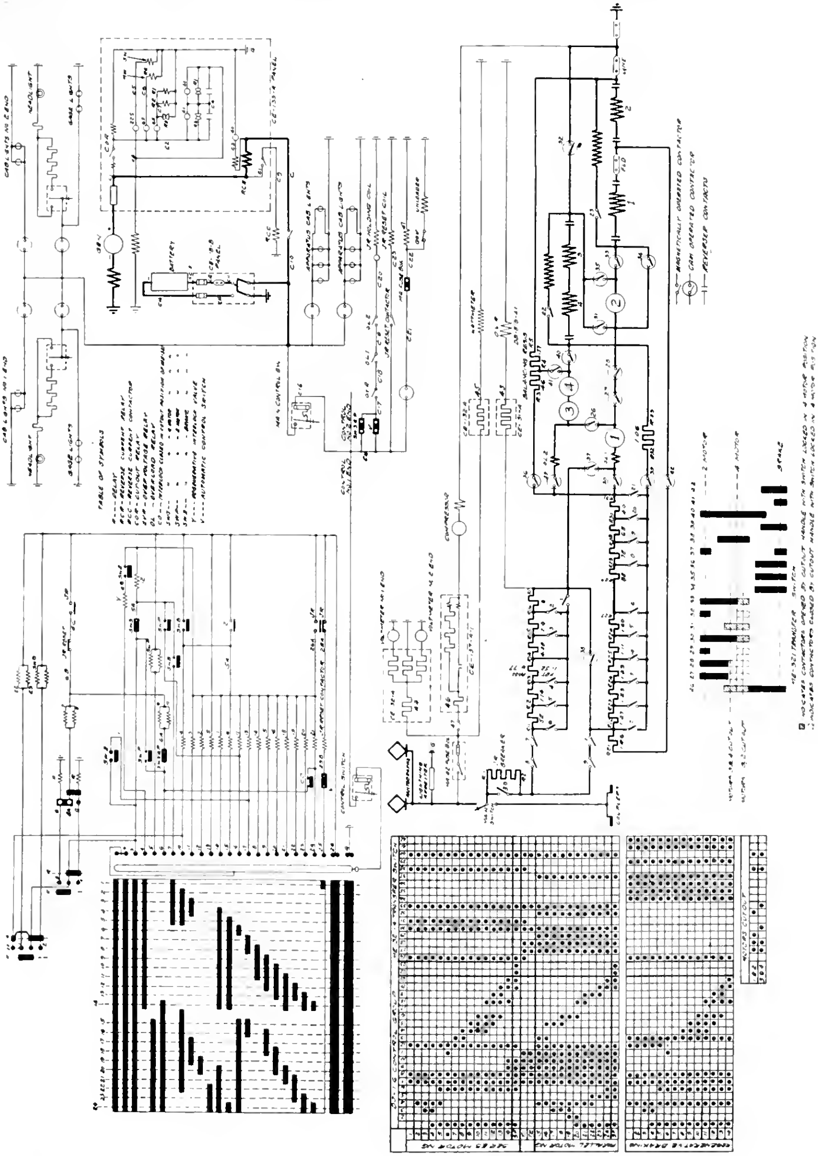

Fig. 8. Schematic Connections of Locomotive

Main Circuit Apparatus

The principal pieces of apparatus in the main circuit are:

2 sliding pantagraph trolleys,

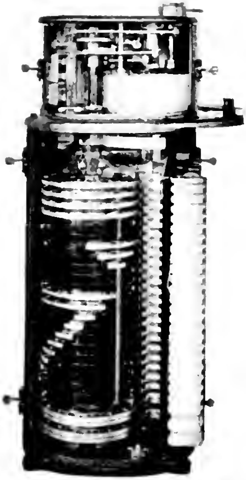

Fig 9. Master Controller with Covers Removed and Arc Chutes Swung Back

1 high speed circuit breaker,

1 group magnetically operated resistor and line contactors,

1 group electrically controlled, pneumatically operated cam contactors for series-parallel and regenerative transfer,

1 electrically controlled, pneumatically operated cam switch for reversing the motors,

32 grid resistors.

High Speed Circuit Breaker: Short Circuit and Overload Protection

A Type JR high speed circuit breaker is connected between the line and the rest of the apparatus in the main circuit. This breaker is shown in Fig. 11 and is similar to the ones used on the C., M. & St. Paul bipolar locomotives. It is used to protect the apparatus and motors against short circuits.

The principle of operation of this breaker will be understood by referring to the diagrammatic sketch shown in Fig. 12. The breaker is closed by a magnetic reset coil and held in by a holding magnet. The armature A of the contact arm is held by the poles of the holding magnet which are separated by a relatively small air gap. In this air gap a series bucking bar is inserted which carries the line current. When the current in the

Fig 10. Operator's Position on the Locomotive Showing Master Controller Ammeters, Gauges and Brake Valves

Fig 11. Locomotive High Speed Circuit Breaker

bucking bar reaches a certain value a flux is set up which opposes the flux in the armature, causing it to shift from the armature to the holding magnet air gap. This releases the armature and it is tripped by a powerful tension spring. Since the armature is released by a shifting of flux with practically no change in the flux of the holding coil, there is no inductive delay in tripping; the operation does not depend upon any latches or triggers; and the result is an extremely rapid operation which is particularly effective in protecting the motors and the apparatus. Tests have shown that on a short circuit the breaker will trip in *eight thousandths of a second*, which is about the time required for a commutator bar to pass from one brush to the next with the motor running at its maximum speed. The value of these breakers in protecting motors and apparatus has been well demonstrated in actual service on the C., M. & St. Paul Railway.

To protect the motors against abuse by heavy overloading, an overload relay is connected in each motor circuit. This relay trips at a predetermined setting and in turn trips the high speed breaker.

The breaker is automatically reset when the controller handle is brought back to the first notch.

Resistance Contactors and Line Breakers

A departure from former designs was made in the main circuit contactors of the Paulista locomotive. The contactor is magnetically operated and is the same in principle as the contactors used on the C., M. & St. Paul and Butte, Anaconda & Pacific locomotives. An improved arrangement is provided whereby the contactors may be assembled in a small space.

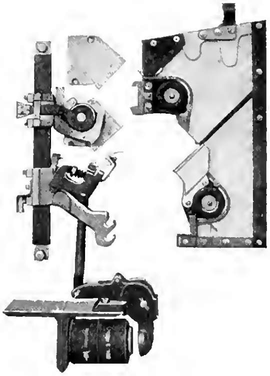
Fig. 13. Exploded View of a 3000-volt Contactor

Fig. 13 is an exploded view of the contactor. This figure shows the extreme simplicity and the few parts that make up the contactor. The coils in the arc chutes are auxiliary blowout coils

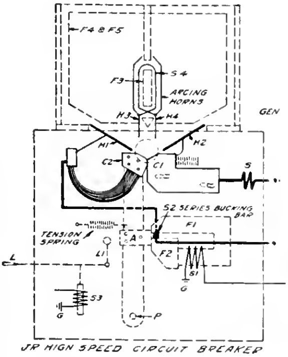

Fig. 12. Schematic Diagram of the High Speed Circuit Breaker

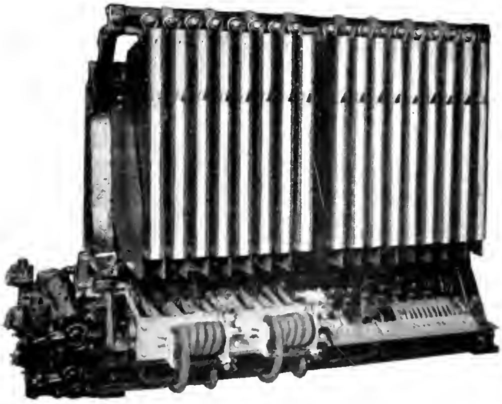
Fig. 14. 3000-volt Transfer Switch for Changing Over the Main Circuits for Motoring, Series and Series-parallel and Regenerative Braking Overload Relays Are Mounted in Front

which carry current only when an arc is being blown out. The arc catches on the arcing horns, which are shown bent around the coils, and travels out on the horns. A very powerful blowout is obtained, capable of clearing even a dead short circuit on the locomotive. In spite of the narrow spacing the contactor is easily accessible and easily removed. By taking out one bolt the arc chute may be swung down and removed. The entire contact element on the insulated rod may be removed by taking out two bolts and one cotter pin. These are points that can be fully appreciated by the maintenance man.

Series-parallel Switch

All contacts for rearranging the main circuits for series, series-parallel or regenerative braking are combined in one pneumatic switch in which the contactors are opened and closed by means of cams. The contactor parts are the same as those used for the individual contactors, thereby allowing an interchangeability of parts, with a minimum of supply parts to be carried in stock. By making these switches cam-operated from a common shaft, the proper sequence of transfer is always assured and no false connections are possible. Fig. 14 shows the transfer switch with its pneumatic engine. The overload relays are mounted on the support below the contactors.

In addition to the three positions obtained by pneumatic operation, a hand switch is added by which contactors may be opened and closed to cut out pairs of motors. Either pair of motors may be cut out in emergency.

Auxiliary Apparatus

The principal pieces of auxiliary apparatus are:

- 1 compressor-exhauster-generator set,
- 1 high-voltage auxiliary group, comprising panels for high resistances for wattmeters and voltmeter coils, and compressor starting apparatus.
- 1 lightning arrester,
- 1 storage battery.

Compressor-exhauster-generator Set

To reduce complications the compressor-exhauster and low-voltage control generator are combined in one set operated by a single 3000-volt series motor. The set is shown in Fig. 16. The compressor has a displacement of 48 cu. ft. of free air, and the exhauster a displacement of 150 cu. ft. The motor is connected to the line by a magnetic con-

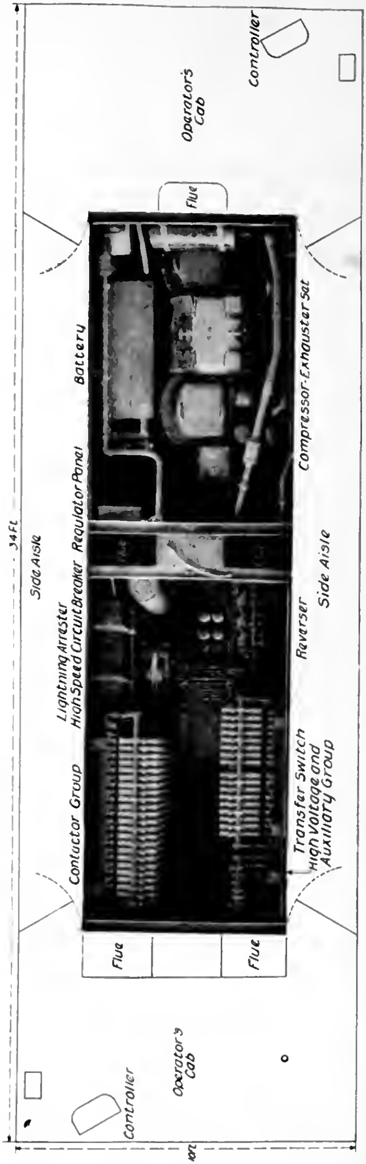

Fig. 15. View of Arrangement of Apparatus in Locomotive Looking Down with Hatches Removed

tactor, through a starting panel which consists of a series resistor and a series contactor which closes when the current has dropped to a predetermined value, shorting out the resistance.

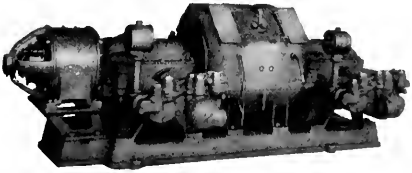

Fig. 16. 3000-volt Compressor Exhaust Set Geared to Control Generator

The set runs continuously. When the pressure reaches 90 lb. an unloader operates and allows the compressor to pump to atmosphere. The exhaust system is equipped with "snifters" similar in principle to a feed valve, which allow air to leak into the system when the vacuum has reached 22 inches of mercury.

The control generator, which is geared to the shaft of the compressor, furnishes control power and also charges an auxiliary storage battery. The generator is connected through a regulator panel, by which its voltage is held constant through a wide range of speed. A reverse current relay between the generator and the battery assures against the battery discharging into the generator when the set is shut down.

Lightning Arrester

The lightning arrester is of the electrolytic aluminum cell type and is protected by an expulsion fuse. This is the standard railway type of arrester, which has given excellent service through years of operation.

Arrangement of Apparatus

Fig. 15 shows the arrangement of apparatus in the apparatus cab, looking down with the hatch removed. At the left is shown the half of the apparatus cab which contains the contactor group, series-parallel switch, reverser, high speed breaker, lightning arrester and high-voltage auxiliary group. The floor covers are removed to show the insulators beneath the floor for hanging the accelerating grids. This view shows the neat arrangement and especially the accessibility of the apparatus. There is an aisle on each side of the apparatus cab from which, by the removal of covers, the backs of the groups where all high-voltage connections are made are readily accessible. The flues for ventilating the accelerating grids are shown on both ends and in the center.

At the right is shown the other half of the apparatus cab containing the compressor-exhauster set, storage battery, regulator and battery panels.

Fig. 17 is a view of the accelerating grids and shows the method of hanging. This view is taken from the side aisle. The apparatus is mounted above the grids, and the grids are mounted in a compartment entirely separated from the other apparatus. They are easily accessible from the side aisles by the removal of covers.

In the design of the apparatus and in the layout of this locomotive a long stride ahead has been made. Economy of apparatus, reliability, simplicity; these must be the keynotes of locomotive design. Unnecessary refinements, while not adding a single ton to the hauling capacity of the locomotive, always mean additional and a greater variety of apparatus, and consequently decrease the reliability of operation.

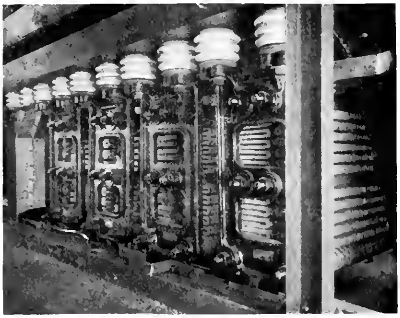

Fig. 17. View of 3000-volt Accelerating Grids Showing Method of Hanging

The Extreme Sensitiveness of the Action of Reducing Atmospheres Upon Heated Copper

By T. S. Fuller

Research Laboratory, General Electric Company

This contribution should be of great value to engineers. The breaking of copper, notably in the form of wire, when subjected to constant movement or vibration, is a source of much trouble and expense. The author not only shows the reason for this brittleness but shows the cure. This is another piece of industrial research that should lead to an advance in the industry.—Editor.

The fact that solid copper containing oxygen is made brittle by the action of reducing gases at high temperature is well known by many, but few, in the opinion of the writer, appreciate the extreme sensitiveness of the reaction.

This particular phase of a broad subject has not received the attention which it merits, and it seems fitting, therefore, at this time, to describe certain experiments which have a very direct bearing upon this phenomenon.

The embrittlement caused by the action of reducing gases upon heated copper has been studied by several, including Moore and Beckinsale,* who have attacked the problem in a very thorough manner, and whose results substantiate those of other investigators on the same subject.

In his discussion of Moore and Beckinsale's paper Mr. R. J. Redding† called attention to his experiments in annealing copper, which was being made brittle by vapors from oil remaining on the articles after leaving the lathe. After establishing the practice of cleaning the metal free from oil, and allowing a free circulation of air in the annealing pot, no further trouble from brittleness occurred.

Our experience has been somewhat analogous to that of Mr. Redding, and the source of the reducing atmosphere in our experiments was, if anything, more obscure than the machine oil described by Mr. Redding.

Copper wires were heated to 800 deg. C. for one hour in air in an electrically heated furnace under varying conditions. The results of the various experiments are summarized in Table I. The term "Ordinary Copper" refers to high conductivity wire purchased in the open market, it is assumed to be refined by the usual methods, and therefore to contain small amounts of oxygen; and the term "Boronized Copper" refers to metal which has been deoxidized by the addition of boron carbide to the superheated melt, thereby producing copper free or nearly free from oxide. Wires which cracked during the first right angle bend were termed brittle.

The first experiment listed in Table I was done in an attempt to find a means of heating ordinary copper to a high temperature without serious oxidation or embrittlement due to an excessive reducing atmosphere. The subsequent experiments were done in an effort to find out if possible why the ordinary copper became brittle when heated in air to 800 deg. C. in an iron tube filled with sand. No. 1 was repeated six times.

In searching about for the source of a reducing atmosphere in an iron pipe packed with sand and electrically heated to 800 deg. C., two possibilities were discussed; namely—

(1) Carbon in the steel pipe and cast iron plug giving CO on heating.
(2) Organic matter on the sand giving CO, CH_4, H_2, etc., on heating.

Experiment No. 2 was a repetition of No. 1, using ordinary copper cable, which became brittle. The boronized cable (oxygen free) used in No. 3 remained soft after the same treatment.

Experiment No. 4 was similar to No. 1 except that the steel pipe and cast iron plug were given a strong preliminary heating in the air. It was thought that by this means sufficient C might be removed from the surface of the metal container to eliminate the formation of a reducing atmosphere from that source. It developed later, however, that this could not be accomplished by a short heating. The copper test wire came out of the experiment soft at the top and brittle at the bottom, with an increase in diameter at the bottom equal to 0.003 inch.

In experiment No. 5 a boronized (oxygen free) copper wire was treated as in experiment No. 1. The wire after the treatment remained soft and did not change in diameter.

Experiments No. 6 and No. 7 are unique in that by the substitution of Al_2O_3 for sand and porcelain for iron the ordinary wires did

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* "The Action of Reducing Gases on Heated Copper," Jour. Inst. Met. No. 1, Vol. 25 (1921), pp 219-258.

† Mr. R. J. Redding, Discussion of Moore and Beckinsale's Paper, Jour. Inst. Met. No. 1, Vol. 25 (1921), pp. 244-246.

TABLE I

COPPER WIRES HEATED TO 800 DEG. C. FOR ONE HOUR IN AIR IN AN ELECTRICALLY HEATED FURNACE

Experiment No.	Kind of Copper	Description of Experiment	Diameter of Wire Before Heating	Diameter of Wire After Heating	No. of Times Experiment was Repeated	Result
1	Ordinary	Packed in clean sea sand in iron pipe—cast iron plug in bottom.	. . .	. . .	6	Brittle
2	Ordinary Copper Cable	Treated as in No. 1.	. .	.	0	Brittle
3	Boronized Copper Cable	Treated as in No. 1.	. . . . . .	.	0	Soft
4	Ordinary	Like No. 1 except pipe and plug first heated to remove some C.	0.115 in.	Top 0.115 in. Bot. 0.118 in.	0	Top—Soft Bottom—Brittle
5	Boronized	Treated as in No. 1.	0.028 in.	0.028 in.	0	Soft
6	Ordinary	Packed in finely divided Al_2O_3 in porc. tube. Wire removed and cooled in air.	0.102 in.	0.102 in.	0	Soft
7	Ordinary	Packed in finely divided Al_2O_3 in porc. tube. Wire cooled slowly in tube.	0.102 in.	0.102 in.	6	Soft
8	Ordinary	Packed in finely divided Al_2O_3 in iron pipe—cast iron plug in bottom.	0.102 in.	. . . .	3	Top—Soft Bottom—Brittle
9	Ordinary	Packed in clean sea sand in porcelain tube.	0.102 in.	. . . .	3	Top—Soft Bottom—Brittle
10	Ordinary	Packed in Al_2O_3 in Shelby steel tube. Cold rolled iron plug in the bottom.	0.102 in.	. . .	1	Brittle
11	Ordinary	Like No. 10 except pipe and plug first heated strongly to remove some C.	0.102 in.	. . .	1	Brittle
12	Ordinary	Like No. 9 except sand first ignited 4 hr. at 600 deg. C. to remove organic matter.	0.115 in.	. . .	0	Soft
13	Ordinary	Packed in finely divided Al_2O_3 in electrolytic iron pipe containing less than 0.003 per cent C, copper plug in the bottom.	0.115 in.	. . . .	0	Soft
14	Ordinary	Packed in finely divided Al_2O_3 in a copper pipe—copper plug in bottom.	0.115 in.	. . . .	0	Soft

not become brittle. Ordinary copper test wires were packed in finely divided Al_2O_3 in porcelain tubes and heated. The test wire of experiment No. 6 was removed from the Al_2O_3 while hot, and that of No. 7 was allowed to cool down with the Al_2O_3 and porcelain container. Both wires were soft, and neither had changed in diameter, showing that Al_2O_3 and porcelain are inert substances with respect to copper. Certainly this can not be said of steel and sea sand; No. 7 was repeated six times.

Fig. 1. Photomicrograph of Ordinary Copper. 75 times magnification

In experiments No. 8 and No. 9 ordinary copper test wires were packed in No. 8 in finely divided Al_2O_3 in an iron pipe having a cast iron plug in the bottom, and in No. 9 in clean sea sand in a porcelain tube. The result was the same in both experiments, e.g. a wire soft at the top and brittle at the bottom.

An attempt was made in experiment No. 10 to study the effect of a steel tube and plug containing less C than those heretofore used as containers. Accordingly an ordinary copper test wire was packed in finely divided Al_2O_3 in a Shelby steel tube having a cold rolled iron plug in the bottom. The effect after heating was to produce a brittle copper wire.

To still further reduce the C present in the iron container, in experiment No. 11 the Shelby steel tube and its cold rolled iron plug were given a strong preliminary heating in air at 800 deg. C. after which an ordinary copper test wire was packed in finely divided Al_2O_3 in the tube. The result after heating was the same as in the preceding experiment, i.e. a brittle copper wire. This would seem to indicate that very minute amounts of C are sufficient to furnish reducing atmosphere enough to cause the embrittlement of ordinary copper. Experiments No. 10 and No. 11 were each repeated once.

Experiment No. 12 was similar to No. 9 except for the preliminary heating of the sea sand to 600 deg. C. for four hours, with stirring, to burn off all organic matter. The ordinary copper test wire in this experiment remained soft after the heating.

Experiments No. 13 and No. 14 were similar to No. 8, No. 10, and No. 11, except for the substitution of an electrolytic iron tube containing less than 0.003 per cent C. with a copper plug in the bottom in No. 13, and a copper tube with a copper plug in the bottom in No. 14, for the ordinary iron containers in the previous experiments. Ordinary copper packed in finely divided alumina in the electrolytic iron and copper containers and heated did not become brittle.

The evidence furnished by all of the above experiments substantiates our hypothesis—that the carbon in the steel pipe and cast iron plug, giving CO on heating, and organic matter on the sand giving CO, CH_4, H_2, etc., on heating were the causes contributing to the reducing atmosphere which caused the embrittlement of the ordinary copper test pieces in experiment No. 1.

Photomicrographs

The experiments described in the preceding pages are well supplemented, and the extent of the damage done to the copper by the various treatments is well illustrated by the following photomicrographs:

The photograph in Fig. 1 shows the characteristic structure of ordinary copper in the annealed condition. Twinning and round globular spots of oxide are common.

Fig. 2 shows what happens to ordinary copper when it is annealed in hydrogen. The wide black lines are cracks which have opened up in the metal. The diameter of this wire was very appreciably increased by the hydrogen treatment.

Figs. 3 and 4 show by the black lines that although the effect of the reducing atmosphere produced in this experiment, e.g. by heating ordinary copper in an iron pipe packed with sea sand, is not as marked as that produced by the hydrogen, yet it is considerable. In fact the difference in mechanical properties between the samples in Figs. 2, 3 and 4 is very small indeed. The diameter of the wires in Figs. 3 and 4 was appreciably increased.

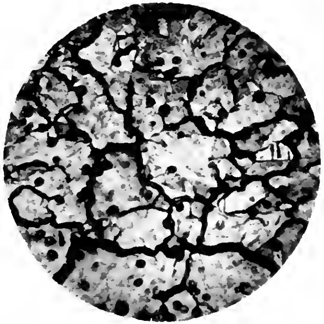

Fig. 2. Ordinary Copper Annealed in Hydrogen for Two Hours at 850 Deg. C. 200 times magnification

Fig. 3. Ordinary Copper Packed in Sea Sand in an Iron Pipe and Heated in Air to 800 Deg. C. for One Hour. 200 times magnification

Fig. 4. Ordinary Copper Packed in Sea Sand in an Iron Pipe and Heated in Air to 800 Deg. C. for One Hour. 200 times magnification

Fig 5. Ordinary Copper Packed in Finely Divided Al_2O_3 in a Porcelain Tube and Heated in Air to 800 Deg. C. for One Hour. 200 times magnification

Fig. 6. Ordinary Copper Packed in Finely Divided Al_2O_3 in an Iron Pipe and Heated in Air to 800 Deg. C for One Hour. 200 times magnification

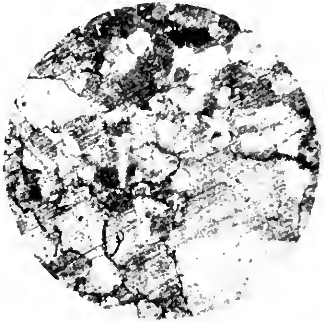

Fig. 7. Ordinary Copper Packed in Finely Divided Al_2O_3 in an Iron Pipe and Heated in Air to 800 Deg. C. for One Hour. 200 times magnification

Fig. 5 shows the effect, or rather the absence of any detrimental effect of the atmosphere in a porcelain tube filled with Al_2O_3 heated for one hour at 800 deg. C. The structure is characteristic of annealed copper.

Figs. 6 and 7 show, by the black lines, the damage done to ordinary copper by the reducing atmosphere produced in an iron pipe packed with Al_2O_3. The diameter of the samples in Figs. 6 and 7 was appreciably increased and their mechanical properties were similar to those of the samples in Figs. 2, 3, and 4.

Summary

As was stated in the beginning of this article the writer is doubtful if many appreciate the extreme sensitiveness of the action of very slightly reducing atmospheres on ordinary heated copper.

The desirable mechanical properties of ordinary copper are completely destroyed by electrically heating to 800 deg. C. in air for one hour in an iron pipe filled with sea sand—two substances which are not usually regarded as sources of reducing atmospheres.

The writer has regarded the small amounts of carbon in the steel, and small amounts of organic matter present on the sea sand, as the sources of this reducing atmosphere.

The ductility of the metal is destroyed by intergranular cracks which probably result from the formation, accumulation, and subsequent pressure of a gas resulting from the reaction of the reducing gas upon the oxide present in the copper.

Oxygen free copper is not affected by this treatment.

If finely divided Al_2O_3 be substituted for the sea sand, and a porcelain, electrolytic iron or copper tube, for the iron pipe, the ordinary copper may be heated to 800 deg. C. without damage.

Ordinary copper becomes brittle when heated in a steel pipe packed with Al_2O_3, or when heated in a porcelain tube packed with sea sand, unless the sand be first heated four hours at 600 deg. C. to remove organic matter.

Very slightly reducing atmospheres for long periods of time have much greater effects than highly reducing atmospheres for short periods of time.

Length-Voltage-Current-Pressure Characteristics of Normal Arcs for Different Electrode Materials

By W. N. Eddy

General Engineering Laboratory, General Electric Company

The characteristics of the arc have been the subject of much study, by Mrs. Ayrton, Duddell and Childe, all having done notable work in arriving at equations which held true over a certain limited range. In 1906 Dr. Steinmetz published an equation which held true for different materials over a large range of arc lengths. The results of these investigations are given in a usable form in the present article, and these, together with the curves and illustrations, should prove useful to many workers in various fields of electrical investigations.—Editor.

Throughout the history of electricity probably the most familiar phenomenon has been the electric arc. At the present time the electrical engineer can take up very few of the more common electrical developments, such as circuit interruption, arc welding, transmission line disturbances, nitrogen fixation, etc., without finding them depending more or less on the electric arc. Considering all this it is remarkable how little we yet know regarding arcs; practically no complete and definite data on arc characteristics are available.

For this reason it is thought possible that a few notes on the length-voltage-current-pressure characteristics of normal arcs (arcs in equilibrium) might prove of value and of general interest.

In 1898 Mrs. Bertha Ayrton collected length-voltage data on carbon arcs, in air, at atmospheric pressure, from 1 to 7 mm. in length, and from that data the following equation was developed:

$$E=38.88+2.07\,l+\frac{11.66+10.54\,l}{I} \qquad (1)$$

E being the arc voltage, l the arc length in mm., I the arc current in amp.

Later Duddell studied similar arcs up to 30 mm. in length and found that Mrs. Ayrton's equation did not hold for arcs longer than 6 mm.

In 1913 Childe gave an equation for the magnetite arc similar in form to that of Mrs. Ayrton's for the carbon arc.

$$E = 33 + 24.5\,l + \frac{25 + 140\,l}{l} \qquad (2)$$

In 1906 Dr. C. P. Steinmetz published data* taken on arcs of different electrode materials in air at atmospheric pressure at lengths up to two inches. From those data he developed, both rationally and empirically, a general arc equation which is described in his "Theory and Calculation of Electric Circuits" as follows:

$$e = a + \frac{c(l + \delta)}{\sqrt{i}} \qquad (3)$$

in which e is the arc voltage, l the arc length in cm., and i the arc current. In this equation a, δ and c are constants depending on the electrode material. The total voltage across the arc is seen to be composed of two parts. The first part a is independent of the current and length and represents the voltage necessary to heat the positive and vaporize the negative electrode, while the second and principal portion of the arc voltage, $\frac{c\,(l + \delta)}{\sqrt{i}}$, is that dissipated in the arc stream as light and heat.

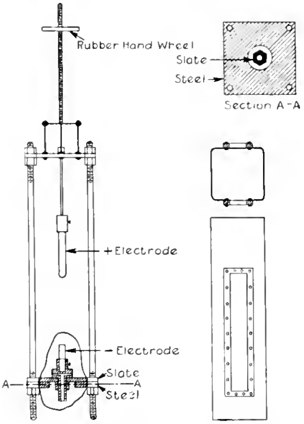

Fig. 1. Arc Chamber Used for Tests

Recently some tests were made on normal arcs with the idea of (1) trying out Dr. Steinmetz's equation at longer arc lengths than used by him in 1906 and (2) finding the effect on his equation of different pressures on the arc stream.

The arc chamber used for the tests is shown in Fig. 1. The casing was of steel with glass windows lined with mica. Air was admitted through the base of the negative (lower) electrode and exhausted through the top of the chamber. The air pressure within the chamber was held at any desired value by means of an overflow valve. Pressures below atmospheric were measured with a mercury column and those above with an indicating pressure gauge. The arc length was adjustable by means of the hand wheel. The wiring diagram is shown in Fig. 2. The voltage supplies used were 600 volts d-c. (50 kw.) for currents above 4 amperes and 2500 volts d-c. (7.5 kw.) for smaller currents. All electrical readings were taken with G-E type DP_2 meters, experience having shown them to be more accurate, reliable and convenient than any recording meter.

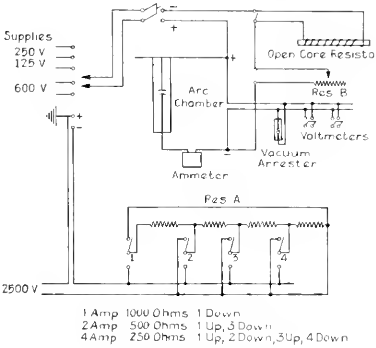

Fig. 2. Diagram of Electrical Testing Connections

The range and accuracy of any data on normal arcs is limited by the stability of the arc. This depends on (1) the electrical conditions such as series resistance, inductance, etc., and (2) mechanical conditions such as air currents, etc. The former was taken care of by using 9 henries series inductance and the highest voltage supply available at the desired current. The latter is the greatest menace to the stability of the longer arcs. Increased pressure increases the eddy currents in the arc chamber and increased current also increases them because of the increased heating. Thus, the stability of the

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* A.I.E.E. Proceedings, 1906.

arc, especially at high currents, decreases rapidly with increase of pressure. Various methods of reducing the effect on the arc of cross currents of air were tried out. These included the shape of the positive electrode (final shape shown in Fig. 3), mica baffles, diameter of arc chamber, electrostatic field, etc.

Some preliminary data were taken to determine the time necessary for the arc voltage to become constant at constant current and arc length. Two typical runs taken successively under the same conditions of current and arc length are shown in Fig. 5. If, after the current has been held constant long enough to allow the voltage to become constant, it is set at a new value, the voltage goes through another similar cycle of variation before it becomes constant. Thus it would seem that the electrodes burn to a different shape for each current and that until this reforming is complete the voltage is not constant. For this reason no data were taken on an arc until it had been running at constant current for a considerable time. This same phenomenon has been noted before by Mrs. Ayrton on a 10-amp. carbon arc 3 mm. long. She found greater voltage variation but less time necessary for the voltage to become constant.

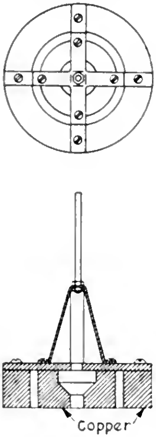

Fig. 3. Positive Arc Electrode

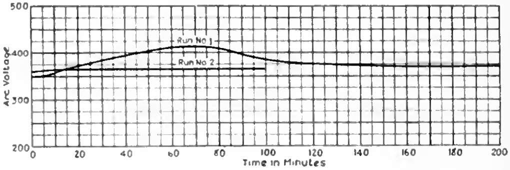

Fig. 5. Variation of the Arc Voltage with Time for Two-amp. Magnetite Arc 9.8 cm. Long

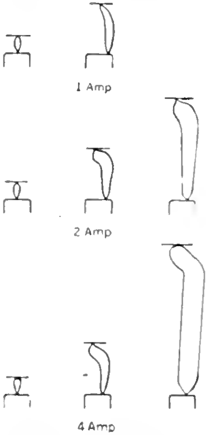

Fig. 4. Sketches of the Arc

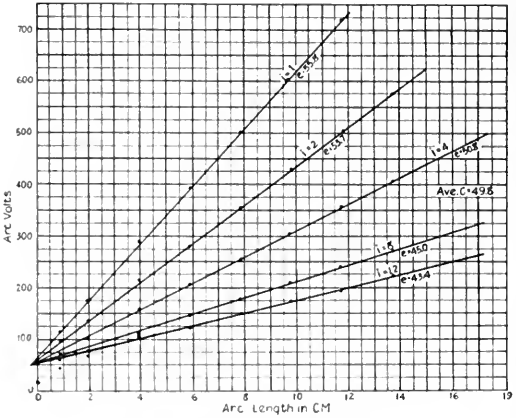

Fig. 6. Length-Voltage-Current Characteristics of Copper Arc at 30 lb. per sq. in. Pressure Absolute

The length-voltage data were taken by closing the circuit with the electrodes in contact and then separating them at constant current, taking corresponding voltage readings across the arc.

From these, data curves were plotted similar in shape to those shown in Figs. 6 and 7. They show the general arc equation to hold at much greater arc lengths than those used for its development. In comparing the curves with the equation the intersection of the curves is seen to be located by the constants a (in volts and therefore measured on the Y axis) and δ (in cm. and therefore measured on the X axis). The factor c determines the slope or direction taken by the curves as they spread out fanwise from the common point.

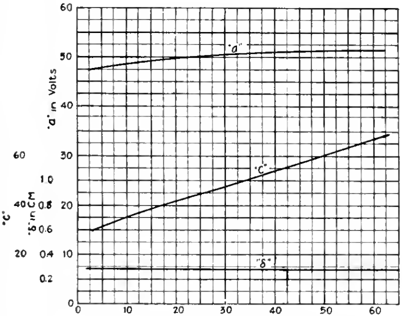

Fig. 7. Variation of the Constants "a," "δ," and "c" with Pressure for Copper

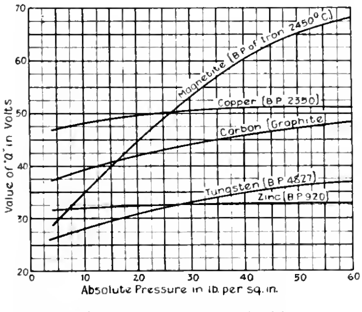

Fig. 8. Variation of the Constant "a" with Pressure and Electrode Material

The effect of pressure and electrode material on the three constants is shown by Figs. 8, 9 and 10.

Thus the general arc equation, when used with curves of this nature, is seen to combine the five variables of arc length, voltage, current, pressure and electrode material.

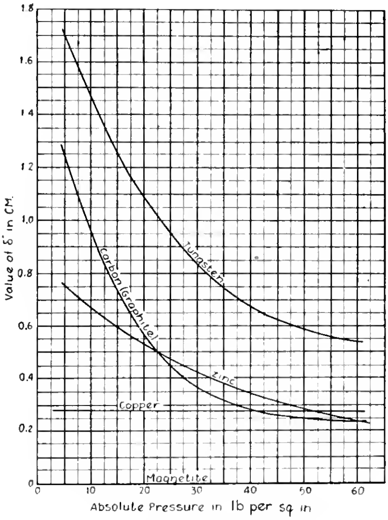

Fig. 9. Variation of the Constant "δ" with Pressure and Electrode Material

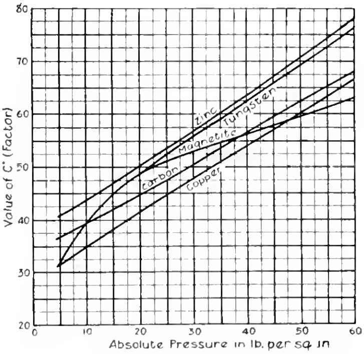

Fig. 10. Variation of the Constant "c" with Pressure and Electrode Material

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Armature Windings

How to Wind Fractional-Horsepower D-C. Motors. Roe, A. C.

Elec. Rev. & Ind. Engr., Jan., 1922; v. 80, pp. 7-12.

(Practical paper, with illustrations.)

Bearings

Fedeler Hot-Bearing Alarms.

Power, Dec. 27, 1921; v. 54, p. 1008.

(Brief description of two devices for indicating the presence of hot bearings.)

Charts

How to Find Voltage-Drop in Electric Circuits. Slack, Edgar P.

Power, Dec. 27, 1921; v. 54, pp. 1009-1011.

(A chart for determining line drop, length of circuit, current values and size of conductor.)

Circuit Breakers—Testing

Testing of Oil Circuit-Breakers by Large Central Stations. Pollard, N. L.

N.E.L.A. Bul., Jan., 1922; v. 9, pp. 62-64.

(Short account of tests conducted by several companies. Gives general results obtained, not specific test data.)

Electric Conductors

Steel-Aluminum and Pure Aluminum Wire for Transmission Lines. Hiller, George. (In German.)

Elek. Zeit., Dec. 15, 1921; v. 42, pp. 1447-1450.

(Shows that correctly designed aluminum-steel conductors are safer than copper wire and that they are applicable to any use. States that American practice is in advance of German.)

Electric Current Rectifiers

Mercury-Vapour Rectifiers.

Beama, Dec., 1921; v. 9, pp. 531-534.

(On the general principles of large apparatus.)

Power Rectifiers. Milliken, J. H.

Assoc. Ir. & St. Elec. Engrs., Dec., 1921; v. 3, pp. 523-551.

(Illustrated description of large-capacity mercury arc rectifiers such as are used in European installations.)

Electric Furnaces

Electrically Heated Forging and Heat Treating Furnace. Little, G. M.

Am. Soc. St. Treat. Trans., Dec., 1921; v. 2, pp. 228-236.

(Illustrated paper on a resistance type electric forging furnace.)

Progress of Electric Steel Furnace. Moore, Edward T.

Blast Fur. & St. Pl., Jan., 1922; v. 10, pp. 37-41.

(Reviews the development of the electric furnace, giving a few statistics and some of the technical considerations. Includes brief bibliography of 1921 magazine articles.)

Electric Locomotives

Lenz Oil Transmission Gear for Locomotive Work.

Engr. (Lond.), Dec. 16, 1921; v. 132, p. 660.

(Short, illustrated description of a German device said to be applicable to Diesel or electric locomotives.)

Electric Meters

Vacuum-Tube Alternating-Current Potentiometer. Wente, E. C.

A.I.E.E. Jour., Dec., 1921; v. 40, pp. 900-904.

(Description of the theory of an a-c. potentiometer for e.m.f's. having frequencies up to 10,000.)

Electric Motors, Induction

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GENERAL ELECTRIC REVIEW

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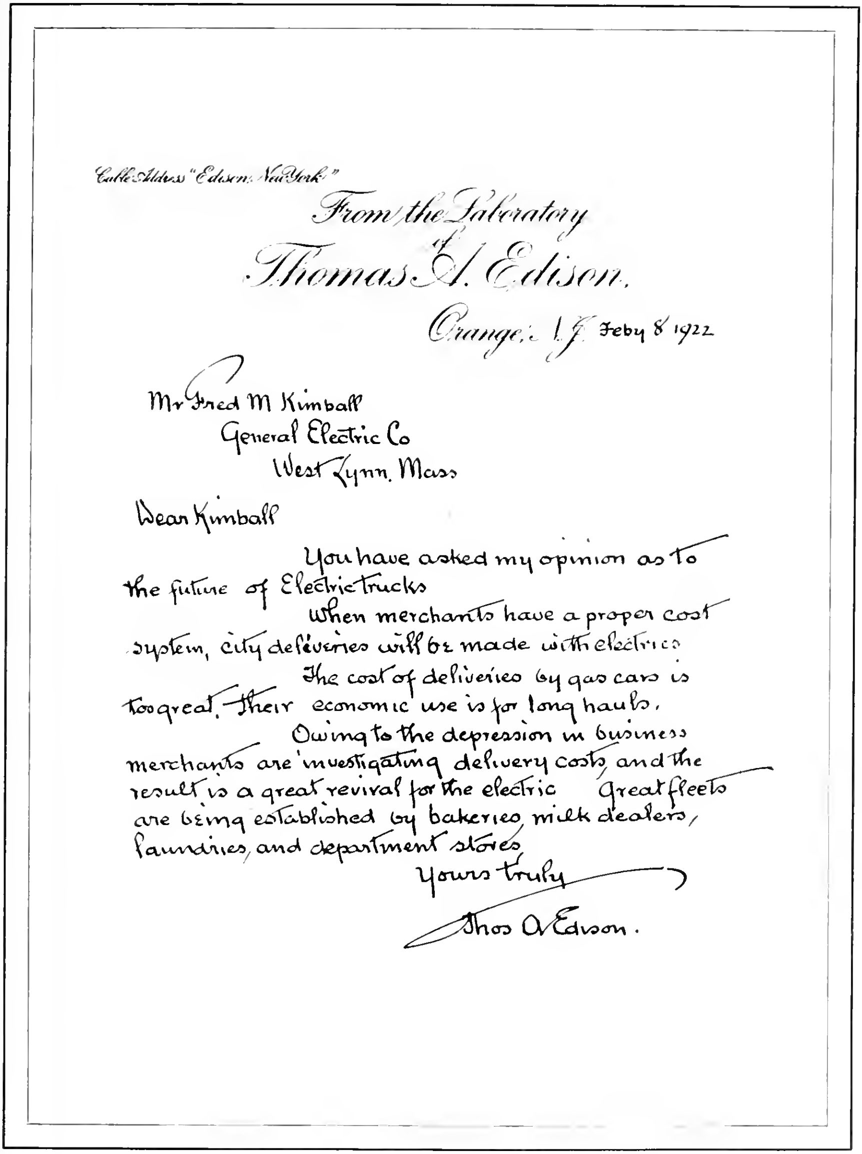
CONTENTS

THOMAS A. EDISON

Mr. Edison had such faith in the possibilities of the electric vehicle that he devoted his inventive genius to developing a storage battery which should use neither acid nor lead in its composition, and which should possess great mechanical strength and have a long life. The results of his labors are well known. It is Mr. Edison's great faith in "Doing Things Electrically," coupled with hard work and unending perseverance, which has made his name a household word throughout the world.



Cable Address "Edison, New York."

From the Laboratory
of
Thomas A. Edison,
Orange, N.J. Feby 8 1922

Mr Fred M Kimball
General Electric Co
West Lynn, Mass

Dear Kimball

You have asked my opinion as to the future of Electric trucks

When merchants have a proper cost system, city deliveries will be made with electrics

The cost of deliveries by gas cars is too great. Their economic use is for long hauls.

Owing to the depression in business merchants are investigating delivery costs, and the result is a great revival for the electric Great fleets are being established by bakeries, milk dealers, laundries, and department stores

Yours truly

Thos A Edison.

Distributing Goods Over Limited Territories

Hauling Heavy Loads Over Limited Distances

Supplementing Haulage with Power for Miscellaneous Applications

Responding to Call Unhindered by Weather Conditions

FOUR OF THE MANY SERVICES IN WHICH ELECTRIC VEHICLES HAVE DEMONSTRATED THEIR SUPERIORITY WITH RESPECT TO RELIABILITY AND ECONOMY OF OPERATION

GENERAL ELECTRIC REVIEW

THE ELECTRIC TRUCK AS AN ECONOMIC FACTOR IN BUSINESS

Electric trucks, void of everything spectacular but on a basis of real economy, are becoming more numerous on the congested thoroughfares of New York, Chicago, Philadelphia, Boston, Cleveland, St. Louis, Kansas City, Los Angeles, Washington, Baltimore, Indianapolis and other cities.

As business men analyze the high cost of hauling and delivery in cities by gasoline trucks and horses, they are more ready to observe that the most conservative business organizations, to whom reliable transportation at the lowest cost is of vital importance, are consistent users of electric trucks.

Only a few weeks ago it was announced that the American Railway Express Company had purchased 105 more electric trucks. This company operates over 1400 electric trucks and its sole business is *transportation.*

Department stores have serious delivery problems and show their approval of electric trucks by using thousands. Bakers, laundries, wholesale firms, ice cream manufacturers, dairies and many others continue to add to their fleets of electric trucks, thus proving the satisfaction and economy received from initial orders placed years ago.

In addition to the repeat orders from transportation experts, it should at least invite the curiosity of the keen business man that there are electric trucks in continuous daily service, 12, 18, 20 and even 24 years old. There are about 1000 in New York City which have been 11 years in service.

Why the electric truck has so long a life is easily explained by an examination of its simple, strong construction. There are few parts to wear out. Its speed is adequate for city traffic and is not a contributing factor to large maintenance and repair expense.

Lower insurance rates, longer life of tires, cheapest and most economical power, no energy consumed when standing idle, and extremely low depreciation are among the many features of the electric trucks that make the cost for each mile, ton-mile or ton hauled the lowest of any known method.

While the comparisons above are made with reference to gasoline trucks yet the horse should not be overlooked.

A proposal by Dr. John A. Harriss, Special Deputy Police Commissioner of New York City, in charge of traffic, urges immediate action in passing a law to end the use of horses in Manhattan by 1925. The horse is too slow, unsanitary, short lived, limited in capacity and endurance.

One electric truck manufacturer has openly challenged any operator of horses to run a comparative test with his trucks, such tests to be audited by a certified public accountant, the loser to pay the costs. He has had no acceptances of his challenge.

The tire cost of a light electric truck is less than the cost of keeping a single horse in shoes for the same work. And the current for an electric truck costs less than food for a single horse doing the same work.

Progress in storage battery development has played an important part in establishing the electric truck on its present economic basis.

The developments in charging equipment, the refinements in motor design, the number of new electric garages, and the realization of the value of the electric truck by central stations who have not only advertised but have donated their show rooms for free public exhibitions, have established the permanence of the electric vehicle.

Frank D. Fagan.

There are certain articles on Electric Vehicles which we received too late for publication in this issue. These we shall publish in subsequent issues of the REVIEW

The Electric Vehicle

By Fred M. Kimball

Manager, Small Motor Department, General Electric Company

It is a far cry from the crude model of an electric car assembled and exhibited by Thomas Davenport, of Brandon, Vt., in 1837, and a somewhat similar vehicle built and exhibited by Benjamin Page, of Salem, Mass., about the same year, to the highly developed and luxurious passenger vehicles which may be seen on any pleasant afternoon along the avenues and parkways of our great cities, or the sturdy trucks and delivery wagons which in constantly increasing number are contributing so largely and effectively to the efficient, reliable, and cheap transportation of our merchandise and other freight.

Fig. 1. Typical Four-passenger Runabout of 1898 (Columbia Electric Vehicle Company)

Not alone in the mind of Thomas Davenport but in the minds of many other far-seeing and imaginative inventors, who glimpsed the boundless possibilities of the new force just becoming known in the first part of the nineteenth century, came the vision of an electrically propelled vehicle which should be noiseless, clean, and so simple in construction and easily operated that anyone who could drive a horse could be safely entrusted with the operation of this unusual conveyance.

Although many experimental electric road vehicles were built in the years succeeding the work of Thomas Davenport and Benjamin Page, it was not until the advent of the storage battery in 1881-2 that the means of supplying electricity for the practical operation of such vehicles was secured, this being a requirement previously impossible of achievement because of the great weight and cost, small capacity, and low efficiency of any primary battery which had been invented.

With the advent of the storage battery, however, renewed efforts were undertaken to develop electric vehicles that should be practicable in construction, reliable in service, and competitive in cost of operation with horse-drawn vehicles both in passenger service and for the transportation of commodities. In connection with this early work, the names of Morris and Salome, Riker, Maxim and Woods, among a galaxy of capable engineers and inventors, come immediately to mind. Their vehicles were ingeniously designed and generally well built, and all had considerable vogue in their day. Experience with these vehicles while demonstrating conclusively the great possibilities of the electric carriage equally demonstrated that the time was not yet ripe for their general introduction and use. Difficulties in respect to construction, weight, radius of action, recharging of the batteries, and cost, all operated in varying degree to restrict the general acceptance of such vehicles by prospective buyers.

It was not until the late 90's that vehicles of sufficient sturdiness and dependability, and capable of being operated at costs reasonably competitive with horse-drawn vehicles, became so generally available as to command the attention of the public. About the same time the prospect of attractive and increasing revenues from charging electric vehicle batteries and the inadequacy of public charging facilities throughout the country began to be appreciated by central power stations; and they, seeking to extend their fields of service and revenue, began here and there to adopt and use electric vehicles and provide charging and in some cases garaging facilities. Their interest and efforts in behalf of the new vehicle did not become very aggressive, however, until about 1900, when several of the larger central stations throughout the country became definitely convinced of the possibility of deriving a large and increasing revenue from charging the batteries employed in electric vehicles, and notably in New York, Boston, Chicago and Philadelphia particular attention was given to the subject.

Under the stimulus of interest and demand, manufacturers of motors and control greatly enlarged their efforts toward the improvement of their products, as did manufacturers of batteries who, having become acquainted with the shortcomings of their batteries when used in connection with road vehicles, made intensive efforts to eliminate all elements of weakness. The announcement in 1901 or 1902 of the work being done by Thomas A. Edison in the development of a new type of storage battery gave renewed stimulus to interest in the electric vehicle, not only by the public in general but on the part of manufacturers and users as well.

Fig. 2. Runabout of 1900 (The Riker Electric Vehicle Company)

Fig. 3. Light Runabout of 1901 (Baker Motor Vehicle Company)

Meantime, the development and extending use of gasoline wagons and trucks had fully demonstrated the important advantages attending the use of horseless conveyances. Not only was it possible to carry larger loads than were practicable with horse-drawn vehicles, but the gas trucks could be operated more speedily and more efficiently; and, in addition, very notable advantages were found in the diminished space occupied on the road, in the freight yard, or on the dock by the horseless vehicle, as well as in the greater ease and exactness with which it could be maneuvered in contracted areas.

Among the principal causes operating to hold back the development and sale of electric vehicles were: (1) The scarcity and comparative isolation of charging facilities; (2) the comparatively high prices of electric vehicles due to lack of standardization and the fact that they were made only in small quantities; (3) the great cost of demonstrating their value and effecting sales; (4) the lack of definite knowledge regarding the limitations of their field of usefulness, or rather the failure to exercise good judgment as to the service in which they might properly be applied, a great mistake on the part of many electric vehicle salesmen in the early days having been their attempts to sell electrics for all classes of service, irrespective of whether they were adapted to such service or not.

Fig. 4. Light Delivery Wagon of 1899 (Riker Electric Vehicle Company)

In addition, there was great lack of suitable and convenient garaging and service facilities. Whereas a vehicle equipped with a gasoline engine might be housed in an ordinary barn, an electric vehicle usually had to be housed where charging facilities were available; and

Fig. 5. Phaeton of 1899 (Columbia Electric Vehicle Company)

Fig. 6. Victoria of 1899 (Columbia Electric Vehicle Company)

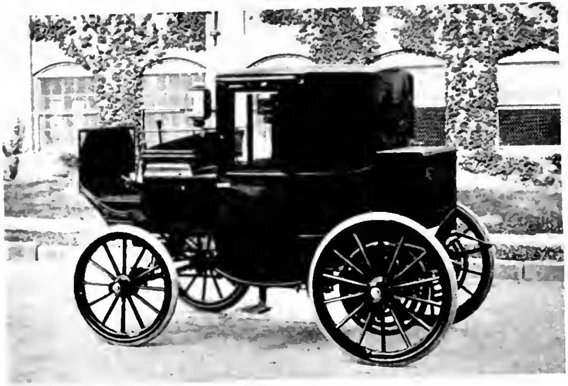


Fig. 7. Brougham of 1900 (Columbia Electric Vehicle Company)

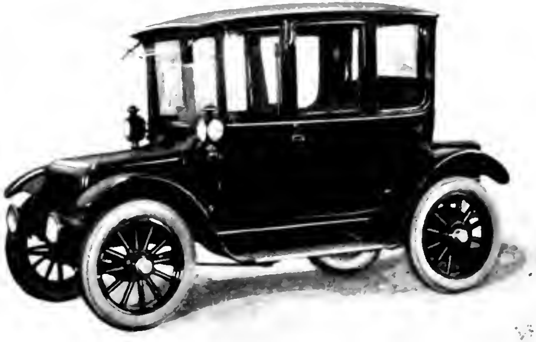


Fig. 8. Sedan of 1922 (Rauch & Lang, Inc.)

Fig. 9. Modern Delivery Wagon (Lansden Company)

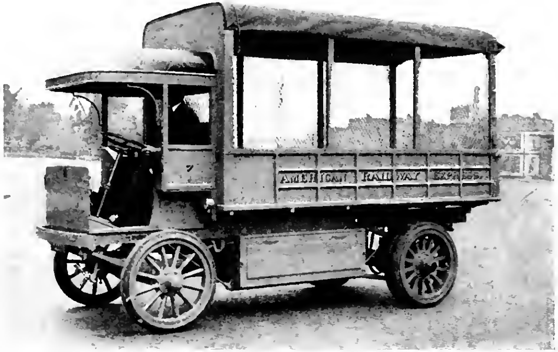


Fig 10. Modern Heavy Mail Type of Wagon (Commercial Truck Company)

Fig.. 11. Ice Cream Delivery Truck of 1922 (Ward Motor Vehicle Company)

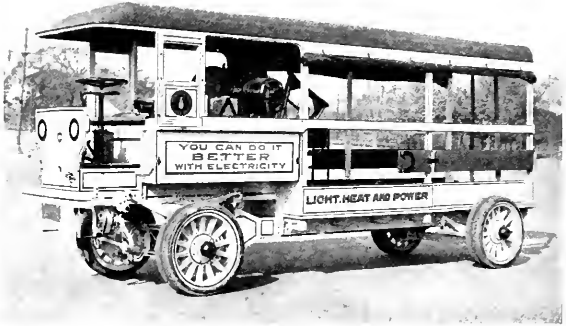


Fig. 12. Heavy Central Station Truck of 1921 (Commercial Truck Company)

in the case of the owner of a single vehicle, to whom no public garage was available, the cost of a private garage provided with adequate service and charging facilities became relatively a large item in the cost of the complete equipment. Under these circumstances, the prospect was unwilling to make the investment, and even in the case of prospective users of fleets of vehicles there were very few who felt inclined to build the necessary garages to accommodate them.

Within the past ten years the situation has been vastly improved. As the appreciation of the limitations as well as the possibilities of the electric vehicle have slowly been demonstrated and disseminated, and its costs and selling prices reduced, public garages have been built for the accommodation of fleets as well as for single vehicles, and portable or semi-portable garages placed upon the market, which equipped with very reliable but comparatively inexpensive and simple charging apparatus have afforded relief in this direction, so that at the present time the problem of housing and caring for the electric vehicle has been greatly simplified and cheapened.

Meantime, experience has shown with adequate exactness the field within which electric vehicles may be profitably employed, and while it is quite possible to design and equip an electric with a speed range quite equal to that of a corresponding gas vehicle, such vehicles are commercially impracticable in use due to mileage limitations, and the field for touring and speed vehicles is by common consent left to the makers of gas cars. On the contrary, where the normal speed required is not in excess of 20 or 25 miles an hour, radius of travel not exceeding 60 miles per charge, and there is necessity for frequent stopping and starting, the electric vehicle finds its legitimate and proper place. Within this field it possesses a great many advantages. Generally speaking, the electric can be operated at 25 to 30 per cent less than the corresponding gas car. Its mechanism and construction are far simpler. It is less liable to derangement. There is little if any fire risk attendant upon its use. Inspection, oiling, and cleaning are more easily and cheaply accomplished. It is particularly dependable under adverse weather conditions. Altogether it requires much less attention and entails much less cost in upkeep and maintenance.

While accurate statistics dealing with the number of electric vehicles at present in use are very incomplete and imperfect, there being no separate registration of electric vehicles, as such, in by far the greater number of our states and territories, yet a careful and painstaking check of all data available taken from the records of licensing authorities, manufacturers of electric vehicles, storage batteries, motors and other adjuncts, indicates that there are at present between 9,300 and 9,600 commercial vehicles, between 19,500 and 20,000 passenger vehicles, 2,300 to 2,400 storage battery locomotives, and 8,300 to 8,500 industrial trucks in use in this country.

For charging these 29,000 odd road vehicles alone, some 80 to 85 million kilowatt-hours of electricity are required annually, in itself no mean revenue producing load for the central stations of the country.

As a pleasure vehicle for smooth, noiseless, and luxurious riding the electric has no equal; as a commercial vehicle within its proper field it is thoroughly reliable and dependable. The supply of gasoline and fuel oil is fixed, and we are drawing at an ever increasing rate upon Nature's stores of these fuels. On the contrary, the supply of electricity is practically inexhaustible, for it can be secured in ever-increasing quantity as long as water flows and fuel burns. The future of the electric car within its legitimate field, in regard to dependability, simplicity, ease of handling, long life, and low cost of maintenance and operation, is assured by its demonstrated superiority.

It has won its recognized place in performing a constantly increasing share of the world's work. It does not assert its applicability to all services, but it does assert and is ever ready to prove its superiority to any other known means of transportation in the wide and important fields to which it is properly applicable.

The Battery Vehicle in England

By R. H. Simpson

Assistant Manager, Traction Department, British Thomson-Houston Company, Limited

The first attempt at a battery driven vehicle in England was made as long ago as 1842, when a small locomotive was tried on the Edinburgh and Glasgow Railway. Few details are available except that the total weight was five tons, that it was driven by an "Electro Magnetic Engine" from a primary battery carried on board, and that it attained a speed of four miles per hour.

The earliest attempt on any considerable scale was made in Birmingham in the year 1890, when a section of track was worked with storage battery cars; but although this system ran for a number of years the financial results were not satisfactory and the line was ultimately converted to the trolley system. The very rapid growth of the trolley system after this date ruled out further experiments, and the rail-borne battery vehicle for passenger service is not in use anywhere in this country.

Meanwhile the development of mechanical road transport, which had commenced with cumbrous steam carriages as far back as 1800, had been severely checked by the Locomotives on Highways Act of 1861. This act provided among other things that any locomotive using the highway should have not less than three drivers, should not exceed a speed of four miles per hour and should be preceded by a man on foot carrying a red flag. These provisions were rigidly enforced and extraordinary as it may seem the act was not repealed until 1896, barely 25 years ago, when mechanical road transport was developing rapidly in other countries.

The result of this legislation was the development of the low-speed heavy steam traction engine to a high degree of perfection, but in spite of it a number of lighter machines were built experimentally, including electric vehicles by Elwell in 1884, Ward in 1886 and Volk in 1888.

In considering the growth of the electric vehicle in England it must be remembered that owing to a very complete system of railways the need for the mechanical haulage of goods by road was not greatly felt, and all early efforts in the automobile industry were concentrated on the provision of a suitable passenger vehicle for private use and on the omnibus. It is noteworthy that in this latter field the battery vehicle even today has not made much progress, owing to the relatively high running speed and number of miles per day which are required. The battery vehicle was tried for both cabs and omnibuses and failed, partly owing to the unsuitability of the material available and partly owing to wrong methods of maintenance and insufficient financial backing to carry the venture to a successful conclusion.

Meanwhile the internal combustion engine had achieved a considerable amount of success, petrol was cheap and batteries were dear, and although experimental work on electrics continued, the early failures had made it impossible to get sufficient capital to try the scheme on a large scale and impossible to find purchasers.

The situation remained thus till 1914 when there were only some 150 electric vehicles all told operating in this country against an estimated number of 40,000 in the United States. Since that time however the progress has been rapid; there are now several thousands in use and they are giving such a good account of themselves that further progress is assured.

The growth in the use of the electric corresponds with the formation of the Electric Vehicle Committee and the valuable work which they did in fixing certain standards of battery voltage and charging plant, in inducing supply authorities to provide charging facilities and in educational work generally. A further contributory cause was probably that the price of petrol had shown a tendency to increase for a number of years, and further that the national road tax on automobiles was collected as a tax on petrol and the electric was therefore in the fortunate position of being tax free. The main cause however was the guaranteed battery which has enabled an accurate estimate of running costs to be made for each proposal and has done more to introduce the electric to new users than any amount of propaganda work. The present road taxes are based on horse power and vehicle weight and the electric has been allowed some advantage as it is realized that it is easier on the roads than other mechanical vehicles.

There is a general opinion that the price of petrol bears very little relation to its cost of production, and the way in which the price has fluctuated in England during the past few years lends color to this assumption. The present price of heavy spirit, suitable only for commercial vehicles, is 23d. (46 cents) per gallon, as against a price in 1908 of 8d. (16 cents) per gallon, and a price in September of 1920 of 41d. (82 cents) per gallon. The price of power on the other hand has maintained a reasonable level throughout and can be purchased today at an average price of about 2d. (4 cents) per unit metered into the battery.

The enormous growth of road transport in this country did not take place until the close of the European War, which found the railways with greatly depleted quantities of rolling stock, and flooded the country with a large number of ex-military vehicles of all sorts and types. These military vehicles were principally of the petrol type, and they are now being re-conditioned and sold at an extremely low figure. It is now possible to purchase a re-conditioned lorry of four tons capacity at a price of something under £400 ($1760), whereas an electric vehicle of the same capacity would cost at least three times as much. The electric vehicle would of course be new, but on the other hand a lorry would have a six months' guarantee and was originally built by a first class maker, so that there is a certain amount of justification for purchasing a petrol vehicle if it is at all suitable for the work required.

Despite the fact that the development of road transport during the last two or three years has appeared to be enormous it must be remembered that much of this represents traffic which has been won from the railways. The actual proportion of our horse-drawn goods transport which has been motorized is estimated at something under 25 per cent. Even in London where road space is extremely valuable there are a very large number of horses still to be seen hauling goods, although of course the horse-drawn passenger vehicle is practically non-existent.

As an example it may be stated that a group of three railway companies who share a main freight terminal in the city of London are still using 3000 horses for their distribution work; and there are a number of express companies, amounting to probably 12 all told, who are still employing something over 1000 horses each. It may be said, therefore, that the electric has barely touched the transport question in this country, since it is of course primarily suited for displacing horse haulage.

Fig. 1. General Vehicle Company Electrics in the Service of the Great Northern Railway, England

With regard to the lines on which these vehicles are developing, it may be said that the most popular vehicle appears to be one of about three tons capacity. Smaller vehicles than these are used for light delivery purposes and some of the large stores own considerable fleets, but generally speaking it has been found that there is no sale for a vehicle of one ton capacity, as the price required is so much greater than the price of a popular make of petrol vehicle which can be adapted for a body of this size.

A most satisfactory feature is that the use of electric vehicles is being generally extended in public service, that is to say, municipalities, corporations, town and district councils are purchasing electrics for such purposes as the collection of refuse, the transport of coal and as many duties as it is possible to employ them on economically. In the past five years the number of vehicles publicly owned in this way has grown from under 20 to something well over 400. Most of these public bodies also own generating stations, and this is of course a powerful reason for the selection of the electric. This is a field which seems capable of very large extension in the future. Probably the next largest field for the employment of the electric is in the service of railway companies and cartage contractors or express companies, who work in conjunction with the railways. All the railways have experimented with the electric vehicle with satisfactory results, and it is reasonable to assume that with the revival of trade a considerable demand will come from them. Here again the railway companies (who were under government control at the conclusion of the war) had to take a number of motor vehicles from the disposal board, so that their purchasing power in this direction has been for the moment curtailed.

The small electric shop truck is being used extensively by railways, docks, workshops and warehouses, and the numbers in service are increasing rapidly. The demand for these at the moment exceeds the demand for the road vehicle.

Reference has already been made to the early experiments with electric cabs and private cars. Although there are a few of these in operation they are by no means popular and indeed have made little headway at the moment. The same remarks apply to battery omnibuses which have proved to be somewhat slow and the frequent boosting required is undoubtedly a disadvantage.

The remaining uses to which electric vehicles are being put are probably very much the same as in America, except that an increasing number are being used here in the service of the various breweries.

There are now over a dozen makers of electric vehicles in this country and the number is being added to by several of the old established petrol vehicle makers who realize that there will be an increasing demand for the electric. All these makers are building a very satisfactory article with the result that the industry as a whole is benefiting by the absence of failures. These works would appear to have sufficient capacity to supply the demand for some time to come both for road vehicles and for shop trucks. Fig. 1 shows a group of electrics built by the General Vehicle Company for the Great Northern Railway, and Fig. 2 a part of the fleet of Orwell electrics (Ransome Sims & Jefferies) used by the Urban District Council of Willesden for the collection of house refuse.

Fig. 2. Orwell Electrics Belonging to the Willesden Urban District Council Dumping House Refuse into Barges

There are of course a number of different drives in use and the practice of the makers is fairly evenly divided between one and two motors. It may be said, however, that the practice of using one motor only is growing and may eventually become standard.

Control gear for road vehicles is by no means standardized as yet, and there are various devices to interlock the brake pedal with the controller, etc., although here again the tendency is to cut out such complications. The Orwell lorry previously referred to is frequently supplied with compound motors for the purpose of obtaining regenerative control and this would appear to be a useful adjunct to the braking and in certain circumstances provides a substantial saving in power.

With regard to the most important question of the battery it would seem that opinion is still divided between the lead and the alkaline cell. The general opinion is that when all costs are taken into account there is nothing to be said either way and the superior characteristics and efficiency of the lead cell are undoubtedly in its favor.

The provision of charging facilities and low rates for power are of course important factors in the development of electric vehicles, and central station engineers are assisting considerably in providing such facilities. It must be remembered that a very large number of supply undertakings are owned by the public, that is to say, they are run by the town or urban council. It is not therefore a simple matter to get permission to go ahead with a "Public Service Garage" scheme, and there is a considerable amount of formality to be gone through in applying to the central government for permission. The Electricity Commissioners have, however, proved themselves very sympathetic and it is now possible for a town to raise a loan for the purpose of building such a garage, and one or two have been erected and it seems possible that there will soon be a considerable number. This of course refers to a garage where vehicles can be completely looked after and not simply to a charging station. There are well over 200 charging stations, up and down the country, having facilities for supplying the necessary voltage for charging electrics.

As there are over 650 public generating stations in the country it will be seen that there will be no difficulty in arranging adequate charging depots, but in the meanwhile since most users and potential users have sufficient business to employ the electric in fleets they will prefer to install charging machinery in their own garages. A low price per unit metered into their own charging set will do more to attract business from these users than the immediate provision of public charging facilities.

To sum up, the electric vehicle in England is a proved success, its use is extending and there is no doubt that it will ultimately clear the horse out of our cities. But it might do more; England is a small country and distances between towns are short, petrol is unreasonably dear and will probably get dearer, power is reasonably cheap and will tend to get cheaper as its use extends. These are ideal conditions for the electric vehicle and ultimately on question of cost it could oust the petrol vehicle as well as the horse. But to do this it must be capable of doing a day's work of any sort with one charge. The problem for the battery maker is, therefore, to produce a cell with the mechanical strength and the life of the alkaline cell, the electrical characteristics of the lead cell, and a capacity per pound weight two to three times as great as the best that has been obtained so far.

Electric Trucks in Express Service

By E. E. La Schum

General Superintendent, American Railway Express Co.

The American Express Company purchased the first electric truck on June 30, 1908, No. 9002, Baker one-ton, Edison A 4, 64-cell battery. This truck was continued in regular service until the latter part of 1919 when, owing to the fact that it had been broken and bent by hard service and in all probability some accident, it was discontinued.

The second and third trucks, Nos. 9003 and 9004, were purchased on July 21, 1908, No. 9003 being a General Vehicle one-ton, Exide Ironclad 44-cell, 9-plate battery. This truck, now No. 987, is still in service and can be seen most any day performing its duties around our West Side Terminal at 33d Street and Tenth Avenue, New York City. No. 9004, a General Vehicle two-ton, 44-cell, 13-plate Ironclad battery, was continued in regular service until the latter part of 1919, when it was discontinued.

The fourth electric truck was purchased and placed in service in September, 1909, being No. 9005, a Baker two-ton, 42-cell, 15-plate Ironclad battery, and was in regular service until 1920, when it also was discontinued.

There is no doubt that the Adams Express Company purchased quite a number of electric trucks at about the same time, but I have no accurate records concerning them.

The satisfaction derived from the use of this small number of trucks convinced us that there was a possibility of economical operation, and in 1911 we began to purchase electric trucks in considerable numbers. In that year we purchased 24 Bakers and 27 General Vehicles of two tons capacity, making a total of 51, and placed them in service in New York City. In the same year two 3½-ton General Vehicle trucks were bought and placed in service in Boston.

From this it will be seen that the shortest life was more than 10 years, and these were really experimental trucks. If it was possible in the very beginning to build a life of 10 years into an electric truck, is there any reason to doubt that the modern electric of today can be successfully operated for more than twice that period?

The American Express Company and the Adams Express Company were the only two of the old express companies that bought electric trucks and placed them in service and kept adding to their fleets up to the time of the merger of the several express companies into the American Railway Express Company, who have continued to add and place trucks in service, as follows:

MAKE	YEAR OF PURCHASE															Number	
Street Trucks	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922		
Atlantic					5		3		22							30	
Baker				24	152	41	1	35	34							288	
Commercial					15	9		2	36	75	41	21	10	4	50	263	
Couple Gear					3					2						5	
Detroit Electric					3				1							4	
G. M. C. Electric					22	3	6	7	16	1	5	1				61	
General Vehicle	1			27	55	43	1	48	57	21						253	
Lansden					28		3									31	
La Schum										1						1	
Oneida Electric										1		5	1			7	
Walker									46	22	29	27	19	35	55	233	
Total																1176	1176
Depot Trucks and Tractors																	
Automatic																4	
Elwell Parker																203	
Mercury																42	
O. A. K																1	
Total																250	250
																	1426

From this you will see that we are operators of 1425 electric trucks and the fact that we have added to them regularly is an indication that we have never had a minute's doubt about their ability to perform satisfactorily. Fifty of these trucks are on order and are now being received by us, which is an indication that our faith is still strong. Furthermore, it is our intention in the very near future to add 54 more electrics to our fleet.

The list is a record of trucks actually in service today and does not show a complete record of the total purchases, because a few electric trucks were lost by fire and a very few others were disposed of on account of obsolescence.

Maintenance of electric trucks requires only a small amount of labor, mainly because there are only a small number of wearing parts; and although the manufacturers of some of the trucks mentioned above are not in existence today, we find comparatively little difficulty in keeping them in repair, as manufacturers of important parts, such as motors, chains, bearings, axles, wheels, steering gears, frames, batteries, tires, etc., are still in existence stronger than ever, and because we manufacture many parts in our own shops. With the modern trucks we find no difficulty in obtaining repair parts from the manufacturers or from reliable manufacturers of parts. Furthermore, practically all the parts are accessible and can be replaced without the expenditure of a great amount of labor, or the employment of exceptionally skilled workmen; in other words, it takes only a short period of training to produce men who can very successfully handle a fleet of electric trucks. This will apply to general maintenance, but of course it may happen that an armature or a field coil in a motor will burn out, either through abuse or improper handling, and for this emergency we keep spare units and the damaged coil can be quickly replaced by our workmen or by competent help to be found in many well conducted electric truck garage institutions. Furthermore, due to the non-vibrating power plant, its continuous torque, and the even speed of the vehicle itself, we seldom find loose rivets, and the regular employment of high class blacksmiths, welders, etc., is unnecessary.

Garage facilities for electric trucks usually appear expensive on first consideration; but it will be found that for a fair sized fleet of trucks the cost of installing battery charging apparatus is not much greater than the necessary storage system required for fuel used in other types of vehicles, and it should be borne in mind that the cost of charging apparatus can be spread over a long period of time.

Much satisfaction and economy develop from the fact that electric trucks are stored in less space than an equal number of wagons, horses, feed and general stable equipment, and can be stored in less space than an equal number of motor trucks of other types. They do not require any extraordinary building construction, and as they are almost entirely free from the hazard of fire it is easy to convert nearly any kind of building, especially stables, into an electric truck garage.

Like any other piece of machinery, electric trucks should be thoroughly inspected after each day's work is done in order that minor repairs and adjustments may be made before they develop into expensive repairs, or, what is still worse, before they interfere with the regular operation of the vehicle. If the inspection and the minor repairs are regularly made the periods between general overhauling will be greatly lengthened.

The cleanliness of the electric vehicle has recommended itself to our operating officials. There are fewer garagemen required and the objectionable features of the regular garage, such as smoke, odor and noise, are absent. Neighboring tenants are free from these sources of annoyance and seldom object to the location of an electric garage, though they frequently object, and I guess legitimately, to a gasoline garage or stable.

In our service the electric truck proved itself to be highly efficient and satisfactory from the beginning. Many of the electric trucks placed in service in 1911, 1912 and 1913 are still performing regularly and economically, and on that record we can hardly doubt that the electrics being built today, with their better design, better material, more accurate castings, and more accurate machining, will perform satisfactorily for a much longer period.

We must commend the engineers of the electric vehicle industry for their untiring efforts to bring about better efficiency, especially in the transmission of power. The development of speed reduction systems has been extremely interesting and gratifying, the progress being from the chain and sprocket to the various types of balanced gears, internal gears and worm gears. All this improvement in the power transmission devices has tended toward the elimination of mechanical troubles and the conservation of electric energy. There is no doubt that today we are getting better motors, better controllers, better steering gears, better springs and better construction throughout, with a lesser number of wearing parts—all of which will bring about more economical and, if possible, more satisfactory results.

Charging switchboards installed in the beginning were of an expensive and more or less complicated nature. This was because we were taught by the battery manufacturers that batteries should be charged only at the normal charging rate recommended by the battery manufacturer, and that we must have apparatus for controlling the current in order to keep away from the high charging rate that was detrimental. These boards are now much simpler and more efficient and can be installed with considerably less cost. We believe that truck and battery manufacturers, and perhaps central stations, should co-operate and if possible bring about a still furthur improvement, or at least agree on the question of constant potential, modified potential, or control by the rheostat method. I say this because I know that many users of electric trucks are at a loss to know which is the best method, and I myself am more confused every day because some engineers, apparently competent to speak, argue that the constant potential method is the ideal method; others equally competent agree that the modified potential is the only way; and still others insist that without current control by line resistance a fleet owner would be running straight into trouble. If the constant potential system is the correct method our problem would be materially simplified. If line resistance is essential why would it not be possible to mount the necessary resistance on the truck and thereby do away with the expense of switchboard installations?

The battery of an electric truck was the first item in its make-up to raise serious doubts in our minds, and we had many misgivings regarding its care, maintenance cost, and reliability. However, nothing happened of a serious nature sufficient to really discourage us. We had the old separators to contend with, the brittle rubber jars that were continually breaking, the soft rubber plug, the inadequate prevention of sloppage, the loss of acid and the trays burned up thereby, the whole job grounded and the current slipping away. We had the alkaline battery with the bottoms rusted out, and the cells with the filler caps corroded until we couldn't knock them loose with a sledge hammer; we have had both kinds blown up, dried up and burned up. But were we discouraged? Decidedly no!

There has been radical improvement, thanks to Thomas A. Edison, Bruce Ford, Dr. Sokal, and many others, and today batteries are produced that can be relied upon.

In the beginning, fourteen months in daily service was about all we could expect from a flat plate lead battery. Twenty months is now easily obtained. Twenty-four to twenty-seven months was a long life for an Ironclad lead battery. Today we have no difficulty in obtaining an average of 34 months. The rubber jars are now flexible and tough and do not crack and leak; covers are properly designed; the present plugs are the product of genius; and the sealing compound generally stays "put." The separators, grids, tubes and fittings have been improved upon, and even the trays are treated chemically so that they withstand the hard usage better than they did.

We find that the Edison battery has been improved, no doubt by better material—certainly by better construction—and while in the beginning four years was a long life, we now find that our average is approximately six years. We have Edison batteries that have been in service more than eight years.

Another thing that is highly satisfactory and found to result in greater economy is the improved battery cradle, by the use of which we find it possible to remove the battery in its entirety from the vehicle and place it where there is light and air and where flushing and cleaning is done more quickly, with much less labor and greater accommodation to our employees. I refer particularly to the Stone battery cradle, and I believe all electric truck manufacturers and all battery manufacturers should encourage the use of this type of battery cradle, or one of equally good design.

In an article written for *Power Wagon Reference Book*, published in 1920, I gave an account of an experience with electric trucks during a severe snow storm in Chicago, during the winter of 1912-13, which I believe will bear repeating here.

> "Bad weather interferes with the efficient operation of vehicular equipment of every kind, and in territory where heavy snows fall during the winter these difficulties are serious, but it is now recognized that horses and wagons suffer in proportion to their average capacity as well as other types of vehicles, such as the electric truck. Under such circumstances, where it is necessary to draw heavily upon the surplus capacity of the equipment above average requirements, the mechanical device stands the strain with more economy than the animal.
>
> "In the author's experience he came directly in touch with this mistaken impression held by a man accustomed to handling horse and wagon equipment,

> and meeting the severe trials of an unusually heavy snow storm in one of our middle western large cities with a confident, fighting spirit that overcame the great difficulties of operating a large number of vehicles in a heavy pickup district in the outskirts of the city. At least, he was accustomed to facing the problem squarely and accomplishing as much in his usual day's work as was possible with the equipment he had. Shortly before the winter set in we substituted electric trucks for his entire horse and wagon equipment and, notwithstanding the misgivings he very apparently felt but seldom expressed, the machines kept going from day to day and, although the number of units was less and the street paving mixed with good, bad and indifferent, their efficiency was considerably higher than that of the old-fashioned equipment.
>
> "Late one afternoon a soft snow began to fall. It was wet and heavy and increased in volume throughout the night, so that by morning the ground was covered with a blanket of 'trouble' from one to two feet in depth. After worrying over his problem through the greater part of the night he began about four o'clock in the morning to telephone his drivers and ordered them to report at the company's old stable building, where our horse and wagon equipment was kept. By six o'clock that morning he appeared at the stable with his drivers with a request that they be supplied with horses and wagons and, notwithstanding his satisfactory but brief experience with the electric trucks, he stoutly maintained that it was not reasonable to expect them to get farther than a few feet from the garage door through such an accumulation of snow. He only agreed to try to use the motor trucks after we had formally, and in the presence of plenty of witnesses, agreed to assume full responsibility for the complete failure to handle his day's work, or any reasonable portion of it that he anticipated and, in fact, felt sure would follow. He instructed his drivers to proceed to the garage and take their machines out as usual, which they did. The conditions were exceptionally severe for the successful operation of any kind of vehicle equipment and the author sat at his telephone throughout the day answering trouble calls from drivers in various parts of the city, and he confesses they were coming over the wire about as fast as one telephone could be made to carry them. Each time he picked up the receiver he wondered if that call would be from the man who had such serious misgivings regarding the ability of his electric trucks to get from the garage to the loading platform, but it was not until nearly the close of the day that he heard from him—then in an apologetic and chastened spirit he quietly reported the breaking of a drive-chain on one of his electric trucks after it had been working satisfactorily all day and had finally picked up its last load and was within a short distance of his depot when a link in the drive-chain snapped. The author told him that a mechanic with a spare chain would reach the vehicle within 15 minutes, make the necessary repairs in five minutes, when the motor truck could finish its day's work. Henceforth the electric trucks in that territory performed 100 per centum efficient, at least so far as any complaints received from that particular agent were concerned. The point is that under bad weather conditions the motor vehicle's efficiency, while reduced as compared with its own performance in fair weather, really increases over that of horse-drawn equipment when the streets become slippery with mud or ice or heavy with snow. The author has before him the record of one motor vehicle operator showing that his equipment was delayed only 45 minutes on account of repairs or breakdowns out of a possible 1980 working hours. If electric trucks are properly selected to meet the haulage proposition, with the size of the vehicles and their batteries and bodies adapted to average requirements, and are then given the intelligent and competent maintenance and inspection they deserve, an operating efficiency of 98 per centum can be maintained."

I repeat this because it so happened that on the morning of January 11, 1922, the day referred to in the *Power Wagon* article was brought vividly to my memory and it shines through the mists of several years a glowing tribute to the efficiency of the electric truck. While I looked out of my window on the morning of January 11th I decided that the day had started in with the makings of plenty of trouble. I drove my own car (a gasoline car) from my home in Yonkers to my office and remarked to several friends who accompanied me that I would like to see some manufacturers of electric trucks and batteries get out with high boots on and obtain the real story of the performance of the electric truck under such conditions. Ordinarily, by 4 p.m. many of the trucks have finished their day's work, so far as travel is concerned, and are at the depot. At 4 p.m. on January 11th I called for a report on the day's performance, which was as follows:

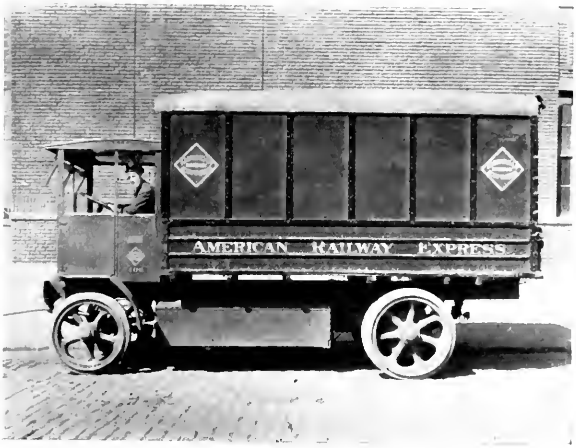
In New York and Brooklyn there were 316 electric trucks on the street. At 3:35 p.m. one truck was towed to the garage on account of differential trouble. At 1:30 one was delayed on account of a blown strap, and in 30 minutes it was on its way. At 1:50 another was delayed on account of chain caught in sprocket, and at 2:55 the truck was again in service. At 1:47 a truck was delayed on account of controller trouble, and at 3:30 it was again working. At 3:35 another was reported on account of chain broken; it was again in service at 4:05. At 3:40 one truck was out of power, and it was not reported until it was brought in by another truck at 4:05. Later in the day we had a few more minor troubles, as follows: At 4:15 a truck was delayed on account of drive-chain off, and at 5:50 it was again on its way. At 4:25 another truck arrived at the garage out of power. At 5:05 a truck was reported with lamps out of order, and at 6:00 it was again in service. At 5:50 another truck with drive-chain broken was reported, and at 6:25 it was o.k. At 7:10 another truck was brought in out of power. At 6:30 another one with lights out, and at 7:25 it was o.k. At 7:10

the 13th, or perhaps the unlucky one, was dead on account of a burnt strap, and by 8 o'clock it was ready for service.

Thus out of 316 electric trucks, four were delayed a short time on account of chains, and two reported tail lights out, leaving a total of seven that might be considered important; and out of the seven only three had exhausted batteries, and even these had practically completed their day's work and simply had to be helped home.

The going on the following day, January 12th, was anything but good. I did not ask for a report because I know exactly what is going on, and if anything extraordinary in the way of accidents had happened I would have had a report of it without asking. Therefore, you can see that bad weather conditions, while they have a retarding effect on all motor vehicle equipment, have no greater retarding effect on electrics than on other types, and this is particularly true of electric trucks where properly applied; that is, on a fixed route where they are required to do a day's work within their particular capacity.

It is not my intention to give a comparison in the way of costs nor a comparison as to reliability, but I can say that with a fleet of 87 electric trucks in a middle western city within the snow belt of the United States, during the 12 months ending November 30, 1921, we obtained 29,251 truck days, from which you will note that the record is a little better than 28 days per truck per month. This is brought about by the fact that in this particular city we do some double shift trucking, which we consider is entirely proper with an electric truck.



The Electric Passenger Car

By Karl Probst

Chief Engineer, Milburn Wagon Company, Toledo, Ohio

It is not within the scope of this article to attempt a detailed history of the electric passenger car. However, it is believed that a brief glimpse into the past will assist in the appreciation of the development which has taken place leading up to the stylish, smooth-running, speedy electric passenger car of today.

Electric passenger cars made their first appearance simultaneously with the birth of the automotive industry in this country some twenty odd years ago. Quite naturally, their introduction created a sensation even though they were crude, two-passenger open affairs—adapted carriages in fact—operating at low speeds and with only fair efficiency. The results obtained from these early experiments were so promising that the electric attracted widespread attention and underwent a period of intensive development, from which it emerged a few years later in a state of perfection and stability from which there has since been no really radical changes made. As a family convenience or as a city car for business and professional men, the electric soon established a reputation for reliability and economy. Its progress was rapid, hundreds going into use annually in all of our large cities; and their general use, as a matter of necessity, promoted the development of adequate means for their care and maintenance.

Taking advantage of every improvement in processes and materials disclosed by the development of the gasoline car, of improvements in batteries, motors, etc., by their respective manufacturers, and of the results of continuous research on their own part, the manufacturers of electric passenger cars have continued to effect a steady improvement in their product until today they are producing electric passenger cars which, while not a complete competitor of, nevertheless have a number of distinct advantages over, any other form of urban and suburban transportation.

The widespread increase in the use of electric motor-driven devices in the home, office and factory in recent years has resulted in almost universal recognition of the reliability and economic superiority of electric power, and as a result electric passenger vehicles are every day attracting greater attention on the part of the public.

No doubt the most important asset of the electric passenger car is its reliability, an inherent quality resulting from the correctness of the basic principle on which it operates, and its extreme simplicity. There are no mechanical complications. Imagine taking a modern gasoline car and removing the engine with its multiplicity of pistons, valves, spark plugs, etc., the carburetor, ignition unit and generator, fan, pump, radiator and water piping, gasoline tank and fuel system, and the clutch and transmission, all with their complications and annoyances, leaving nothing but the battery, starting motor and the starting button! These three units represent the essentials of the electric car. The battery and motor furnish the motive power; the controller regulates the speed. Each of these units has demonstrated its dependability beyond a doubt. Vehicle motors are characterized by their high efficiency, good commutating characteristics, general rugged construction and great overload capacity, combined with the ability to give uninterrupted service over long periods of time with little or no attention. Storage batteries, too, have reached a state of perfection such that they can be relied upon to give continuous service throughout their life without care beyond an occasional filling with distilled water and proper charging. Controllers of today are practically all of the continuous torque type, free from destructive arcing, having few moving parts and characterized by rugged and compact construction.

The utility of the electric car is independent of weather conditions. In winter, it is always ready for use. There is no delay due to hard starting or actual disappointment due to frozen and burst parts. The electric has power to suit every occasion, acceleration and flexibility in dense traffic, and a reserve of steady power for mud, deep snow or heavy roads. Stalling in traffic, on hills or railroad crossings is next to impossible. The feeling of security and confidence inspired by the ready response to its controls makes the electric the preeminent car for women, and explains, in part at least, the appeal it has always made to the woman buyer.

Of equal importance to the owner of an electric is the fact that its reliability is so little affected by its age. Probably the most disappointing feature of the gasoline car is its inability to maintain its initial standard of performance over any considerable period of time; although this may vary with the quality of the car, the cause is fundamental and the result certain. With its multiplicity of moving parts, gas tight fits and its numerous adjustments, experience has proven that the satisfactory performance of a gasoline engine cannot be maintained without constant care and adjustment. Service experience shows that 90 per cent of privately owned cars do not get proper attention. The result is a constant decrease in the satisfactory operation of the car. The power plant of the electric, the motor, with its single moving part—and that one rotating in practically indestructible bearings—is inherently free from this defect with the result that it gives unvarying service throughout the life of the car. The power transmission units, too, are simple and few in number. There is no clutch and gearset. Not being subjected to the shocks incidental to gear changing and faulty clutch manipulation or the destructive shocks accompanying high car-speeds, these parts seldom require any attention other than periodical lubrication. Bodies, fenders, etc., also are singularly free from rattles even after long use, due principally to the fact that owing to the regulated speeds at which the electric operates road shocks are much less violent and their effect correspondingly less destructive, because of the ability of the designer to use springs of greater deflection or resiliency than is possible in cars designed for high-speed operation.

The same factors, resulting in the continuous perfect performance of an electric, its freedom from mechanical complications and the inherent characteristics of electric motive power, contribute largely to the low depreciation rate of this type of vehicle. The useful life of the electric car has been placed at 10 to 18 years. While these figures will vary with different authorities and conditions, it is surely reasonable to expect longer life from the electric car than from other usual types of automotive transportation.

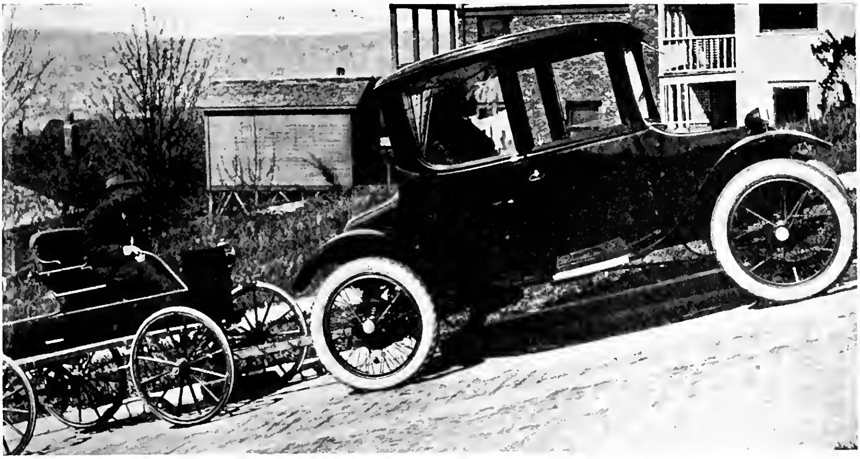


Fig. 1. Twenty Years of Progress in Electric Passenger Vehicles

The simplicity of the electric vehicle has already been pointed out. It naturally follows that having fewer parts than gasoline cars for example, there will be a smaller number to wear out or shake loose. Friction will also be reduced materially, consequently there will be less depreciation. One of the most important characteristics of electric motor power is the absence of vibration, the probable cause of 90 per cent of all mechanical troubles in automobiles. It has been the constant aim of engineers to eliminate vibration since the first self-propelled vehicle. The one-cylinder gasoline car was noisy and jerky, and it did not take long for it virtually to shake itself to pieces. Going to work on the principle that less violent explosions of greater frequency would result in smoother running engines, engineers developed the first two-cylinder engine. Then came the four and six, followed closely by the eight and twelve-cylinder cars. Engineers still disagree as to the best number of cylinders but they are all striving for the same features —less destructive vibration and more uniform torque. In the electric motor, both of these features are accomplished perfectly. The lack of vibration and violent impulses of power are two of the principal causes of the long life of the power plant and transmission units of electric passenger cars.

Low depreciation and continuous perfect performance result in a high second-hand value of electric cars compared with gasoline cars of equal original value and equal age.

While long life and possible high re-sale values are no small factors in the eyes of a discriminating buyer, the question of primary importance to the average owner or prospective purchaser of an automobile is: What does it cost to keep it running?

The items entering into the cost of operation of an electric consist of battery renewal, tire renewal, cost of energy and cost of repairs, oiling, etc. All of these items vary considerably under different circumstances and all are, within certain limits, subject to the control of the driver. For example, by too frequent and severe use of the brakes and too rapid acceleration, it is possible to reduce the mileage of an electric car capable of giving 80 miles on a single charge of the battery to 50 miles. The life of tires, too, may be reduced 25 to 50 per cent by lack of intelligent attention and by careless driving. General repairs and depreciation are likewise affected. The following figures, obtained from the records of one of the largest manufacturers of electric vehicles in the country, represent average values.

Present day batteries have a life varying in car-miles from 10,000 to 20,000 depending on their excellence. The cost of their renewal varies from two to three cents per mile. Tires show an average renewal cost of one cent per mile. This represents a mileage of 12,000 to 18,000 miles, figures which at first thought may seem high but are easily explained by the fact that electric pleasure cars are only operated at moderate speeds and for the most part are driven on well-paved streets and roads. Service records covering a large number of cars for an extended period of time show that the total cost of repairs, oiling, etc., varies from three-tenths to one-half of a cent per mile. With electric energy at five cents per kilowatt-hour it costs about 80 cents to fully charge a battery capable of supplying sufficient energy for 60 miles of travel. This represents a cost of one and three-tenths cents per mile.

Summing up, the total operating expenses of an electric passenger car will not be far from five to five and one-half cents per mile. As near as can be determined from the most accurate data obtainable, the direct operating cost of an electric passenger car is about 60 per cent of that of a gasoline car of equal excellence and accommodations. When all other items, such as insurance, depreciation, etc., all of which favor the electric, are considered, the total cost to own and operate an electric car, as compared with a similar gasoline car, will approach a ratio of one-half.

It will, no doubt, seem somewhat of a paradox that an article of such undoubted economic merit still continues to be in minority use. The cause of this, experience has proved, is psychological, and not due to any lack of merit, mechanical or electrical, on the part of the electric. The average person is so thrilled by speed and sensational performance that these overshadow all other considerations.

The time is not far distant, however, when the shrewd business man will consider the purchase of an automobile on the same basis that he does any other machine which he uses to carry on his business. In other words, its ability to meet his requirements—its reliability, economy, and cost of ownership and operation—will be the guiding factors.

When that time comes, the superiority of the electric car will at once be recognized and then electric passenger car manufacturers will have the majority support of the man who must consider efficiency and economy as his first essentials.

When passenger cars are selected scientifically, more electrics will be used.

The Development and Present Position of the Electric Truck in the Automotive Field

By H. S. Baldwin

Engineer, Automotive Department, Lynn Works, General Electric Company

It would be futile to compare the tremendous growth and production of the gas truck, during the past fifteen years, with that of the slow but steady growth of the electric truck. The application of each form of motive power to propel trucks involves certain marked differences which places each in a distinct and separate field of operation.

The gas truck, with its prime mover, change gears, and readily renewable fuel supply, has demonstrated its peculiar fitness for long suburban and interurban hauls. The electric truck however has always been best fitted for city and town work, where the hauls are shorter and freouent stops are required, either on account of traffic or to distribute merchandise.

In an industry which has reached such vast proportions in the space of a few years, it is not surprising that the gasoline truck has far outnumbered the electric. There is today in the United States one motor car for every twelve persons, and more than nine times as many passenger cars as motor trucks.

The popular mind has been trained in the use of gasoline propelled vehicles, and it is most natural that this form of truck should therefore appeal to the average person. Moreover, the early manufacturers of electric trucks followed their own inclinations and designed their machines along lines independent of the gas truck. Thus, they did not take advantage of the many refinements of detail which it was possible to embody in the gas truck on account of the greater volume of vehicles built.

Again, the condition of city and town streets ten or fifteen years ago was such as to cause injury to the battery; few charging stations were available, and the difficulty in obtaining spare parts and the general lack of information regarding the battery and the use of electrical apparatus all worked to the disadvantage of the electric truck.

Some of the early battery trucks were well designed, and there are numerous examples of such machines which have been in continuous service from ten to twenty years and are still in commission. This, indeed, is one of the outstanding features of the electric truck—its great length of life.

With the recent improvements in road surfaces within our cities, with facilities for charging batteries quickly and economically, and also with the adoption of mechanical details which have been developed in the gas truck, the electric truck is slowly but steadily growing in favor for city and short haul work. Many of our largest express and dry goods companies, also retailers, distributors, and manufacturers, have found, after a most thorough and careful study extending over many years, that the electric truck is best fitted for their use.

The electric truck has several inherent advantages, such as definite and fixed maximum speed limit, freedom from the use of inflammable fuel, and ability to operate in winter without special attention or danger of freezing. Other advantages are the absence of the great number of mechanical parts used in the gasoline engine, clutch, and gear set.

Long experience has shown that the electric motor is particularly adapted to automotive work, and with its single rotating element, the armature, is ideal for traction work. The battery, while still a somewhat heavy unit, has been much improved in output, due to refinement in design and manufacture of plates, jars, and carrying trays. Taking these advantages into account, it is not surprising that the experience of large users of electric trucks indicates an average saving in operating cost, including all details of expense, of from 25 to 30 per cent as compared with the gas truck for similar service.

In the case of the Lynn Works of the General Electric Company, where a number of trucks and industrial tractors are used in and about the plant, records show a saving of 30 to 40 per cent over gas trucks of similar capacity and used for the same service. It is interesting to note moreover that the operating time of the electric truck, without repairs, is found to be much greater than in the case of the gas truck, which is frequently in the repair shop. The electric trucks have been in service for about ten years, and are still in good condition and require only moderate attention and repairs.

Fig. 1. Electric Delivery Trucks in Ice Cream Service (Commercial Truck Company)

Fig. 2. Delivery Wagons in Dry Goods Service (Lansden Company)

Fig. 3. Bakery Delivery Wagons (Ward Motor Vehicle Company)

One of the great drawbacks to the use of the electric trucks has been the difficulty in obtaining convenient and prompt attention to battery charging or replacement. This condition, however, is being rapidly improved due to the increasing use of the electric truck in our cities; and it may safely be said that it is no longer a serious factor. Much remains to be done, however, in the standardization of batteries and means for quick handling.

An important advantage of the electric storage battery truck, as a unit, is its inherent torque characteristic. This is something which is not generally understood. The torque of the electric truck motor increases as the speed decreases, thus giving an automatic change to a speed which can be maintained so long as the battery holds out. On the other hand, the gasoline engine delivers maximum torque at high speeds, thus requiring a series of change gears and a clutch to permit its use. It will readily be seen that the torque characteristics of these two motive agents are directly opposite, and that the electric truck has a real advantage in the matter of torque delivered at the driving wheels. To give a concrete illustration: A competitive test was recently made at Camp Holabird, Md., between a five-ton electric truck and a Class B Liberty truck, as built for the U. S. Army, the latter carrying a load consisting of a two-ton cement block. The trucks were placed in position opposite to each other, the rear ends being connected by a strong chain. The Liberty truck was allowed to start and it commenced to pull the electric truck backward. However, as soon as the driver of the electric threw his controller to the running point, the Liberty truck slowed down, stopped, and then began to move backward. A more powerful gasoline truck was then produced, but the results of the test were the same. The test was made on level, concrete road, and each machine had an equal opportunity. This peculiarity of the electric truck is well known to engineers but has been lost sight of in the great popularity of gasoline driven machines.

Among the uses to which the electric truck is particularly adapted are the delivery of express packages, general merchandise, distribution of milk, ice and ice cream, coal, and similar commodities. Several large companies, such as the American Railway Express, and the Westcott, have proved beyond all doubt that the battery truck is the most economical for their short haul city service. The former company has a total of 1426 electric trucks in its service.

It is interesting to note that of late years several electric truck manufacturers have invested large sums of money in modern plants equipped with the latest machinery and facilities to manufacture trucks in every way equal in detail of construction to any gas trucks of corresponding size.

Having pointed out the steady growth of the electric truck during the past fifteen or twenty years, its great reliability and low cost of operation, together with its safety and convenience, a word regarding its future might be ventured. As the relative merits of the gas truck and the electric truck are studied by large users of such machines, the electric has demonstrated its right to existence and its superiority for city or suburban work where frequent stops are required. With the more modern equipment and plant for manufacture of electric trucks and batteries, and with the improvements which have been made in batteries, motors, and other electrical equipment, there is every reason to expect that the electric will not only continue to show a growth but that this will increase as time goes on. It must be remembered that the entire automotive industry has been created within a single generation, and this is a short period of time for a development of this magnitude. Almost all of the great inventions have required many years to reach a state of maximum refinement and usefulness.

Great improvement has been made in apparatus for charging batteries, and central stations today are much more inclined to recognize the value of the added load of charging many batteries.

The storage battery, which has always been used as an argument against the electric truck, is now neither so heavy nor is it the somewhat delicate component that it was in past years.

Furthermore, it is interesting to note that many gas trucks are today equipped with storage batteries of sufficient capacity to start the engine and to supply energy for the running lights. While this battery is of comparatively small size, it nevertheless forms an important part of the equipment of the truck and requires the same kind of attention as is required for the battery of the electric truck. The only difference is that of size, and the fact that it is normally charged by a small dynamo on the truck and therefore need not be removed for charging. In making this statement the fact should not be lost sight of

Fig. 4. Electric Delivery Wagons in Dry Goods Service (Lansden Company)

Fig. 5. Forty-one Delivery Wagons in Laundry Service (Ward Motor Vehicle Company)

Fig. 6. Baggage Express and Transfer Trucks (Commercial Truck Company)

that, in many instances, the battery of the electric truck is not removed for charging, which operation can often be performed during the night hours. In some cities, moreover, enterprising central stations have arranged to transfer fully-charged batteries of standard form of construction. This plan should receive attention and further development.

Another suggestion has been the sale of the electric truck without battery, the battery to be considered as a separate unit for which a definite rental charge will be made. This amount, of course, must be sufficient to pay the interest on the cost of the battery, its maintenance, and a reasonable profit. This plan has been in operation in Hartford, Conn., since 1912, and, it is stated, is being given serious consideration by battery manufacturers. It appears that its introduction would add greatly to the success of the electric truck and cause a much more rapid growth than in the past.

Having referred to the electric truck and its application in a general way, the remainder of this article will be devoted to a brief discussion of a number of pertinent subjects to show the improvements which have been made during the past 10 or 20 years, not only in the truck itself but in conditions surrounding and affecting its use.

Attitude of Central Stations Toward the Electric Truck

In the early days of the electric truck industry little encouragement was given by the central stations of our large cities. It seemed to be the general impression that the financial return for charging electric storage battery trucks would not, for a long time, justify the investment in charging apparatus, facilities, and the trouble involved. Unfortunately, this attitude continued for many years and a most fertile field for the use of electrical energy was overlooked as not having sufficient promise. This undoubtedly has been an important factor in retarding the progress of the electric truck, as it has meant that the user of one or two trucks found it necessary to provide his own charging facilities, with the attending cost of equipment and labor. This naturally worked in favor of the gasoline truck; and it was due only to the real advantages of the electric storage battery truck, which were demonstrated by express companies and merchants owning comparatively large fleets, that the industry survived. Fortunately these large users of trucks were able to provide their own charging facilities, which they did in many instances. To-day, however, the central stations of our larger cities have begun to appreciate the real value of the electric truck as an outlet for their supply of electrical energy; and they are now encouraging the truck user by providing facilities and making more attractive charging rates.

Roads and Highways

The rapid increase in the number of automobiles of all kinds in use in the United States has brought about a marked improvement in street and highway construction. Fifteen or twenty years ago the slow moving horse-drawn vehicle did not require the hard smooth surfaces which have been found necessary for the successful use of the automobile. In those days the principal thoroughfares of our large cities were of Belgian Block construction, set in a sand-base. Naturally, after a few years the blocks settled in spots causing extremely rough surfaces. Side streets were, for the most part, of water-bound macadam construction, which when well made had a reasonable life so long as the horse was the principal motive agent. Suburban roads, as a rule, were also of ordinary macadam construction or, in many cases, of gravel or dirt rolled to give a fair surface. There was little demand for through highways for the transfer of merchandise. Trucking for the most part was confined to farmers bringing their produce to market. There had never been an occasion for the wonderful military roads, such as are found in Europe, and which, frequently of Roman origin, played an important part in transportation in the World War.

As soon as the public realized the importance of the automobile, steps were at once taken to provide suitable roads, both urban and suburban. The uneven Belgian Block was entirely inadequate and caused great injury to the early automobile, also greatly reduced its speed of operation. Water-bound macadam and gravel roads could not resist the effect of driving wheels and rapidly became unusable.

For a number of years there was much uncertainty as to the best road construction for the automobile. At present, however, there are several types which have proven successful; viz., the cement-concrete, Belgian Block set in cement, the asphalt-bound macadam and asphalt concrete. To these might be added vitrified brick and wood block on a cement base. All of these have given good results in actual service, and each has been found to be adapted to special load conditions. These types of road surface were largely brought about by the automobile; on the other hand, the automobile has created a demand for thousands of miles of modern roads made along the most approved and best lines. It is easy to see the cause and effect. The modern road and the improvement in the automobile have moved in parallel, the one being dependent on the other. As a result, road conditions are such as to greatly favor the operation of automobiles in our cities or for longer distances between our principal commercial centers. Today it is possible to reach almost any city by using the automobile truck or passenger car over roads which, for the most part, are level and of hard and durable surface.

Progress has been made, yet there is much to be done. Every State in the Union is planning great extensions of automobile highways. While the improvements already made have been brought about largely by the increase in gas trucks, it is clear that the benefit has been greater to the electric truck, particularly from the standpoint of the battery.

In the early days batteries were frequently injured, due to the extremely rough road surfaces in our large cities. Today conditions have been reversed, and a great obstacle to the increase in the number of electric trucks has been definitely removed.

Electric Truck "Fleets" and Special Applications

It is an interesting fact that the electric truck is frequently found in groups or "fleets," numbering sometimes one hundred or more, operated by companies of the highest standing; and these vehicles for the most part represent repeat orders based upon use extending over a period of years.

An enumeration of the many prominent users of the electric truck has been recently published both by truck manufacturers and by the Electric Vehicle Section of the N.E.L.A., and goes to prove that the electric truck has stood the test of time.

Reference has been made to the many general uses to which the electric truck has been successfully put, but there is no reason why these should not be greatly increased now that so many improvements have been made in truck components.

Battery Handling

In the early electric truck the battery was located in about every conceivable place and manner. In the first truck built by the Columbia Company, the battery was pushed in a space under the body directly from the rear. In later machines the same operation was performed from the side, a rigid cradle being attached to the frame of the chassis for this purpose. For convenience in handling, the battery was usually made up of a number of sections. Later many trucks were built in which the battery was made self-contained; that is, was held together in a separate tray of sufficient strength so that it could be handled as a unit. Most of these arrangements are to be found in the battery truck of today, modified to agree with the ideas of the manufacturer and local conditions.

Some twenty years ago elaborate and extensive systems for handling batteries were devised by the engineers of the Electric Vehicle Company, and installed at their stations in New York City, first at 1684 Broadway, and later at 8th Avenue and 49th Street.

While the Electric Vehicle Company was somewhat ahead of its time, the plans then worked out are most interesting even today; and with the growth in the number of cars used, it is safe to say that many of the old schemes for quick and economical handling of batteries may be again put into service with improvements to meet present conditions.

There is no reason why there should not be one or two standard methods of carrying batteries in trucks, also of handling batteries in stations. These might include the system of sliding the battery in a fixed cradle from the side and the plan of raising the battery from below and attaching by hooks. Here is a subject which may well be given the consideration of our truck manufacturers.

Body Construction

In the matter of body construction much has been accomplished of late years in the direction of special designs to meet the requirements of both the gas and electric motor trucks. In the early days there was little practical experience to guide the body builder and for this reason designs were frequently produced which were not only heavy, but awkward and expensive, and did not meet operating conditions. These defects have been gradually eliminated, until motor truck bodies are now well developed in structural details, and wood and metal are combined to produce the necessary strength without excessive weight. This of course means lower cost, greater life, and less dead weight to be moved about over the road. Taking it all in all, it will be seen that the body is an extremely important detail of the truck and has a vital bearing on the matter of efficient operation.

Much greater attention is now given to the protection of the driver in cold and stormy weather, and as the result enclosed vestibules are frequently provided.

The electric truck is particularly adapted to the dump body, owing to the fact that the mechanism for lifting the body can be operated by an independent electric motor.

Another interesting feature is the removable body which can be loaded in the warehouse and later swung onto the chassis and fastened. This plan does away with the long wait required for loading, and under certain conditions permits the chassis to be operated more economically.

Bodies of excellent design and construction are now available and this art has passed the experimental stage. They may be of the permanent, enclosed type, or provided with bows and canvas top covers. Various forms of stake and express bodies are also available.

Regarding the matter from an artistic standpoint, bodies are now pleasing in appearance; the lines are more mechanical and have less of the influence of the horse-drawn truck than heretofore.

The electric truck presents many possibilities in the matter of loading, operation of winches, blowers, drills and accessories of various kinds. A number of interesting bodies have been developed for public service corporations, with many useful electrically operated auxiliaries.

There is a wide range of possibilities for special applications in which the energy of the battery can be used to operate small motors for short periods of time in connection with the storage battery truck.

Summary

This article has merely touched upon the salient points in an endeavor to show that in every detail the electric truck has kept well abreast of the development in automotive construction, both from a mechanical and electrical standpoint.

Analyzing the facts presented, there is good reason to believe that the electric truck will soon force its way to an important position in the motor truck world.

Electric Baggage Delivery Wagon (Walter Motor Truck Company)

Electric Vehicle Operation

By R. MacRae

Commonwealth Edison Company

One of the first questions that occur to anyone who starts to look into the electric vehicle situation at the present time is this: Why is it that the rate at which electric vehicles are coming into general use is so slow when it is an easy matter to get almost any number of testimonials from business concerns that are using these vehicles for all kinds of city traffic, and who are in a position to give intelligent and unbiased opinions?

Here are extracts from the letters of a number of users of electric trucks:

"Electrics give much better service than gasoline trucks with 65 per cent less operating cost."

"Ten electrics during the last season cost less for operating expenses than four gasoline trucks."

"This work cannot be done by gas trucks as quickly nor with the satisfactory results we have obtained from electric trucks."

"We are operating only two gas trucks, both of which will be replaced with electrics when they are worn out."

"We started out right when we chose the electric vehicle rather than the gas truck."

"We have found the electrics the cheapest delivery system of all."

With regard to the life of an electric vehicle, the superintendent of transportation of one department store says: "We have some electric cars that are over eleven years old and I challenge anyone to pick out one of these from among others that were put into service only two or three years ago. I expect these cars to look the same ten years from now."

Another says: "We have been using electric cars for over ten years and we never had to rewind an armature or to throw an armature away for any cause."

With such a display of testimony before us it would be impossible to account for the relatively small number of these vehicles now in use, if it were not that equally unbiased and spontaneous opinions can be obtained from others who have tried out electric vehicles and failed to get satisfactory service from them.

This brings up the question: Why do some users of electric vehicles get good service from these vehicles while others do not? The answer is that some electric vehicles are operated under unfavorable conditions and by operators who not only do not know anything about electric vehicles but who are making no effort to learn anything, because they have been told that there is nothing to learn.

This situation, which is unquestionably responsible for the poor showing that electric vehicles make when compared in numbers with gasoline vehicles, is due almost entirely to the fact that less consideration has been given to the subject of electric vehicle operation by those who are interested in the electric vehicle industry than to any other on which the success of the industry depends.

The popular fiction that a child can operate an electric vehicle has been a fixed part of the creed of electric vehicle salesmen for so long a time that comparatively little progress has yet been made in the way of creating, as far as the general public is concerned, the conditions necessary for the successful operation of electric vehicles.

For the same reason very little has been done to enable the operators of electric vehicles to obtain the necessary technical training. (By operators is here meant the men who are responsible for keeping the vehicles in proper working order, and not the drivers of the vehicles.)

The first step towards securing operating conditions that can be considered even respectable is a recognition of the fact that operating conditions will not improve unless some effort is made to improve them, and that the conditions and methods of operation developed for horse-drawn vehicles, or gasoline vehicles, are not adapted for electric vehicle operation.

Some valuable work of an educational character has been done by individual battery companies and by some central station companies, but what has been accomplished is so small compared to what remains to be done that these efforts can be considered merely as a start in the right direction. What the situation calls for is an organized effort by the electric vehicle industry as a whole, along the lines that have always been recognized as essential to the successful operation of gasoline vehicles.

Such an effort is needed because there are some who still have the impression that electric vehicles can be operated successfully by persons who have no technical qualifications of any kind, and who consequently are unable to distinguish good operating conditions from bad. Actual results show that this impression is wrong and it is now generally recognized that 95 per cent of the so-called electric vehicle failures of the last ten years have been failures of operation and not failures of the vehicles themselves.

We all know of electric vehicles that were pronounced a failure in one town which afterwards proved a success in another, and of operators in large cities who claim that they can use electric vehicles to advantage in some sections of the town while they can not use them economically for the same kind of work in another. In such cases as these it is not a question of the limitations of electric vehicles with which we have to deal, but one of inadequate operating facilities.

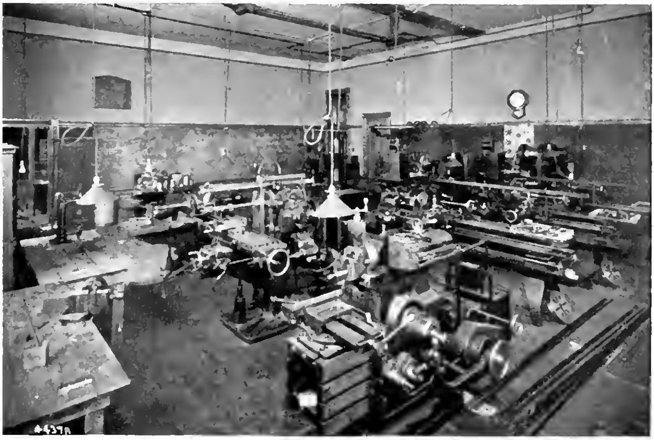


Fig. 1. A School Machine Shop for Training Electric Vehicle Operators

But why, it may be asked, discuss electric vehicle failures when it is possible to point out so many cases where electric vehicles are doing better work than could be done with any other type of vehicle? In the introduction of any new piece of apparatus there will inevitably be some cases of failure due to the lack of experience with the apparatus, but a reference to these failures is not good advertising.

This, of course, is true, and the only excuse for referring to the failures is the evidence which goes to show that the industry has something yet to learn from these failures. The well known saying that "nothing succeeds like success," is sometimes supplemented by another to the effect that nothing succeeds like failure, when the failure is the means of teaching something that could not be found out in any other way.

Electric vehicle failures have shown very clearly what should have been clear even without the failures, namely, that it is not possible to get good service from electric vehicles when they are turned over to the care of men who know nothing about batteries, motors, and electrical instruments. This is particularly true when these vehicles are used for commercial purposes, and in competition with gasoline and horse-drawn vehicles.

To get good service from horse-drawn vehicles it is necessary to employ men who have been trained as horseshoers, harness makers, veterinary surgeons and the like; while to qualify as a gasoline vehicle operator, the obvious thing to do is to take a course in some automobile school of which there are any number.

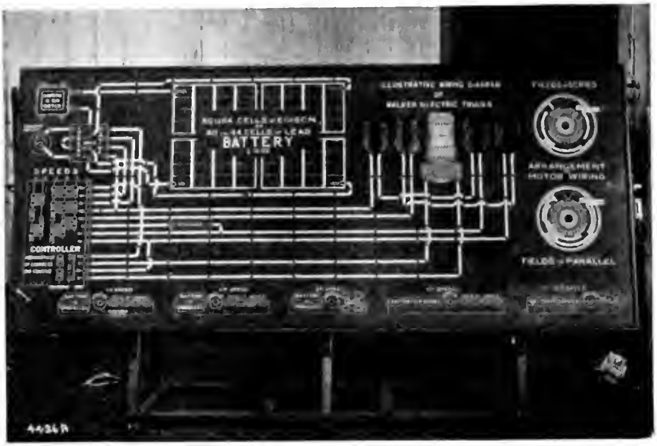
It is equally important and necessary to have trained men to operate electric vehicles. There is no mysterious virtue in an electric vehicle by which it will continue to give good service when its operation is left entirely to some one who never had an opportunity of learning anything about electrical apparatus.

The first attempt to provide technical training of any kind for electric vehicle operators was made a little over a year ago by Prof. E. G. Cooley of the Continuation Schools of Chicago In this experiment Mr. Cooley had the co-operation of the Commonwealth Edison Company and the local electric vehicle industry.

This school, which is the only one of the kind as far as we know, is located at 26th Street and Wabash Avenue. It is in charge of Mr. John Crowell, as Head Master, and has a complete equipment of all the apparatus and instruments necessary for a technical course of this kind, as well as a modern machine shop in charge of an instructor which is open to students taking the electric vehicle course. Several classes have already been conducted with an average attendance of about a dozen in each class.

The illustrations are from photographs taken at the school. They are intended to give an idea of the equipment that is available for use in connection with the electric vehicle course.

The development of the electric vehicle industry will bring about an increased demand for competent operators, and competent operators will in turn create a demand for more electric vehicles.



Wiring Diagram of Circuits Traced with Miniature Lamps Operated by a Motor for the Training of Electric Vehicle Operators

Experience of Users of Electric Trucks in New York City

By Charles R. Skinner, Jr.

Manager Automobile Bureau, New York Edison Company

The purpose of this article is to set forth concrete examples and facts why the electric truck should be more extensively used, within its field of application, in the transportation of merchandise throughout the country. On the part of industry, conditions generally are causing a careful investigation of the wide range of electric vehicle advantages. All signs point to big developments and the electric vehicle is rapidly coming into its own. Over 800 electric trucks have been sold in this district during the past two years. The sales in 1921 alone were over 400 per cent of any other year in the history of the industry.

Take for instance the baking industry which uses 806 electric trucks representing an investment in excess of $300,000. Among the most prominent users are the Ward Baking Company, the National Biscuit Company, the Shults Baking Company, and the Cushman Bakeries. A letter in our file from the Cushman Company says: "Our experience with electric trucks has shown them to be 33 per cent cheaper to operate in New York City than the gas car. They have proved dependable and satisfactory." The electric vehicle is the favorite mode of transportation by bakeries not only because of its economies but also on account of its cleanliness, which is the prime requisite in the handling of food products.

This company also uses horse-drawn and gasoline trucks, but it is understood that the horse equipment will be supplanted by electrics. It is interesting to know that the drivers of the horse-drawn wagons, who are familiar with the various delivery routes, are transferred to the electrics. This is brought about very easily owing to the simplicity of the electric, as one is not required to possess much mechanical knowledge to learn how to drive a storage battery truck. It has been found by experience that a shorter time is required to train a novice to drive an electric than any other type of motor vehicle.

Of course, many people know something about the extent to which the American Railway Express Company is using electric trucks. The latest reports show that this company, throughout the country, is using a total of 1176 electric street trucks. Of this number 324 are in constant service in this district, 105 having been placed in service since January 1, 1922. An interesting feature of the new 20 five-ton units which are to be used in New York City is that they are to be operated on a 24-hour basis. This will be accomplished by means of standardized interchangeable batteries and battery cradles, each truck being provided with a spare battery unit; thus at the end of the first shift the battery in use will be removed by means of an electric industrial elevating platform truck, insuring a rapid exchange which it is estimated will require less time than it takes to fill the tanks of the five-ton gasoline trucks which the electrics are replacing. Most persons will undoubtedly be surprised to learn that these 20 trucks used on a 24-hour basis will require approximately 600,000 kw-hr. of electric energy

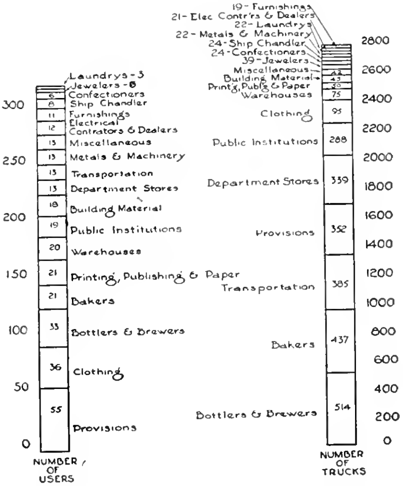


Fig. 1. Classification of Electric Trucks and Users by Industries. Manhattan and Bronx, 1921

annually, equal to the amount of current consumed by a large New York hotel.

When, returning to the city from a trip, a traveler passes his trunk check to a representative of a baggage express company, he probably does not stop to think what an important part the electric truck will play in the delivery of his baggage. The companies which handle the major portion of baggage in New York City are the Westcott Express Company and the New York Transfer Company, the former using 51 electrics and the latter 29, with an additional order pending. In 1920 the Westcott Express Company found that, of a fleet of electrics and gasoline trucks installed in their New York City service in 1912, all the gasoline trucks had worn out and were out of use, while all the electrics were yet in service. Upon further investigation they found that the electrics not only outlived the other type, but saved them money and did the work just as effectively. As a direct result of this investigation the electric truck fleet has been increased in numbers, until today they have 51 in service.

Table I covers all the facts brought out.

The department stores have long realized the advantages of the electric truck for their deliveries, and 13 such firms in New York City use 339 electrics. Among the larger users are John Wanamaker, Stern Brothers, B. Altman & Company, R. H. Macy & Company, Lord & Taylor, James McCreery & Company, Hearn, and Gimbel Brothers. Three of the above mentioned firms have placed orders for a total of 30 electric trucks within the past 12 months, for they have found by experience and careful cost accounts that the cost per package delivery by the electric truck is considerably less than by any other type of motor vehicle.

Now let us see what the provision merchant has to say about the electric truck for his line. He gladly imparts the interesting news that 55 brother merchants depend on 352 electric trucks to deliver their orders, and not only do they do their work well and economically throughout the city but they cover a much broader territory.

The merchant also produces a map, showing that his electric trucks are called upon to go to Newark, Elizabeth, Staten Island, and Brooklyn. Looking on his daily chart we see that his trucks often are required to travel from 35 to 45 miles per day. In this group of users we find such firms as Park & Tilford, Swift & Company, National Sugar Refining Company, Acker, Merrall & Condit Company, Charles & Company, Armour & Company, and many other prominent mercantile organizations.

The flexibility and adaptability of the electric truck are well exemplified, for while packing concerns like the ones mentioned require a long mileage radius for their work, traveling even as far as Bayonne and Edgewater, New Jersey, the opposite is true of some of the grocery firms. In the Acker, Merrall & Condit Company several different sizes of electric trucks are used, ranging from the five-ton size to the small 750-lb. car. The large trucks are employed in transfer work, that is, the hauling of flour, canned goods, and

TABLE I

DIFFERENCE IN OPERATING COST BETWEEN AN ELECTRIC AND A GASOLINE TRUCK. COMPILED AFTER A THIRTY-DAY TEST

Gasoline Truck 6½ Years Old

Number of working days (9 hours each) 28	
Overtime, 43 hours	4—7 hours
Total days service	32—7 hours
Number pieces baggage handled	3,296
Garaging (estimated)	$25.00
Gasoline cost	154.28
Oil cost	6.75
Repairs outside garages	10.00
Material used	5.91
Labor	13.43
Time lost on account of breakdowns on street, 5 hours 10 minutes—cost	5.95
Time lost in garage obtaining equipment, lights, etc., and starting motor, 4 hours 35 minutes—cost	5.25
Total cost	$226.57

Electric Truck 8½ Years Old

Number of working days (9 hours each) 29	
Amount of overtime, 39 hours	4—3 hours
Total days service	33—3 hours
Number pieces baggage handled	3,294
Charging and garaging truck (outside garage)	$63.00
Allowance for battery	33.00
Material used in repairs	2.01
Labor	7.58
Time lost for repairs, 40 minutes—cost	.76
Time lost in garage obtaining equipment, etc., 1 hour 20 minutes—cost	1.53
Total cost	$107.88

fancy groceries from the warehouses of the company to the branch stores. This of course is heavy trucking and capacity loads are always carried at least one way. But at the branch stores, particularly uptown, the neighborhood deliveries are made with the small electrics. For a long time this neighborhood delivery had been made with horses and there was much doubt expressed at the ability of the electrics to do the work at a cost which would make their use advisable. However, it was decided to try the experiment, and today the electrics have taken the place of horses at two branch stores and will in all probability replace the horses throughout the company within a short period. One example like this is sufficient to silence the skeptical and is conclusive proof that electric trucks can do the work of horses and to better advantage, at least in the class of service just cited.

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Fig. 2. Territory Covered by Electric Trucks from the Manhattan District

The firms who make use of electric trucks are of high character. They are not "fly by night" concerns but have established reputations for honesty, judgment, and careful insight into business conditions. This is an added point in favor of the electric truck for if these firms use and endorse it, and they do, it must supply the best delivery facilities obtainable for the purpose.

Printing is another industry which uses electric trucks to advantage. As an example of the kind of work done, the trucks used by the Carey Printing Company, Inc., furnish an illustration. This is not an isolated case, for nine printers use 19 electric trucks in Manhattan.

The Carey Printing Company prints *Harper's Bazaar*, *Le Costume Royal*, *Shadowland*, *La France*, and numerous other periodicals and advertising booklets. Seven floors of the structure at 36th Street and Tenth Avenue and two adjacent warehouses are required to make room for all the activities of the Carey Press. In their transportation department, the truck problem has been solved, as it is coming to be solved in more and more industries, by the purchase and use of electrics.

Four years ago, the company bought three five-ton storage battery vehicles and, having watched the performance of these and checked up their cost, augmented the fleet by the addition of two more trucks in 1919. The latter cars are of the six-ton chain-driven type. One gasoline-driven truck is maintained for the purpose of making long distance deliveries but all other hauls are made by electric vehicles. A working average of between 15 and 17 hours daily has come to be the rule for these cars and an overload of one half ton to one and a half tons is regularly added without any undue strain or stress. Four and five loads per day are carried by each electric and the material consists of packages of magazines and periodicals whose weight approximates 25 to 42 lb. A truck is sent on its way with 400 to 600 of these packages as its quota per trip.

At the beginning of the day the trucks do some of their hardest work, it being a common thing for the Carey Press to deliver 30,000 lb. of printed matter before 9 a.m., while toward the end of the day the bulk is nearly as great.

The work is done on day and night shifts, and the presses of the Carey Printing Company are almost never still. In handling the material it is piled on wooden skids; Cowan Transveyors serve to convey the heavy bundles to the freight elevators where they are lowered to the street level.

At this point the electric trucks take up their tasks. From the Cowan Transveyors the packages are loaded onto the trucks and are then delivered at their several destinations throughout the city. The policy of the Carey Press has made it possible for their trucking cost to be met by the revenue received from carrying loads for outside firms in addition to their own transportation. After four years' experience with the storage battery vehicle, the Carey Printing Company has found that no other mode of transportation so adequately meets their city haulage requirements.

When we begin to investigate what part the electric trucks play in the public utilities world, we find an especially strong point in their favor in the fact that the New York Edison Company is replacing four five-ton trucks equipped with electric winches for cable pulling purposes, with four new electric units of the same size. On further inquiry we find that the trucks to be replaced were purchased in 1904, having done the hardest and most difficult kind of work faithfully for 18 years. We are informed that throughout the country there are 75 central stations which use 795 electric trucks, 109 of which have been purchased during the past twelve months. Thus, by using the electric, there is a double benefit. By using it themselves they are not only placing their transportation department on the most effective and economical basis, but at the same time are setting an example for others. We are told that approximately 30,000,000 kw-hr. of energy is sold annually in the New York district alone for charging storage batteries. When we realize that the storage battery load is entirely an off-peak one, it is evident that little or no investment is necessary for extra generating or substation equipment. Therefore, this type of business is much desired. A simple comparison will show the advantage of this load. Let us consider how much current is used in charging the electric vehicle as compared with the largest current consuming household appliance — the electric iron. Records show that the 7000-lb. truck uses in one month about 650 kw-hr., while the iron in the same time uses about 10 kw-hr., an increase of 6400 per cent.

The following figures illustrate the long life of the electric truck. Among the 4362 electric trucks that were in use in New York City, January 1, 1921, there were:

5 trucks over 23 years old
7 trucks over 20 years old
25 trucks over 18 years old
33 trucks over 17 years old
106 trucks over 15 years old
221 trucks over 12 years old
980 trucks over 10 years old
1,580 trucks over 8 years old
2,448 trucks over 6 years old
2,899 trucks over 5 years old

A recent report made to the Joint Commission on Postal Service in the New York district shows that approximately $200,000 in operating costs can be annually saved by the government by replacing a certain part of their present equipment with electric trucks. The advantages are:

(1) Design much simpler, fewer complicated parts.

(2) Less repair work, as there are no reciprocating parts to set up internal vibration.

(3) Small stock of parts necessary, as there are fewer parts to wear out.

(4) Trucks can be regulated absolutely as to speed; fewer accidents from careless driving.

(5) Decreased insurance rates; fire, liability, and theft.

(6) Tire cost less than 50 per cent. (It costs less to keep tires on a light electric than it does to keep a single horse in shoes for the same work.)

(7) No radiators to freeze; cold weather brings no fear to the owner of an electric.

(8) Ten dollars will buy all the grease and oil necessary for an electric for one year.

(9) It uses no energy when standing idle and is always ready to move.

Other important points which should be taken into consideration are:

(1) Its cost for each mile, ton-mile, or ton hauled is the lowest for any known motor truck.

(2) It is not subject to the delays incident to starting an engine, shifting gears, etc.

(3) It will operate more days during each year and more years.

(4) It is clean and its driver, having no adjustments to make, can keep clean.

(5) It is sturdy and well built.

(6) Its speed is automatically governed by its design and not by the whims of the driver.

Fig. 3. Electric Truck and Trailer, 14th Sanitary District of New York City

Another place where the electrics have proved their merit is in the fourteenth sanitation district, which comprises one-eighth of the island of Manhattan. Here three electric tractors are used to haul trailers. One of them hauling a trailer is shown in Fig. 3. Often the loads are so great that two trailers are hauled at a time, in which case the tractor must haul from 10 to 14 tons of material. These tractors dispose of 1765 cubic yards of rubbish, 1380 cubic yards of garbage, and 2364 cubic yards of ashes, making a total of 5509 cubic yards of material, which work is performed with a saving of labor, time and money. One of the three tractors is over ten years old and performs the work which formerly required ten horses to accomplish. By the further use of the electric truck, tractor, and trailer in this particular field of city work, large sums of money may be saved.

There is one field for which it seems the electric is especially suited, and that is ambulance work. Where quietness and reliability are so necessary and where such great care must be exercised in conveying the sick, the electric excels all other methods. The superintendent of a New York hospital told me that removing a patient from a well heated home, which is none too well ventilated, and rushing him through the streets at an excessive speed is often disastrous; hence the electric, the speed of which has been set by electrical engineers, reduces this danger to a minimum. On other than the electric type of ambulance the speed is variable according to the fancies or whims of the driver. At this time there are four hospitals using 12 electric ambulances. The Bellevue Hospital was one of the first to adopt electrics and, although discarded for a brief time, it is interesting to know that two new electrics of the 1500-lb. class have recently been placed in service and are at all times ready to respond. The New York Hospital is another advocate of the electric ambulance, having four in service, the first one being purchased in 1905, the second in 1909, followed in 1910 by number three and the last in 1911. During one year these four ambulances responded to more than 8000 calls. The mechanical repair cost on these trucks is remarkably low and for many years the annual expense for the four trucks has been less than $100.

Actual achievements are convincing another big industry that the electric truck of today is a practical car in every respect for its field of work. The electric truck has made the task of handling household goods an easy one. Storage warehouse owners to the number of 20 are using 75 electric trucks and are most enthusiastic over the results which they are obtaining. Some of the companies use a removable body, which can readily be taken off the truck and placed on a carrier. Its place can then be taken by another body and the truck can again be sent out. This is an excellent idea as the truck spends but little time in awaiting its load. It is rather surprising that this type of carrier is not more prevalent, as it is a great time and money saver. We have found that two-thirds of a truck's time is often lost in awaiting or discharging goods. Depreciation and other charges go on irrespective of whether the truck is in motion or not; and until ways are found to cut down waiting time, trucking charges will be high. In moving furniture, a moderate pace is a desirable one so as to avoid breakage, thus the speed of the electric truck is more than sufficient. Among the users are the Manhattan Storage and Warehouse Company, Lincoln Safe Deposit Company, Bowling Green Storage and Van Company and others.

Where electric equipment is used, relatively little congestion and confusion occur. When in 1912 the Hygeia Distilled Water Company purchased its first electric truck, the management was not at all certain that the experiment would prove successful. At that time this company was using 54 horses. However, the electric steadily gained in favor, as it was soon found that one electric was accomplishing the work of two or three teams of horses, and gradually more electric trucks were added until ten trucks were doing the work of the 50 horses which they had replaced. Today there are 58 electrics serving with great success in ten water bottling companies.

It is an economic shame that transportation costs are not investigated more fully by the average business man, because if this were done the manufacturers of electric trucks would probably be unable to fill their orders. This statement is substantiated by the following telegram which was read at the Electric Vehicle Luncheon held in Chicago, 1921, during the National Electric Light Association Convention:

> "I am pleased to learn that the electric vehicle for city traffic is receiving more attention lately from the electric lighting companies. Any merchant who keeps accurate costs will buy electrics.
>
> "Thomas A. Edison."

Competent authority has asserted that 80 per cent of all gasoline trucks in New York City could be profitably replaced by electrics. Consider what this means. There are at present 57,000 gasoline trucks in this district. Suppose that not 80 per cent but only 50 per cent, or 28,500, of these were replaced by electrics. The average cash saving of electric vehicles has been determined at $8 per car day, but in order to be sufficiently conservative, let us say that the saving would be not $8 but $4. Multiplying 28,500 by $4 we have $114,000 which extended over 300 yearly working days becomes $34,200,000 or the interest at 6 per cent on $570,000,000. In other words, the supposedly astute New York business man is deliberately allowing the interest on over a half billion dollars to trickle through his fingers yearly. This takes into account the monetary saving only, to say nothing of increased efficiency, relief of traffic conditions, and added cleanliness, plus the lowered fire, theft, and liability insurance charges. Records tell us that the number of electrics destroyed by fire is almost negligible, and the writer knows of no instance of an electric being stolen.

The staggering total of these figures gives some idea of the task confronting the truck manufacturer, the salesman, the battery manufacturer, and the central station. Far from being dismayed, however, these organizations are going ahead and are constantly devising means to surmount and conquer the obstacles in their paths, central stations are extending their services and capacities, and manufacturers have enlarged their plants for speeding up production. Extensive advertising campaigns are being carried on by storage battery manufacturers, vehicle manufacturers, and central stations and this influence has already made itself felt. The sales of electric trucks in 1920 and 1921 prove that the electric is rapidly taking its rightful place in city work.

TABLE II

A FEW OF THE WELL KNOWN USERS OF ELECTRIC TRUCKS IN NEW YORK CITY

Company	No. of Trucks
Acker, Merrall & Condit Co.	14
Altman & Co., B	21
American Railway Express Co.	324
Baker, Carver & Morrell	8
Bush Terminal Co.	57
Consolidated Gas Co.	52
Cushman's Sons, Inc.	149
General Baking Co.	10
Gimbel Brothers	54
Gorham Co., The	15
Wanamaker, John	24
Horn & Hardart Co.	12
Macy & Co., R. H.	57
Maillard, Inc., Henry	10
Manhattan Storage Warehouse Co., The	13
National Biscuit Company	15
New York Edison Company, The	121
New York Railways Company	31
Shults Bread Co.	75
Stern Brothers	39
Tiffany & Co.	21
Ward Baking Co.	200

The Electric Vehicle in Boston

By E. S. Mansfield

Superintendent Operating Bureau Accounts Department, Edison Electric Illuminating Co., Boston

The sun in its daily course strikes the rock-bound shores of New England before it visits the other flourishing sections of our beautiful country.

There are many other things besides the sun which have struck New England first, among which may be included the electric vehicle; and as Boston is the commercial center of New England, if not still the "Hub of the Universe," we shall ask Boston to stand for the whole of New England, which is so closely associated with it, as well as the Metropolitan center located in the eastern part of Massachusetts.

The first electric automobile in Boston was built in the summer of 1888 by Fred M Kimball of the Fred M. Kimball Co. of Boston. This machine was constructed for P. W. Pratt and was first exhibited in Winthrop Square and later on Columbus Avenue in Boston; also at Central Park, New York City; and on the Boardwalk at Atlantic City.

It consisted of a tricycle driven by a specially designed bi-polar electric motor of about one-third horse power. Electric power was supplied by a storage battery consisting of six Julien cells, mounted in a wooden crate suspended from the main frame of the vehicle by means of spiral springs, so arranged as to relieve the battery crate from strain or jar. A triple reduction through one set of gears and two chain drives gave the vehicle a speed ranging from 6 to 8 miles per hour on a smooth road. Its total weight without passenger was about 300 lb

The next electric vehicle in Boston about which we have any information was a two-passenger electric carriage built for Fiske Warren in 1891 by the Holtzer-Cabot Electric Co. of Boston. This car was equipped with a 5-h.p. series-wound motor especially designed for a speed of 600 r.p.m. and driven by 40 "11-E" chloride accumulator cells coupled to control in four groups of ten cells each to produce speeds of 4, 8, and 16 miles per hour when running over good level roads, and on the middle speed the carriage would run about 40 miles on a single charge of the battery. The weight of the carriage with batteries was nearly 3000 lb., yet it could be operated with great ease and was a very satisfactorily running carriage.

In 1893 W. H. Blood, Jr., now of Boston but then of Kansas City, Mo., designed a one-seated box buggy electric car which when completed was run about the streets of Kansas City and then shipped to Philadelphia to be equipped with a new style of battery but was destroyed in a wreck during transit. The motor was series wound, of high efficiency and built to run on 60 volts supplied by a battery furnished by the Electric Storage Battery Co.

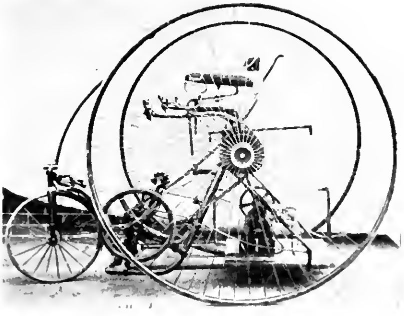

Fig. 1. The First Electric Vehicle Constructed by Fred M. Kimball, 1888

The drive consisted of rawhide wheels on each end of the armature shaft, bearing on iron flanges bolted to the inside of each rear wheel. Ingenious devices were provided for the electric control, for steering, regulating the speed, and for braking. The speed of this car was about 20 miles per hour and but for its untimely end would doubtless have given good service.

In 1895 the Holtzer-Cabot Co. produced another electric wagon, modelled after the English "brake," for a wealthy resident of Boston. Its weight was about 5100 lb. and was of solid and durable construction throughout.

The batteries contained in the body and under the front seat consisted of forty-four 250-ampere-hour chloride accumulator cells with a normal discharge rate of 25 amp. The motor was a special 7½ h.p. 4-pole series wound machine, having a speed at full load of 250 r.p.m. and an efficiency of 89 per cent.

The car had a speed of from 4 to 15 miles per hour and could take ordinary grades with ease.

In 1896 Col. Pope first started to manufacture the Columbia electric in Hartford, Conn., and in 1898 the Electric Vehicle Co. was organized in the same city.

The first real commercial use of electrics in Boston dates back to the formation of the New England Electric Vehicle Transportation Co. in 1899. The Company had a sumptuous office and garage in the Cyclorama building in Boston and used electric vehicle hansoms, the product of the Electric Vehicle Co., to offer taxi service to the citizens of Boston. Arrangements were made to exchange batteries when exhausted for fully charged batteries and the prospects for success were very promising; local conditions and lack of experience however soon helped to prove that the vehicles were not yet commercially practical and the venture was in advance of the times and the experiment proved a failure.

A period of electrical vehicle rest in Boston followed this unfortunate experience until a type of commercial electric was produced by the Vehicle Equipment Co. in the year 1902, which company was succeeded by the General Vehicle Co. in 1907. These proved to be of a more practical type and marked the beginning of the present electric vehicle era.

On March 11, 1909, 44 men representing the central stations and electric vehicle interests of greater Boston met at a banquet at the Hotel Tuileries in Boston to discuss means and methods of developing the use of electric vehicles, and as a result the Electric Vehicle and Central Station Association was organized; this in turn was absorbed by the Electric Vehicle Association of America, which dated from October, 1910. Much of the development during the succeeding years was due to the energetic efforts of these associations.

The Edison Electric Illuminating Company of Boston having purchased and put into use a number of commercial electrics found that they filled a truly economic place in transportation, and within the sphere of the electric showed a marked saving over other methods of transportation formerly employed, and decided that the time had come when it should publicly announce the results of its experience and start a campaign of endorsement and education for the purpose of stimulating a more general use of electrics.

On March 3, 1911, the Company gave a dinner at the Hotel Thorndike to which were invited 200 manufacturers, agents, and representatives of electric vehicles and storage batteries throughout the country. About 100 responded, and at the meeting the Edison Company announced its educational campaign for the development of the electric vehicle industry and outlined in detail its plans for carrying out this campaign.

Fig. 2. Electric "Brake" Manufactured by the Holtzer-Cabot Electric Company, 1895

The Company purchased 34 electrics and had plans for further purchases to show that it believed in taking its own advice.

A comprehensive advertising and publicity campaign was instituted, electric signs favoring electrics were erected, electric vehicle pamphlets and booklets were prepared and distributed. A research department at the Massachusetts Institute of Technology was endowed for the purpose of securing comparative data on the various types of transportation. Charging facilities were installed in its various stations and a representative appointed to spend his entire time on electric vehicle matters and to confer with agents and prospects in an effort to increase the use of electrics.

The Company also equipped the Atlantic Avenue Electric Garage to be run under a committee of the Electric Vehicle Association of America, and formed the Electric Vehicle Club to promote co-operation and efficient methods of business development.

This novel action awakened a large degree of interest not only in Boston but throughout the country and many letters of inquiry were received and a number of electrics put into use, but the vehicles themselves had not yet become sufficiently developed nor was the time yet ripe; so that the results hoped for were not wholly realized, but the effects of that campaign are still bearing fruit and doubtless will continue for years to come.

The Atlantic Avenue Electric Garage opened its doors on April 1, 1911, and at once proved its usefulness by supplying impartial service of the highest grade to all makes of vehicles at very attractive rates. As private garages became more common and the owners of fleets provided their own garage facilities, the necessity for such an institution no longer existed and its business was turned over to private interests.

The Electric Vehicle Club of Boston was organized in April, 1911, and elected officers and committees to attend to the various classes of work required. Meetings were held weekly and conventions, parades, and outings were arranged to increase the business and social activity of its members and to enlist the interest of that part of the public having transportation problems.

In order to place it on an independent, self-supporting basis it was reorganized during the latter part of the year 1912 under the name of The Electric Motor Car Club of Boston, with a paid secretary, and a membership of over 125. This Club continued to function until the preliminary problems had been worked out and other interests were able to carry on the work when it dissolved. The Electric Vehicle Committee of the New England Division of the N. E. L. A. now carries on this work.

During the last ten years the electric vehicle has progressed slowly but surely in Boston. Some manufacturers have closed their doors, others have sprung into being, agents have come and gone but the public are still using electrics, some of the older types continuing to make good, and the number is increasing.

It took some years to determine the exact field of the electric and many misapplications were bound to fail; the lovers of the horse were loth to make a change; while many others must needs find out by actual experience with gasoline machines that they have made a mistake before they are willing to accept the electric. All this takes time and when we realize the limited number of manufacturers and agents of electrics compared with those in other fields it is a wonder that the electric has done as well as it has. The user, however, is its greatest friend, and when the users of properly applied electrics have become more numerous the battery propelled vehicle will increase by its own momentum.

There are distinct fields for the horse, the electric, and the gasoline machine, and one should not attempt to trespass on the field of another.

Boston has a fairly good percentage of electrics and although not possessing some of those characteristics of other cities which have brought to them larger numbers, the future should bring more and more of the electric type and the history of the next few years should show that the efforts of the earlier days in Boston spent in pushing the electric vehicle have been amply rewarded.

Design and Application of Motors, Controllers and Resistances for Storage-battery-driven Vehicles

By J. C. Clendenin

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In tracing the design and development of the storage-battery-driven electric vehicle, it will be noted that the problem of the engineer has been to construct a car of minimum weight for the load to be carried, together with the highest possible efficiency of transmission. This has meant the most economical use of the energy available from the batteries, as well as the greatest possible amount of mileage. Therefore, in the design of a motor to drive a vehicle of this type, studious attention has been given to questions of material and output per pound as related to electrical efficiency, in order that long periods of successful operation might be secured with no attention other than the inspection necessary to insure proper lubrication and care of brushes.

Fig. 1. Comparative View of the Smallest and Largest Standard Automotive Motor of the Two-brush Stud Type

In the first type of battery-driven vehicle developed in the 90's, the type of motor used was of consequent pole design having relatively light weight and high speed for the output required. One motor was geared to each rear wheel through spur gearing. These machines had fairly high densities, which resulted in a low overload efficiency and torque; and this fact, combined with the small amount of energy available from the earlier form of storage battery, gave limited car mileage.

In a later model the size of the motor was substantially increased and was of the four-pole type, mounted on the driving axle by means of axle arms cast on either the bearing heads or magnet frame. A second point of support was secured by a spring suspension from the chassis to a lug on the magnet frame. Two motors were used, one driving each wheel, pinions on the armature shafts being meshed with annular gears attached to the wheel.

With this form of gearing it was not possible to obtain a high ratio of gear reduction, and therefore it was necessary to use a rather heavy, low-speed motor. The drive however was fairly efficient, and the motors had good electrical characteristics which, combined with marked improvements in the storage battery construction, greatly increased the operating mileage of the electric vehicle, and placed it for the first time in position to become a successful bidder for the transportation of merchandise in and about city and suburban districts.

As time went on, however, improvements were made in the transmission, and manufacturers of electric vehicles adopted a form of drive wherein a single motor was suspended from the center of the chassis in place of the two motors formerly mounted on the axle, and the power was communicated to the rear wheels through a double reduction consisting of a silent chain, bevel or spur gear to a countershaft as a first reduction, with a roller chain from the countershaft to either wheel as a second reduction.

With this construction it was possible to use a fairly large high-speed motor, with the result that the windings were of much lower resistance and the electrical losses were greatly reduced, and with additional improvements in the battery, whereby greater output per pound was secured, the operating mileage was still further increased.

Coming to the present period of construction of the electric vehicle, we find three general methods of motor application in use which embody the best results from previous years of careful investigation and operating experience. In the first method the motors are mounted on the axle and the power communicated to either two or four wheels through a system of annular and spur gearing operating in oil. In this form of drive either two or four motors are used of a size adequate to give high electrical efficiency at both normal load and overload. In the second method of application, the motor is mounted on the chassis and the power communicated to a live rear axle through a worm or spiral bevel gearing. In the third method, the motor is mounted on the chassis and the power communicated in the first reduction through a bevel gearing to drive shafts which are geared, in turn, through pinions and annular gears to the rear wheels.

In order to provide a motor which can be adapted to any of these three forms of transmission, the General Electric Company has developed a type in which the magnet frame and commutator end bearing head are one-piece castings, machined from end to end. This design lends itself to the application of whatever form of suspension brackets may be necessary in order to assemble the motor in the vehicle. The armature is mounted on ball bearings, and the bearing heads, both commutator and pinion end, are of the enclosed type so that the motor is thoroughly protected from moisture. The machines are developed in nine frame sizes, providing single or double motor equipments for the lighter truck or passenger car, or for any vehicle of greater size up to the truck of five tons capacity or even higher. The relative size of the largest and smallest of these motors is shown in Fig. 1.

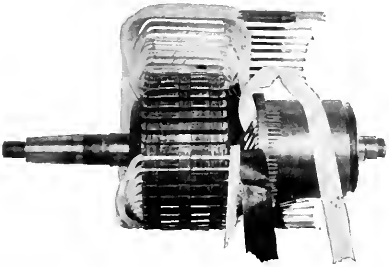


Fig. 3. Method of Coil Assembly in Standard Automotive Armature Showing Application of Insulation

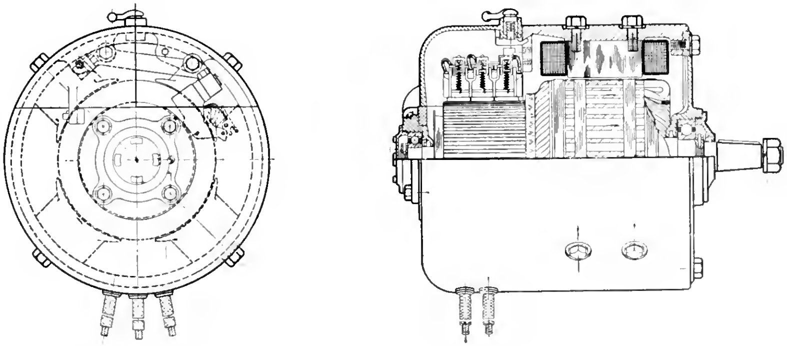


Fig. 2. A Cross Sectional View of a Standard Automotive Motor of the Two-brush Stud Type

These motors are all of the two-brush stud, four-pole construction, and are compactly built as shown in Fig. 2. Both the fields and armature are wound with rectangular wire, the field coils being formed to the curvature of the frame, while the armature coils, on the pinion and commutator ends, are developed for assembly in the shortest possible space as shown in Fig. 3. These features insure the use of the greatest amount of copper for the space available, and result in a motor which has low tooth density, high torque ratios, and liberal overload capacities for the material employed. The machines are designed to operate totally enclosed continuously on normal load with a 65 deg. C. rise above 25 deg. C. ambient air, and for one hour on 200 per cent load with a maximum of 75 deg. C. rise. The average brush density on normal load is 25 amp. per sq. in. and a copper-graphite brush is used where the machine is designed for operation on 60 volts or less.

A second type of automotive motor which has been built within the last few years is constructed with a magnet frame made from a steel plate in which handhole openings are punched. This plate is pressed into cylindrical form and welded, and in a final operation is forced through a sizing die. The magnet frame, which is shown disassembled and assembled in Figs. 4 and 5, can be made from much less material than the type in which steel castings are used, and where liberal allowance must be made to cover wastage in finishing. This type of motor is built with a four-brush-stud construction which makes it possible to secure a greater active magnetic section without any material increase in the weight or cubic contents of the machine. These motors, which have the same speed torque characteristics as those previously described and developed with two-brush-stud construction, have so far been built only in the smaller sizes suitable for use on passenger vehicles or the light delivery wagon. The construction however has worked out successfully, both from the standpoint of manufacture and operation; and it is particularly adapted to installations where it is possible to apply the four-brush-stud construction without interfering with methods of motor suspension in the chassis.

Fig. 4. Magnet Frame Constructed from Steel Plate

In selecting a motor for any type of vehicle it is important to consider first the service to which the vehicle is to be applied—whether for passenger or commercial use. In the pleasure vehicle, for instance, where the load can be predetermined and where service is usually under favorable conditions, the motor can be designed with a torque ratio of approximately 4 to 1. This will result in good acceleration and lively operation on grades. In the commercial vehicle, however, especially in the low-speed truck of high capacity, it is desirable to have the torque ratio as high as possible in order to protect the battery in the severe all-year service in which these cars are used. This is of special value when the truck is negotiating steep grades, under which operating conditions it is desirable that the energy available be converted into high torque at the expense of reduced speed. The series characteristics of the automotive motor provides the speed reduction and this, combined with the high torque, safeguards the battery from excessive discharge and greatly extends the radius of operation of the vehicle. The motors developed for this class of service have also higher overload capacity than those required in pleasure vehicle service and are usually of greater size for equivalent electrical ratings.

Fig. 6 shows an interesting comparison between the torque and efficiency of two motors developed with the same rating and speed but with different torque ratios. The curve in dotted line indicates a torque ratio of approximately 4 to 1. Maintaining the same normal load speed, the curve in solid line shows a torque ratio of 4.7 to 1, this increase being secured by added length to the magnetic section of the armature and fields without increase in the C^2R loss, thereby increasing the overload torque by reduction in tooth density secured by added material. Should it be desired to increase the torque ratio without increase in motor size, this would be accomplished by either a reduction in the slot section, with a corresponding decrease in the size of the conductor, or by a slight increase in the armature slot section and number of

Fig. 5. Assembled View of a Motor Built with Steel Plate Magnet Frame

turns per armature coil. In both these methods, however, the armature resistance would be increased and the increase in torque would be secured at the expense of correspondingly reduced speed.

These curves are developed to indicate the operation of a motor on 42 cells of lead battery. However, the conclusions as drawn would apply to a similar equipment designed for operation on 60 volts, or 60 cells of Edison battery. The electrical rating in this case would be 60 volts, 53 amp., 2000 r.p.m.: the 57-amp. point, and multiples thereof, corresponding to the 40-amp. point, and multiples thereof, as shown on the curve.

Other important points to be considered in selecting a motor for a storage-battery-driven vehicle are the form of transmission used, the ratio of reduction, the car speed desired, and the type of tires used. The watt-hour consumption per ton-mile and the consequent demand upon the motor is dependent upon these factors taken collectively.

Aside from the battery, which will not be considered in this article, there are two other pieces of apparatus which are necessary to complete the electrical installation of a storage-battery-driven vehicle; namely, the controller and resistance.

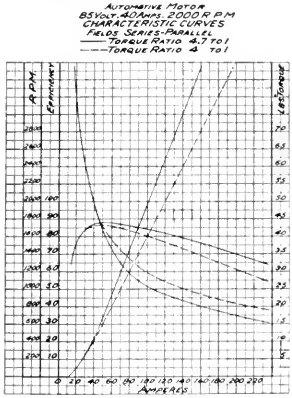


Fig. 6. Characteristic Curves Indicating a Comparison Between Two Motors of the Same Electrical Rating but with Different Torque Ratio

The character of the control to be used on an electric vehicle is dependent upon the class of service to which it is to be applied. In pleasure vehicle work a controller is required which will have a sufficient number of speeds forward to give easy acceleration and moderate operating speed, with one or more shunt speeds for spurting. On the delivery wagon and truck, high speeds are not required, consequently the controller is built with only a sufficient number of forward positions to give easy acceleration and an economical operating position.

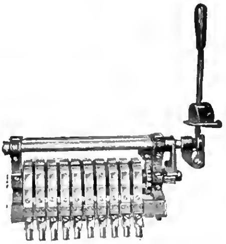


Fig. 7. Assembly of Standard Sector and Pinion Controller

A controller which can be used to meet either of these conditions has been so designed that by changing the overall length, the number of contact fingers, and cylinder contact arrangement, it can be adapted to the various connections required. The cylinder is driven through a pinion and sector gear, the latter being fastened to a shaft to which the operating handle is attached. By using this form of gearing a reduction of approximately 3 to 1 is secured, and as a result the distance through which the handle moves is greatly reduced in comparison to that through which the cylinder passes in moving to the various positions forward and reverse, as shown in Fig. 7.

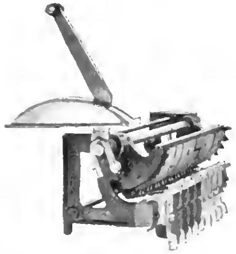


Fig. 8. Assembly of Standard Direct-operated Controller

This controller is designed to be mounted with its finger base directed toward the floor of the car, thus allowing the leads to be extended downward and making the connections readily accessible. All contact segments and fingers liable to replacement on account of wear are so designed as to be easily removed.

In addition to this type of controller, another has been developed having a cylinder made from a moulded segment which is attached by spiders to the operating shaft. The cylinder is operated by a handle attached directly to the cylinder shaft, the handle movement being reduced in this case by the fact that the diameter of the cylinder is much greater than that of the type just described. This controller, as well as the one previously described, can be developed for either single or double motor equipment, and with a different number of speeds forward and reverse, by increasing or decreasing the length, as shown in Fig. 8.

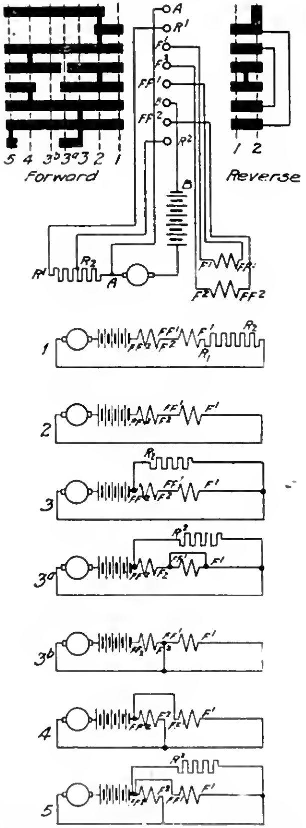


Fig. 9. Diagram Showing the Connections Necessary to Secure Continuous Torque in a Single Motor Equipment

In order to secure smooth acceleration, it is necessary that the current flow uninterruptedly while the controller cylinder is passing to the various notches forward and reverse; and both types of controllers are therefore designed for continuous torque.

The method of securing continuous torque is shown in Fig. 9. There would normally be no interruption on a single or double control, with series batteries, so long as the motors in a two-motor equipment and the two sets of fields in a single-motor equipment were kept in series. Referring to Fig. 9, which shows a single-motor equipment, on the third position the motor fields are in series and shunted with resistance *R2*. As the controller cylinder passes between positions three and four, the *3a* short circuit is introduced around one set of fields. Referring to the segment layout, it will be noted that this is introduced by the contact finger dropping across the gap on the contacts *F2*, connecting them to *F1* and *FF1*.

In the next position, *3b*, the shunt *R2* is removed. The field connection *FF1* is open, leaving field terminal *F2* connected to the line *F1*. Referring again to the contact finger, *F2* has now passed across the gap.

On the next point, which is the fourth position, the terminal *FF1* is connected to *FF2*.

To accomplish the changes required, the resistance is first introduced across the series field, after which one set of field coils is short-circuited, the other remaining in full strength.

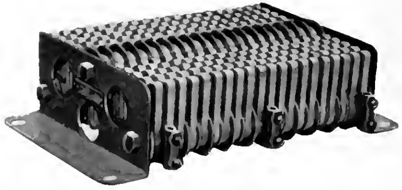


Fig. 10. Standard Cast Grid Resistance Box

The connections of the resistance and short-circuited field are now broken, after which the previously short-circuited fields are placed in multiple with the other. Although during the transition only one set of fields is used, it has been found that, on a four-pole motor with sets of coils 180 deg. apart, there is very little momentary increase in operating current.

For a two-motor equipment the general scheme is the same, except that instead of one motor with series and parallel fields there are two motors in series connected through the transition in series parallel.

The concluding piece of apparatus to be considered is the resistance box. The standard type of this unit is shown in Fig. 10, and is made from three or more sizes of cast grids, the selection of which is dependent upon the current to be drawn. The grids are assembled with mica insulation between sheet steel end-frames in a sufficient number to give the required overall resistance. The resistance is provided with taps to secure intermediate resistance points.

The Storage Battery for the Electric Vehicle

By Bruce Ford

Vice-President, Electric Storage Battery Company, Philadelphia, Pa.

During the past decade storage batteries have come into such general use in starting and lighting of automobiles, farm lighting plants, amateur radio sets, etc., that it is no longer necessary to explain what a storage battery is. In the propulsion of electric vehicles it is customary to use the maximum number of cells consistent with the charge source; the nominal 110-volt direct-current source calls for 40 to 42 cells of lead acid battery or 60 cells of the nickle-iron-alkali type.

Historically, the storage battery dates back to 1860 when a Frenchman, Gaston Planté, discovered that electrodes of lead in dilute sulphuric acid would build up to high capacity when numerous reversals of current had alternatingly oxidized and reduced the coating thus formed on their surface. The process was so tedious as to be commercially impracticable and it was not until 20 years later that an American, Charles F. Brush, and a Frenchman, Camille Faure, almost simultaneously developed a process of applying lead oxides in the form of paste to supporting and conducting grids, thus immediately providing the means for changing the storage battery from an interesting laboratory demonstration to an article of commercial possibility.

During the early 80's the prevailing idea for the use of storage batteries seemed to be in self-propelled vehicles, and storage battery street cars were invented and promoted and in some cases were successfully operated in competition with the horse car, cable car, and crude trolley lines then in vogue. Development in the trolley line field and the perfection of the underground wire system during the early 90's, however, furnished a better solution for the street car problem and such storage battery systems as were in operation were one by one superseded by the trolley. Henry G. Morris and Pedro G. Salom, of Philadelphia, had in the meantime taken advantage of developments which had been applied in bicycle improvements and built what they called an "electrobat," a sort of glorified "quad" with a carriage body, carrying a storage battery, an electric motor and controller. In 1897 a livery service of cabs was operating in New York and soon afterwards stations of electrically propelled taxicabs were installed in the major cities. Concerns were organized in different parts of the country for the production of various types of private vehicles from the smallest equivalent of the horse-drawn buggy to the elaborately furnished brougham and landaulet types. In all the early development the competition incentive was that of the horse-drawn vehicle and these earlier vehicles were practically horseless carriages affected by the bicycle development, such as the adoption of tubular frame construction, pneumatic tires and handle-bar steering.

Storage battery vehicles for commercial use followed later, but early enough so that they were built for service in competition with the horse-drawn vehicle. The later competition was the gasoline propelled automobile which has brought the electric vehicle in both private and commercial applications to its present day standard.

At the time of the introduction of the electric vehicle the successful uses for storage batteries were almost exclusively stationary—central stations, power houses, house lighting plants, etc., for which the heavier but more rugged Planté type of plates was more suitable and methods had been developed to overcome the manufacturing difficulties of this type. The earliest applications of the storage battery for automobile propulsion were made with plates of the modified Planté type which had proved very satisfactory in other lines of service. The makers however soon foresaw the necessity of a battery having more capacity and less weight; and in 1900 developed, from one of the many existing pasted types, a battery which has demonstrated its superiority in durability over other forms of pasted plates and in high capacity and lightness over the Planté type. The important feature of this plate is the grid. Relatively heavy vertical ribs of the full plate thickness are joined by a greater number of light horizontal ribs on the two faces, these ribs being in staggered relation on opposite faces. This construction gives a series of vertical pencils of active material between the vertical ribs, locked in by the horizontal surface ribs. The principle of a central core of material retained by surface ribs is still almost universal in pasted plates, although there are numerous modifications, such as the "diamond" grid, "herringbone" grid, etc. The change from the original modified Planté type to the first pasted type resulted in an increase of 45 per cent in capacity or from 6 to 8¾ watt-hours per pound of cell.

For some years after the adoption of pasted plates (in 1900) the only change was a trend toward thinner plates and narrower separation in order to secure higher capacity. The first step increased the output to about 10 watt-hours per pound and the next to about 10⅓. With the latter step the practical limit of capacity for the lead battery seems to have been reached, and even then at some sacrifice of life compared to the thicker and more rugged plates. It, therefore, seemed highly desirable to develop a type of cell which would give a longer life than any of the pasted types without substantial sacrifice of capacity. Again, a Frenchman, Philippart, provided the basic idea, which was to use the grid only as a conductor buried in the material and to retain the material by means of a laminated insulating envelope. His units were cylindrical, with a lead alloy core and a large number of superimposed thin hard rubber washers surrounding the material. Crude and frail, these plates never were commercially successful, but on this principle was developed the Exide-Ironclad positive plate, giving about 9⅔ watt-hours per pound of cell and two to three times as long life as any of the previous pasted types.

The grid of the Exide-Ironclad positive plate consists of a number of parallel, vertical metal rods united integrally to horizontal top and bottom frames. Each vertical rod forms a core which is surrounded by a cylindrical pencil of peroxide of lead. This, in turn, is enclosed by a hard rubber tube having a large number of horizontal slits, serving to provide access for the electrolyte to the active material, but so fine as to practically eliminate washing out of the material. Each tube is provided with two vertical ribs projecting on opposite faces of the plate, serving to stiffen the tubes and also acting as insulating spacers. These ribs take the place of the ribs on the separators used in flat pasted plate batteries and allow the use of plain sheet separators.

The cylindrical form of tube is peculiarly well adapted to perform its function, since no amount of expansion or contraction will tend to alter its shape, and the internal strains are thus kept uniform. Buckling of the positive plates is unknown in this type of battery.

Thus far we have considered only the plates, but the other parts, while merely accessory, are of great importance. Prior to 1900 the automobile battery was equipped with separators of perforated hard rubber, ribbed to maintain the plate spacing. In service the active material would gradually find its way through the perforations, eventually short circuiting the cell, and it soon became evident that an imperforate but porous separator was essential. Many materials were tried, and the solution was found in thin sheets of wood, grooved to permit circulation of the electrolyte. Experience soon proved that "raw" wood contained substances which attack the positive plates, and chemical treatments were devised for removing such ingredients. It was also found that a thin sheet of perforated hard rubber between the wood and the face of the positive plate aided materially in both retaining the active material and prolonging the life of the separator.

The cell containers in the earliest batteries were hard rubber jars, and no substitute for this material has been generally used as yet, although great improvements have been made in strengthening the material.

The intercell connectors underwent many changes. Originally the plate straps were T shaped, the "tail" being bent upward and bolted or burned to that of the adjoining cell. Next came a connector shaped like an inverted U, straddling two adjoining jar wells and joined to the two plate straps. So-called "top" straps were then used—flat straps clearing the jar tops, with the positive plate lugs of one cell and the negative of the next burned in. This necessitated very long plate lugs with cell covers notched for them to pass through. Still another form was the "L" strap, set below the jar top, but with a neck extending upward and out across the jar wall to be burned to a similar projection from the next cell.

All these types necessitated marginal openings in the cell cover, making a tight seal impractical and resulting in more or less slopping of electrolyte. The adoption of the pillar strap, now practically universal in some form, allows a tight seal between the jar wall and cover.

The battery trays have from the start been made of heavy wood, and so far no satisfactory substitute has been found. The wood is either impregnated or coated with an acid proof compound and the larger sizes are usually iron-bound or reinforced.

In the Exide-Ironclad cell has been incorporated a cover structure having several advantages over the type used with flat pasted plates. The strap posts are provided with a shoulder and a threaded portion above. The cover, which is dished and provided with a marginal flange to contact with the jar walls, rests on the post shoulders with a soft rubber gasket between and is firmly held in place by means of alloy nuts drawn tight and locked on the threaded portion of the post. This arrangement gives a deep sealing space to the marginal flange while the top of the cover is flush with the top of the jar. Thus a tight seal is provided both around the posts and between the cover and the jar walls. Instead of the soft rubber vent plug generally used with flat plate batteries a hard rubber plug is used having a heavy interrupted thread so that a quarter turn positively locks it in place, a soft rubber gasket giving a tight seal.

The intercell connector, instead of being solid lead alloy, is made up of thin strips of copper, lead plated to prevent corrosion, and their ends cast into lead alloy terminals. The latter form rings which fit over the strap posts and are burned in place. The advantages of this built up type are twofold: the use of copper instead of lead alloy gives higher conductivity, and the laminated structure gives a flexible instead of a rigid connection.

The value of a finely slotted retainer having been demonstrated for preventing the material from washing out of the positive plate, the same principle has been applied to flat plate batteries. The hard rubber sheets placed against the faces of the positive plates have been provided with a large number of fine slits instead of the round perforations formerly used. This results in a substantial increase in life, although it still falls considerably short of the life of the Exide-Ironclad.

All of the foregoing applies entirely to the lead type of cell. About 1908 Edison brought out his nickel-iron-alkali battery which has since been used quite extensively in electric vehicles. In this cell the positive active material is peroxide of nickel, the negative is sponge iron. Both materials are retained in nickel plated perforated steel pockets, in tubular form for the positive and rectangular for the negative, the units being held in a nickel plated steel framework. The electrolyte is caustic potash solution, the separators hard rubber pins, and the cell container a nickel plated steel can.

The nickel-iron battery has a higher capacity per unit of weight than the lead battery, giving about 14 watt-hours per pound of cell. The capacity per unit of space, however, is slightly lower.

Each type has some advantages over the other.

Charging Systems for Electric Vehicles

By R. E. Russell

Supply Department, General Electric Company

Battery charging in the early days of the electric vehicle was a very different proposition from the present method. The instructions for lead batteries (the only type then made) were about as follows:

> "Begin and maintain the charge at the 'starting' rate, as indicated on the battery name plate, until the voltage reaches 2.55 per cell; the current should then be immediately reduced to the 'finishing' rate and continued at this rate until the voltage stops rising, the readings being taken at one half hour intervals."

The present instructions for lead batteries are summarized in the brief statement:

> "In general, any charging rate is permissible which does not produce excessive gassing or a cell temperature exceeding 110 deg. F."

Following either of these statements literally accomplishes the same result: If a battery is charged according to the old instructions, by an intelligent operator, there is little chance of "excessive gassing or a cell temperature exceeding 110 deg. F."

The main trouble which battery manufacturers found with the old instructions was that they were not closely followed. In the first place it is difficult to follow such instructions unless a man is in almost constant attendance to adjust the current, take voltage readings, and stop the charge at the proper time. Furthermore, there was with the old rules little or no instruction as to how to hurry the charge; and instead of putting a heavier current into the battery at the start, when it does little or no harm, the current would be continued at the high rate when it should be reduced, and violent and injurious gassing and overheating would result.

For several years storage battery engineers have kept in mind the following objectives concerning battery charging:

(1) Reduction of time required to charge.

(2) Elimination of the "human element" as far as possible.

(3) Simplification of charging systems.

At the same time the obtaining of greater life and mileage from the vehicle battery.

The efforts of storage battery engineers have resulted in a gradual evolution in battery charging methods. The Edison battery was also introduced during this period of evolution. There are now three methods of charging in use. These are listed below in the order in which they came into use.

(1) The *series-resistance or constant-current method* is the original charging system, already mentioned. It is still used where an attendant is available or where the other methods might be impractical due to a great variety of battery voltages or other reasons.

(2) The *constant-potential method* was adopted in several garages a few years ago and gave good results, but it has disadvantages which will be discussed later.

(3) The *modified constant-potential method* is really a combination of the two foregoing methods and is fast gaining in popularity.

The elementary connections of the three systems are shown in Fig. 1.

Before taking up the various charging methods a brief statement of limitations of the lead and the Edison types of batteries is given.

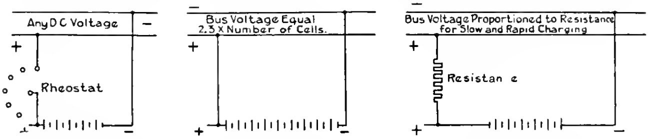
Lead Battery Charging

The battery temperature should not be allowed to exceed 110 deg. F. Higher temperatures injure the plates.

The battery cannot absorb charging current at a rate higher than a certain maximum. This maximum depends on the number and size of the plates in each cell; on the condition of the battery; on the state of charge (a fully charged battery will absorb current at a very much lower rate than one entirely or partially discharged); on the battery temperature; and other more minor factors.

When a charge is started on an entirely discharged battery the rate may safely be made quite high, but when the specific gravity of the battery becomes high with the approach of complete charge the input must be reduced to a very low rate, which is usually termed the "finishing rate," and unless this lower rate is approximated there will be violent gassing and heating in the cells, and any current over the finishing rate will be wasted in decomposing the water in the battery into hydrogen and oxygen.

If time were not a factor, there might be only one method of charging lead batteries—the constant current method. One could start the charge at the finishing rate and, continuing at that rate, complete the charge in 16 to 20 hours. But time is a very important factor in commercial establishments, where it is necessary to get out production, transfer materials, and deliver goods. Therefore, systems must be used that will charge the battery in the proper length of time to make the vehicle available for whatever work it has to perform. Systems are in use that will charge batteries in as short a time as three and one half or four hours, and from that up to eight, ten, twelve or more hours, depending on requirements of the vehicle in which the battery is used, that is, the time available for charging.



Series-resistance or Constant-current Method

Constant-potential Method

Modified Constant-potential Method

Fig. 1. Elementary Diagram of the Three Prominent Charging Methods

There is one point that should be remembered, namely, that the first cost of a battery charging equipment is very nearly in inverse proportion to the time that is available for charging. This will be explained in detail later.

Edison Battery Charging

The manufacturers of Edison batteries usually recommend charging their batteries at an approximately constant rate, averaging the same as the normal discharge rate or higher.

The modified constant-potential method has been used on Edison batteries with good results. The bus voltage on such a system should equal 1.85 volts times the number of cells in series. The resistance in series should be such as to give about 150 per cent of normal current at the start of the charge.

The temperature of Edison batteries should not exceed 115 deg. F.

Specific gravity readings are of no value in indicating the state of charge of Edison batteries. A voltage of 1.80 volts per cell with normal current flowing indicates full charge.

Boosting current of from two times normal for one hour up to five times normal for five minutes are recommended by the manufacturers provided the temperature remains at 115 deg. F. or below.

As the charging of Edison batteries is summed up in the foregoing statements, the following discussion on charging methods will have particular reference to lead batteries, but by comparison with the foregoing statements it will be obvious as to where they apply to Edison battery charging.

Constant-current or Series-resistance Method

As shown in Fig. 1, this method consists of a battery charging rheostat, connected in series with the battery, which allows for manual regulation of the charging current. An ammeter connected in series, either permanently or by a switch (when there are several such circuits from the same bus line) indicates the charging rate.

The operation of such a system is somewhat as follows: The operator plugs in the battery to be charged, adjusts the current at a rate of about three times the finishing rate, and allows the charge to continue at this rate (making frequent adjustments of current) until the voltage of the battery reaches about 2.5 volts per cell, and then reduces the current to the finishing rate and allows the charge to continue until the voltage of the battery and also the specific gravity stops rising over a period of two or three hours. Such a charge will take from eight to twelve hours, depending on the age and general condition of the battery.

The principal advantage of this system lies in its flexibility. Several different sizes of battery can be charged at different times from the same circuit, which makes it very useful in public garages where a variety of electric cars are charged. Its principal disadvantages are:

It makes charging results uncertain, due to relying on the attention given by the operator in charge.

It costs more to install than the other systems.

It requires more time for charging.

The Constant-potential Method

As the diagram in Fig. 1 shows, this method consists in connecting the battery directly across a bus voltage equal to the number of cells times 2.3 volts. There is no resistance in series (except that in the battery leads) and consequently the current at the start of the charge will be 10 to 15 times the finishing rate, but it will begin at once to taper toward the finishing rate and as the voltage of the bus is so low there is little or no chance of damaging the battery by high rates.

The advantage of this method lies in the possibility of charging in about 15 per cent less time than the quickest combination of the modified constant-potential system, and at the same time there is very little likelihood of damaging the battery.

The disadvantages of the system are:

If only one or two cars are charged, the charging apparatus must be very large to take care of the high starting rate (100 to 150 amperes per battery). If a large number of cars are to be charged from the same bus, it is possible to start one battery at a time and wait a short while (about 15 to 30 minutes) before putting on the next battery.

Probably the greatest disadvantage lies in the fact that any slight variations in bus voltage cause great variations in charging rates which may be harmful to the battery.

Furthermore with such a system all the batteries must be of the same number of cells to work off one bus. Also internal conditions in the batteries may make undesirable variations in charging rates.

It should be said, before going on to the next method of charging, that the constant-potential system is being used in many installations for charging fleets of trucks having batteries of the same number of cells. The owners and operators are highly pleased with the operation and speed of charging.

Modified Constant-potential Method

As the name implies and as Fig. 1 shows, this system is very similar to the constant-potential system. The only difference in connections is the addition of a fixed resistance. This resistance acts as a cushion to take care of "shocks." These shocks result from the heavy inrush of current at the start, that is so hard on the charging apparatus, the connections, and sometimes on the battery. They also result from the variations in bus voltage that without the resistance would cause still heavier variations in charging current.

There is no doubt that the modified constant-potential system is the system of the immediate future and for that reason a more extended discussion of it will be undertaken.

Referring again to the modified constant-potential diagram in Fig. 1, it will be noted that the bus voltage must be proportioned to the resistance for slow and rapid charging. For example: Assume a single cell of 15 plates is to be charged; with a bus voltage of 2.45, and a resistance of 0.002 ohm, the initial current would be about 120 amperes and the charge would be completed in about six hours. The other extreme for the same cell would be: With the same bus voltage and a resistance of 0.016, an initial current of only 25 amperes would flow and the time of charging would be 24 hours.

Based on this comparison, it will be seen that in order to determine the kind and capacity of charging apparatus the following information must be available:

(1) Time allowable for charging.
(2) Number of cells and capacity in ampere-hours.
(3) Number of batteries to be charged at one time.

It should be noted that if rapid charging is required the apparatus will be more expensive than for a slow charge. It is impossible in this article to go into all the details of resistance, bus voltage, etc., necessary to lay out a charging system for a given set of batteries, but this information is available in very complete form in a bulletin published by The Electric Storage Battery Company of Philadelphia. This bulletin contains information and curves that, while they apply to that Company's make of lead battery, would be of great value to anyone desiring charging information for any other make of lead battery.

To show the operation of this system on a typical battery, two charging curves on an Ironclad battery are shown. This battery has a rated six-hour discharge rate of 136 ampere-hours.

The curve Fig. 2 shows a charge completed on this battery in $5\frac{3}{4}$ hours. Note the rapid reduction in charging current from the start at 60 amperes.

As a contrast, the curve Fig. 3 shows the same battery charged in eight hours. Note the slow taper in charging current on this curve.

If the straight constant-potential charging system had been used on this battery, there would be no resistance in series and the curve would be like that shown in Fig. 2, but the starting current would have been at least double and would taper still faster until it reached the finishing rate or less. The charge would be completed in about five hours.

The finishing rate on this battery is given by the makers as 10 amperes. Note that in these curves the current finishes below that rate and, therefore, heavy gassing is prevented. The same would be true on the straight constant-potential system.

Automatic Charge Cut-off

Regardless of the method of charging used or the kind of battery charged, a device for disconnecting the battery when the charge has been completed is almost essential and is being used in almost all modern installations. The most practical device so far developed is a combination of ampere-hour meter and electro-magnetic trip for opening the charging circuit. An ampere-hour meter is made having a contact making device that operates when the pointer has reached the full-charge point. The ampere-hour meter is preferably mounted on the vehicle containing the battery. As the vehicle discharges the battery, the pointer revolves toward "discharge" and when the battery is connected to the charging source the pointer starts towards "charge," but at a lower rate to make up for losses in the battery; and when it reaches the "full" point it operates the electric trip and stops the charge. It is possible to have the ampere-hour meter on the charging switchboard, but it has to be set by guess as to the number of ampere-hours needed in that battery, and the results become uncertain. Such a practice is necessary in some cases where the batteries are used in industrial trucks and the lack of springs and rough usage make damage to an ampere-hour meter quite possible and might make the cutting off of the battery very uncertain due to damage in the instrument.

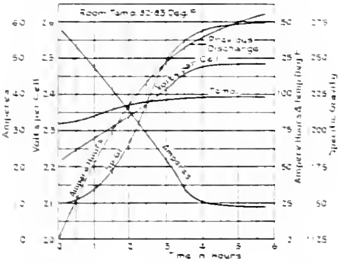


Fig. 2. Charging a 4-cell Ironclad Exide Battery in 5¾ Hours by the Modified Constant Potential System. Bus voltage 10.12 volts (2.53 volts per cell). Resistance in series 0.0214 ohms (0.00535 ohms per cell)

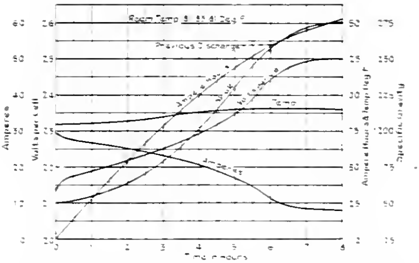


Fig. 3. Charging the Same Battery as in Fig. 2 in 8 Hours with Same Bus Voltage but Resistance Increased to 0.0665 Ohms (0.0166 Ohms per Cell). Data for these curves furnished by The Electric Storage Battery Company

Types of Battery Charging Equipment

It is not the intention of the writer to go into details of the various types of charging equipment, but simply to show by a few words and illustrations how the various methods of charging are worked out in actual practice.

There are, broadly, two classes of charging propositions:

(a) For charging a single battery.
(b) For charging more than one battery, as in a fleet of trucks, locomotives or other vehicles.

For the single battery, the modified constant-potential method has for years been the only one used. The mercury arc rectifier has been used in the home garage for charging the electric passenger car and on account of its great simplicity is still being used for this purpose. The motor-generator set for a single vehicle is also being used to a large extent and, although it requires somewhat more attention than the rectifier, is giving excellent service.

Both of these devices are inherently modified constant-potential devices as they start the charge at a relatively high rate and the current tapers down as the charge progresses. The motor-generator set has somewhat more of a taper charge than the rectifier. With the motor-generator set the current starts on a discharged battery at a rate of about five times the finishing rate and tapers in eight to ten hours to the finishing rate or less. If the set is equipped with an ampere-hour meter cut-off the set will be shut down and the battery disconnected after a certain number of ampere-hours is put in. The motor-generator set is made for both alternating and direct current. Of course, for direct-current a rheostat can be used, but if the number of cells is less than 30 it is more economical to use a motor-generator, and in any case the charging characteristics are likely to be better with the motor-generator than with a rheostat on the direct-current line.

Fig. 4. Taper or Modified Constant-potential Charging Motor-generator Set in Home Garage

For a fleet of trucks, the charging equipment will consist of:

(1) A switchboard and its equipment.

(2) If alternating current only is available, a motor-generator set for converting the alternating current to the proper bus voltage for charging. If there is direct current, the motor-generator set will not be necessary, although if the number of cells is very small (say below 30) probably greater economy and better charging characteristics will be obtained if a motor-generator set is used to secure the proper bus voltage for modified constant-potential charging. A thorough investigation must be made in each case, which would include a comparison of cost of alternating-current power as compared with direct current.

To attempt to go into a complete discussion of details of all the possible combinations that can be made up for battery charging in this class would take up too much space, so a brief discussion of a few representative installations and switchboards illustrated will be undertaken. This will probably be of some value as they are typical of the kind of requirement likely to be met.

Fig. 4 shows the installation of an alternating-current direct-current taper or modified

Fig. 5. "Safety First" Charging Panel in a Copper Mine

Fig. 6. Twenty-circuit Battery Charging Switchboard for Constant-current or Series-resistance Charging

constant-potential charging motor-generator set and control cabinet. This set starts charging at about 35 amperes and tapers to a finishing rate of 7 amperes.

In order to show where charging sets may be installed, Fig. 5 is included to illustrate a single-circuit "safety first" panel in an Anaconda copper mine at the 2800-ft. level. The charge is started and stopped by push buttons and a rheostat adjusts the current going into the mine locomotive battery.

Where a number or fleet of truck batteries are to be charged the sectional type of switchboard is used as shown in Figs. 6 and 7. Each

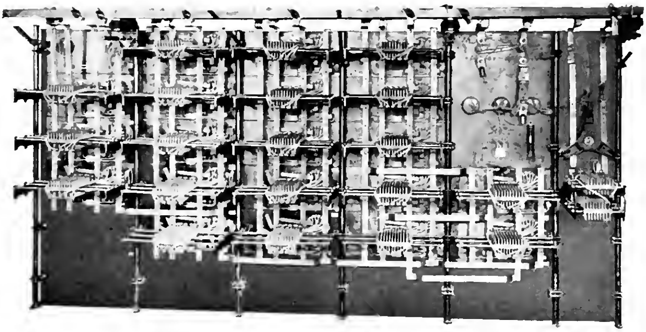


Fig. 7. Rear View of Switchboard Shown in Fig. 6

Fig. 8. Eight-circuit Battery Charging Switchboard for Constant-current or Series-resistance Charging with Automatic Cut Off and Ampere-hour Meters in Each Circuit

Fig. 9. Twenty-one-circuit Switchboard for Straight Constant-potential Charging

charging section is a complete unit with resistor mounted on the back. A spring switch is provided for putting into that circuit the ammeter and voltmeter shown on the top right-hand section. This is a typical installation of a series-resistance or constant-current charging panel. There is no provision for automatically stopping the charge. This installation is in the garage of the Ward Baking Company at Columbus, Ohio.

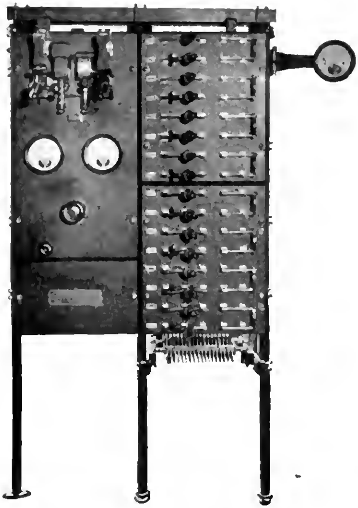


Fig. 10. Modified Constant-potential Charging Switchboard with Eight Circuits

Fig. 8 illustrates the same system of charging as in Figs. 6 and 7, but in this installation the charge is automatically stopped by contacts in the ampere-hour meter tripping the shunt trip breaker, one of which is connected in each charging circuit. As already stated, the ampere-hour meter should be mounted on the vehicle, for when mounted on the switchboard only an approximate estimate can be made for setting the instrument.

A constant-potential board is shown in Fig. 9. Two generator control panels are shown at the left. A generator voltage regulator holds a flat bus voltage and two ten-circuit panels provide for connecting the batteries and also for putting the ammeter and voltmeter in circuit when required. Provision is made for putting the rheostat (shown at the top of each panel) in series with any circuit on that panel, to give a slower charge. This switchboard was installed about 1917 for the Ward Motor Vehicle Company at Mount Vernon, N. Y.

An eight-circuit modified constant-potential board is shown in Fig. 10. Each circuit has one double-pole single-throw switch for cutting off the circuit; an ammeter-voltmeter switch, and a double-throw switch. The last mentioned switch has two positions; one puts very little resistance in circuit for a quick charge, and the other position puts in more resistance for a slow charge. Fig. 11 shows the rear of this switchboard. This board was purchased by the Consumers Baking Company of New York in 1921.

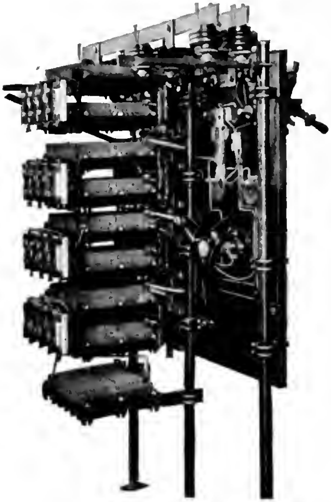


Fig. 11. Rear View of Switchboard Shown in Fig. 10

Advantages of Gasoline and Electric Trucks with Interchangeable Parts

By Maurice Walter

Chief Engineer Walter Motor Truck Company, New York City

The modern electric truck has conclusively proven that in its particular field of urban transportation it is unparalleled for efficiency and economy. The field of interurban transportation, long hauls, and operation in hilly countries is still restricted to the use of gasoline motor trucks.

Many users of motor truck transportation are confronted with the problem of meeting both types of service conditions, and therefore find it necessary and desirable to use both gasoline and electric trucks in their particular fields.

One of the vital problems for the successful and economical operation of motor trucks is the training of personnel to operate, maintain, and repair the truck equipment. Concerns which use a variety of types of motor vehicles find that it is a very difficult matter to train mechanics to "service" all the different units properly and that the problem is greatly facilitated by standardizing on a limited number of different types of machines. If the electric and gasoline trucks are made with interchangeable brakes, driving parts, bearings, springs, etc., it is a comparatively easy matter for the service mechanics to learn the quickest and proper way of working on these parts, with the result of a minimum loss of time and cost for maintenance of these units. It is well understood that every type of machine has its own peculiarities which must be watched and attended to in order that the unit be operated at minimum cost. Lubrication requirements differ with the various types of motor trucks, and it is apparent that with a similar construction in both the gasoline and electric truck this very important matter of lubrication can be reduced to a routine schedule and effected at small cost and loss of time.

Fleet owners have found from experience that in order to service break downs and to make quick and prompt repairs, it is necessary that they carry a certain quantity of service parts on hand in their own repair shops. With many different models the total investment in these parts runs into a very large amount which can be reduced when the gasoline and electric units are made so that they can both use the same spare parts. The reduction in the number of different parts carried also facilitates the matter of storage and accounting for these parts.

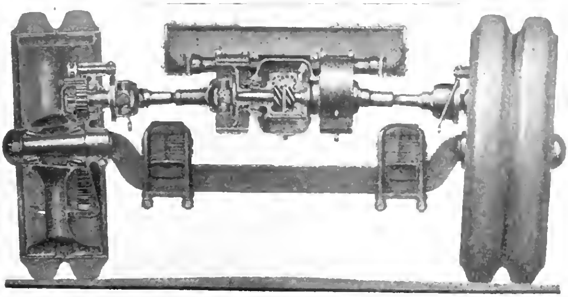


Fig. 1. Partial Cross Section of a Double-reduction Axle That is Readily Adaptable for Either Electric or Gasoline Trucks

The consideration of the advantages of gasoline and electric trucks with interchangeable parts is so favorable that transportation people have often expressed surprise as to why this idea has not been carried out to a greater extent. The main difficulty lies in the fact that the conventional types of final drive as used in most gasoline trucks today are not readily adaptable to electric truck construction. Certain types of double reduction rear axles, however, can be used with very good advantage on both types of machines. The double reduction axle shown in Fig. 1 is of a type that is readily adaptable for either gasoline or electric trucks.

The electric truck, because of its lower speed, requires a greater reduction through the final drive than is required in gasoline trucks of the same capacity. In this axle, this greater reduction is provided by changing only two parts; viz., the bevel pinion and bevel crown gear. The remainder of the parts such as the axle proper, wheel bearings, wheels, internal gear, pinion and the bearings for the pinion, the universal joints, felt packing, and other minor parts are entirely interchangeable for both types of machines.

While it would appear that the gasoline truck because of its higher speed would need to have more effective brakes than the low speed electric truck, this is not the case because the electric truck operating in the city is more frequently called on to make short quick stops, and also in the case of the electric it is necessary not only to apply the braking force and check the inertia of the machine but at the same time the brakes must dissipate the flywheel inertia of the armature which is of a considerable mass and rotates at high speed. On this axle the service brakes are located on each side of the dfferential so that they have the advantage of the leverage of the wheel gear reduction and are therefore very effective in stopping a heavily laden truck. These service brakes are operated by a foot pedal. The wheel brakes are operated by a hand brake lever with a conventional ratchet construction. With this construction it is clear that the brake parts including brake lining, levers, linkages, and brake connections can be made entirely interchangeable on both types of trucks.

A positive drive or locking type of differential is very desirable in electric truck service because such a device acts to prevent unnecessary slipping of either of the drive wheels thus eliminating waste of current. This is of special importance when operating on snow covered streets. In the case of the gas truck a locking differential is very desirable when bad road conditions are met, in order to prevent stalling of the truck. In recent years a number of positive drive type differentials have been placed on the market, but it is important to note that many of these devices are not satisfactory for electric truck service because while they tend to give a positive drive to both wheels they have the objection of offering an excessive rolling resistance when the vehicle rounds a corner, in this way wasting an appreciable amount of current. A properly designed worm and worm gear differential can be made which will give 100 per cent traction to both drive wheels under all service conditions and which will operate round a corner without noticeable increase in the current draw of the machine.

Considerable importance has now been attached to the reduction of unsprung weight of motor vehicles because it is recognized that the magnitude of the impact when a fast moving truck hits a bump in the road is

Fig. 2. A 5-ton Gasoline Truck with Front Axle and Steering Mechanism Parts Interchangeable with Those of an Electric Truck of the Same Capacity

in direct proportion to this unsprung mass, so that the axle construction that embodies a minimum of unsprung weight causes less damage to the road and to the truck when operating at the higher speeds of gasoline motor trucks. In the case of the electric truck the reduction of unsprung weight is desirable because with the decreased unsprung weight the wheels do not bounce but constantly retain their contact with the road which eliminates spinning or slipping of the drive wheels and the consequent waste of electric power.

Experiments have shown that by inclining the rear wheels of a motor truck to a slight angle, in the same manner as the front wheels are inclined, the rolling resistance of the vehicle is appreciably reduced. This is of importance in electric trucks in that it reduces the current draw due to the decreased rolling resistance. Gasoline trucks are frequently called upon to operate over narrow country roads with a high crown in the road surface, so that with the usual parallel wheels the inside tires bear the full brunt of the weight of the truck and load; with the inclined wheels the weight is more evenly distributed over both tires which materially increases the life and wear of the rear tires.

The electric truck should be made with a shorter wheelbase in order to reduce the overall length and to give a short turning radius which is highly desirable for operation in congested traffic. This of course requires a shorter frame than can be used with the gasoline truck. However, such parts as the front bumper and cross members can be made entirely interchangeable. The frame should be so designed to have the same width and arranged to take exactly the same body on either the gas or electric models.

In order to shorten the wheelbase as much as possible and to give the proper distribution of weight on the front and rear wheels of the electric truck, it is desirable to locate the electric motor approximately over the rear axle. This position makes the motor entirely accessible for repairs and adjustment and avoids interference with the battery cradle.

It is now an accepted practice to locate the batteries under the frame between the front and rear axles. This requires a somewhat higher frame than is desirable for the gasoline truck. The springs can be made interchangeable on both models by making the spring hangers somewhat higher to take care of the increased frame height. It will be noted that the parts that are changed are not subjected to wear and the only time that they would need to be replaced would be in case of a severe accident. The spring shackle bolts, bushings, and spring clips and all the other parts used in the spring mounting should be entirely interchangeable.

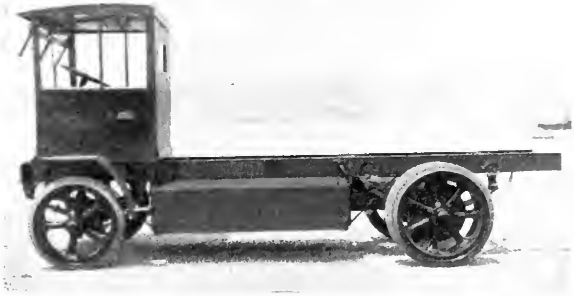


Fig. 3. A 5-ton Electric Truck with Front Axle and Steering Mechanism Parts Interchangeable with Those of a Gasoline Truck of the Same Capacity

The function of the front axle and steering mechanism is entirely the same in both gas and electric trucks; these parts can therefore be readily made interchangeable.

Figs. 2 and 3 show a 5-ton gas model and a 5-ton electric model in which this ideal of interchangeable parts has been carried out in a very practical manner with extremely successful results as regards the performance of both type of machines.

The Special Industrial Truck

By W. A. Meddick

Manager Industrial Department, The Lakewood Engineering Company

Every manufacturer of industrial trucks knows of the constant demands for special models. Too frequently he has only discouragement to offer to the proponents of these devices. Occasionally it has happened that a proposed design for a special handling proposition has been rejected by the truck manufacturer only to be carried through to a successful conclusion by the man on the job, who, acting with the zeal of the inventor, determines to obtain a solution to show that it can be done. Unfortunately, the manufacturer in these cases is limited to designs for machines that will have a wide enough application to make production profitable.

Many new machines for special jobs, however, have been developed, the truck manufacturer and the user acting in concert. It is the purpose of this article to give some specific examples of such trucks.

A few words tracing the development of the electric industrial truck will not be amiss. The first designs of industrial trucks were for use in railway baggage stations, and solved only the transportation problem. In these burden bearing trucks, power and loading space were combined in one unit. The next step divided the functions of these platform trucks, placing the load on trailers and using an electric tractor for hauling the trailer train. The demand for improvement of these devices lay in the direction of reducing the labor required for loading and unloading the transportation unit. The elevating platform truck, capable of picking up a movable platform on skids, developed in answer to this demand and greatly reduced the unnecessary rehandling of material in process of manufacture, and is one of the most widely used types of trucks today It was but a step to increase the height of elevation of this type of truck to include the functions of both transportation and tiering machines, and such machines are now used extensively.

The material moving operations to which industrial trucks have been applied have logically become classified into transportation and handling problems with a considerable overlapping of the two in the case of self-loading trucks. Thus, for transporting materials or freight over distances of from 200 feet to 1500 feet between variable points, the electric storage battery tractor and trailer are adapted. For handling material or goods not over 200 feet, where the packages weigh over 1000 lb. and points are not fixed, elevating and tiering trucks are economical. The need for the special truck is most commonly found in the latter class where it is important, if possible, to pick up and place the load quickly with power.

The advantages of a lift truck and a tiering machine are combined in an electric truck whose platform is capable of being elevated with a two-ton load to a maximum height of eight feet. The elevation of the platform is accomplished by two vertical screws driven by a separate motor. In Fig. 3 this machine is shown tiering tobacco hogsheads. The maximum elevation of eight feet is just sufficient to rick the hogsheads three high. It has been estimated that the cost of handling tobacco in this manner is only about one-third of the cost by the old hand methods. Of course such savings by the use of a special truck are only made if the equipment is continuously in use.

Handling rolled paper is a typical example of the special truck problem. Although rolled paper has been economically handled in quantity by tractors and trailers, by elevating trucks, and in small quantities by hand, there has long been a desire to use a truck which would automatically pick up a roll of paper standing on end and transport it to the desired point. Such a machine would prove its economy in loading and unloading paper in box cars. A burden bearing truck handling rolled paper by means of a special mechanism mounted on the platform, and dropping over the end of the truck to the ground, is illustrated in Fig. 4.

A special truck has recently been applied to handling charges in and out of annealing and carbonizing ovens. Articles for heat treatment are packed in annealing boxes and customarily pushed or handled into the ovens by means of a small hand buggy. By the hand method one pot at a time is introduced in the furnace. In a certain plant, ordinarily, a battery of eight ovens would require a crew of four men who would consume about twenty minutes in unloading and loading each furnace. Using the special truck, one man does all the work of unloading

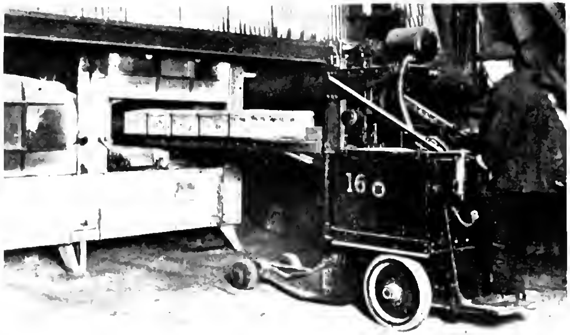


Fig. 1. Special Electric Tiering Truck for Handling Charges In and Out of Annealing and Carbonizing Ovens

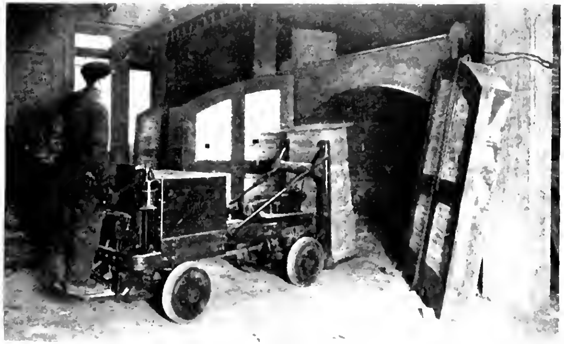


Fig. 2. Special Electric Tiering Truck for Handling Large and Heavy Annealing Pots

Fig. 3. Electric Lift Truck and Tiering Machine for Handling Tobacco Hogsheads

Fig. 4. Special Electric Lift Truck for Handling Rolled Paper

and charging a single furnace in from two to three minutes. Saving wear on the furnace floor tiles, conserving heat (the doors are open only long enough for the truck to pick up or deposit its load) and reducing labor costs are among the benefits derived. The truck itself is a tiering truck with two angle arms substituted for the standard platform. The truck picks up two rows of pots from a special packing table and sets them in the furnaces, the channel arms being lowered and withdrawn, through depressions between ribs on the furnace floor. These furnaces are built on legs so that there is ample clearance underneath for the front wheels of the truck to run in. Figs. 1 and 2 show the truck with the arms and another type of machine for a similar purpose for handling larger and heavier single pots.

Some of these special trucks have been evolved by adding the mechanical devices for handling to standard units. This has meant a sacrifice of convenience and perfection in the final composite machine. One manufacturer has attempted with considerable success to design a standard chassis for a handling truck, to which a variety of platform and arm attachments may be fixed to suit the material to be handled. The underlying aim in the design of this chassis has been to develop an elevating and tiering truck whose platform overhangs the front wheels so that it may be dropped down to the ground or so that the truck can handle materials in piles without any ground clearance being required for the front wheels. Of course, load limits are less than for other types since the truck and batteries must overbalance the load sufficiently to give at least three hundred pounds weight on the drive wheels to maintain good traction.

This truck has found a satisfactory application in handling tin plate in storage and in loading box cars in a large tin plate mill in the Chicago district. For this purpose it is equipped with overhanging drop forks. As the forks are made of 1½-in. flat bars and can be lowered to the floor, the necessary clearance under piles need be only two inches. By this means a great economy is effected in storage space as compared with that required were the tin plate to be stored on the 12-in. skid used with the standard electric lift trucks. The high lift of the truck is advantageous in piling and in maneuvering into the freight cars, as the loads can be raised to clear piles previously laid down in the car.

By substituting a channel arm for the forks, coiled wire may be easily handled. The loads may be taken off a rack or picked up from the ground if the coils are stacked on edge. Loads up to approximately 2000 lb. may be handled in this manner.

The foregoing examples illustrate some of the types of special trucks. This list is not all-inclusive, nor does it exhaust the possibilities in special trucks. The types selected are intended to indicate the limiting features to be considered in the applications of the electric industrial truck, and to bring out the elements of balance, adaptability and interchangeability in mechanical design.

It is a safe prediction that the future will see existing types much more widely adopted and special trucks and accessories rapidly made to serve many purposes where present handling methods are laborious and expensive.

The Use of Mechanical Equipment on Modern Water-front Terminals with Particular Regard to Industrial Trucks, Tractors and Trailers

By William Lansing, Jr.

Engineer in Charge Mechanical Equipment, Department of Docks, New York City

The problems of terminal freight handling at water-front stations are so many and so varied that no one who has studied the matter intensively will attempt to advocate any general solution of them. Much has been written concerning the needs of particular apparatus for handling certain kinds of freight and while there is undoubtedly some merit in such discussion, the best known terminal engineers are growing very chary in giving advice on this subject without thoroughly studying the exact needs of each separate installation.

It has been said that there are not a dozen men in the United States who can specify a complete and efficient equipment of mechanical material handling devices for a marine terminal. I not only agree with the above, but it is my opinion that the number can be cut in half and be more accurate.

The construction of modern dock terminals with adequate warehouses contiguous thereto is in the chrysalis stage or worse in New York and, I understand, this also applies to every seaport in the United States. There is no field that is so virgin, in the entire engineering profession, as that of the proper equipment of these terminals. Many cities with better press agents than New York has developed so far have from time to time boasted of their very efficient water-front terminal service, as compared to that of this port, and have gone to great length to disparage New York's methods. When these boasts have been boiled down to plain hard facts it is found that in most cases, while serious attempts have been made to better conditions, and some progress has been made in that direction, there are at the present time few, if any, really efficient dock terminals being operated at any port in this country and those in New York are not inferior to them.

In New York City I feel that we are on the high road to great deeds in the mechanical freight-handling line. The construction by the City of the two piers at Stapleton, Staten Island, leased to the Pan-American Terminal & Dock Corp., with a supporting system of warehouses which will be in full operation within a few months, I consider the best thought out and most comprehensive individual freight-handling plant in this country for marine service. Also the Dock Commissioner's plan for the modernization of the North River piers from Vesey to Perry Streets, where 17 modern steamship terminal piers of sufficient width and length to accommodate the greatest of ocean-going carriers will take the place of 34 piers which were constructed on the plans of General Geo. B. McClellan, promulgated in 1871, and have long since outgrown their usefulness; the equipping of these piers with mechanical apparatus for the economical handling of freight; and most important of all, the proposed abolition of the pier shed as a warehouse by arranging for a comprehensive supporting system of warehouses along the marginal street, will prove to be the greatest of all modern marine terminal developments over a large extent of water front.

The City is proceeding, as will be seen from the above, along the lines of the most modern thought, although I have mentioned only two of the many plans being studied and thought out by the City authorities.

In studying equipment for the economical handling of freight at our terminals the industrial truck and the tractor and trailer are necessarily essential parts of such equipment.

The railroads are using much of this apparatus on their piers with great economies resultant therefrom, in spite of conditions of congestion existent due to the narrow piers occupied by them.

The great steamship companies have installed this apparatus and are enthusiastic over the results obtained, but only a limited use is being made of this apparatus on both railroad and steamship piers because of the delay in getting the freight on and off the ships, railroad floats and other floating carriers due to the lack of other efficient mechanical equipment.

The pier sheds have been and are being used as storage warehouses which is an impossible condition for the rapid and efficient handling and distribution of cargo.

Many of our piers, while they are, so far as length and depth of water in their slips are concerned, capable of accommodating the largest ocean-going vessels, can only be used as one-sided propositions; for a pier only 60 ft. to 80 ft. in width cannot by any possibility take care of a vessel on each side at the same time. This congestion arises from the necessary space for cargo, both incoming and outgoing, which must be on the pier, at least temporarily, the driveways for motor trucking and the actually necessary equipment or motor driven industrial trucks, tractors, and trailers to properly distribute incoming or outgoing freight.

The City realizes just what it is up against and is fighting and fighting hard to construct its new piers of proper dimensions and to provide the necessary system of supporting warehouses in the rear of them so that mechanical equipment may be efficiently and economically operated.

Industrial truck installations on waterfront terminals may be divided roughly into the following classes:

1. The load carrying truck with fixed platform.
2. The elevating platform truck with sufficient platforms either stationary or on wheels.
3. The tractor with its train of trailers.

So far as pier operation is concerned, for hauls up to about 700 feet in length either the first or second type is recommended, and beyond that distance the tractor with its trailers is deemed most efficient. For distributing unloaded freight within the pier shed, a proper equipment of either load carrying trucks or elevating platform trucks should take the freight from the point at which it is unloaded from the vessel by crane or cargo winch and distribute it for handling either by truck or freight car. This freight should then be piled by another device such as the piling truck or tiering machine of which there are now several on the market which are satisfactorily efficient. It should be understood that this freight will remain on the dock a time not exceeding 72 hours and most of it not more than 48 hours.

Any freight which is to remain for a longer period of time than the above should be taken to the warehouse. The time limit on freight remaining on the pier must be strictly adhered to, as otherwise the congestion becomes so great as to hamper the flexible movement of the truck or tractor system.

For transportation of steamship freight between points in the pier shed and the supporting warehouse system, both in and out, the use of tractors and trailers will be found, I think, to be the most efficient and economical procedure. For moving the freight between floors, my studies have led me to believe that the vertical elevator will eventually be superseded by the inclined elevator or escalator. The vertical elevator wastes too much valuable time which will be saved by the inclined type between floors in warehouses and even between the first and second stories of the pier sheds themselves. By using escalators or inclined elevators this operation can be made practically continuous.

The question of pavement within pier sheds, between the sheds and warehouses and within the warehouses themselves, is of paramount importance. Efficient operation of any system of industrial trucks is impossible unless the pavement is in first class condition. In its pier sheds the City is now using the pressed asphalt block which is regarded as the very best possible. This pavement can be easily repaired and kept with a smooth surface so that no battery troubles or other deterrents to efficient operation are likely to occur. Care should also be taken to keep the roadways between the piers and warehouses and the floors in the warehouses themselves in an equally satisfactory condition.

In this short article I have been able to touch only a few high spots in the great problems of mechanical freight handling, with particular respect to the use of industrial trucks, tractors and trailers on steamship terminals, but these few appear to me to be of vital importance. So far as pier operation in New York City is concerned, I am not satisfied that any present installation is doing the work of which it should be capable. This is due to many things, among which are the construction of many of our piers, which is out of date and not well suited to the efficient use of this machinery; the lack of warehouse space in the vicinity of the piers and the consequent congestion within the shed area; and the ignorance or lack of study of the question of what apparatus will actually produce the best possible results.

The saving induced by the use of proper mechanical equipment on piers as against hand labor or inefficient machinery is undoubtedly very great.

I hesitate to advance any opinion of my own but I believe that an efficient system of industrial trucks, tractors and trailers installed together with other proper mechanical freight handling machinery on a modern steamship terminal will save at least 50 per cent in the cost of handling freight at that terminal, and I think I am fairly conservative in that estimate.

I am given the benefit every now and again of some such illuminating opinion as the following: "The only agitation for any mechanical devices on piers is artificial and has been created for selfish reasons by the manufacturers themselves," which opinion proves conclusively to me that many people who seem perfectly normal otherwise are in the stone age of thought as regards the proper handling of freight at water-front terminals.

The labor unions are said to be against the full use of mechanical equipment on piers because of the supposed reduction of force such use will entail. From time immemorial this argument has been advanced against the installation of every labor-saving device but labor has been educated to see that this is a fallacy because the increased output has provided a job for every man and at an increased compensation.

There is a very vital and obvious need for educational enlightenment in this regard at least so far as comprehensive water-front developments are concerned and for my part I am sure I am working along the right lines and that each year brings us nearer to victory in the fight for proper freight handling apparatus on piers and water-front terminals.

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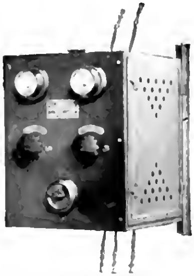

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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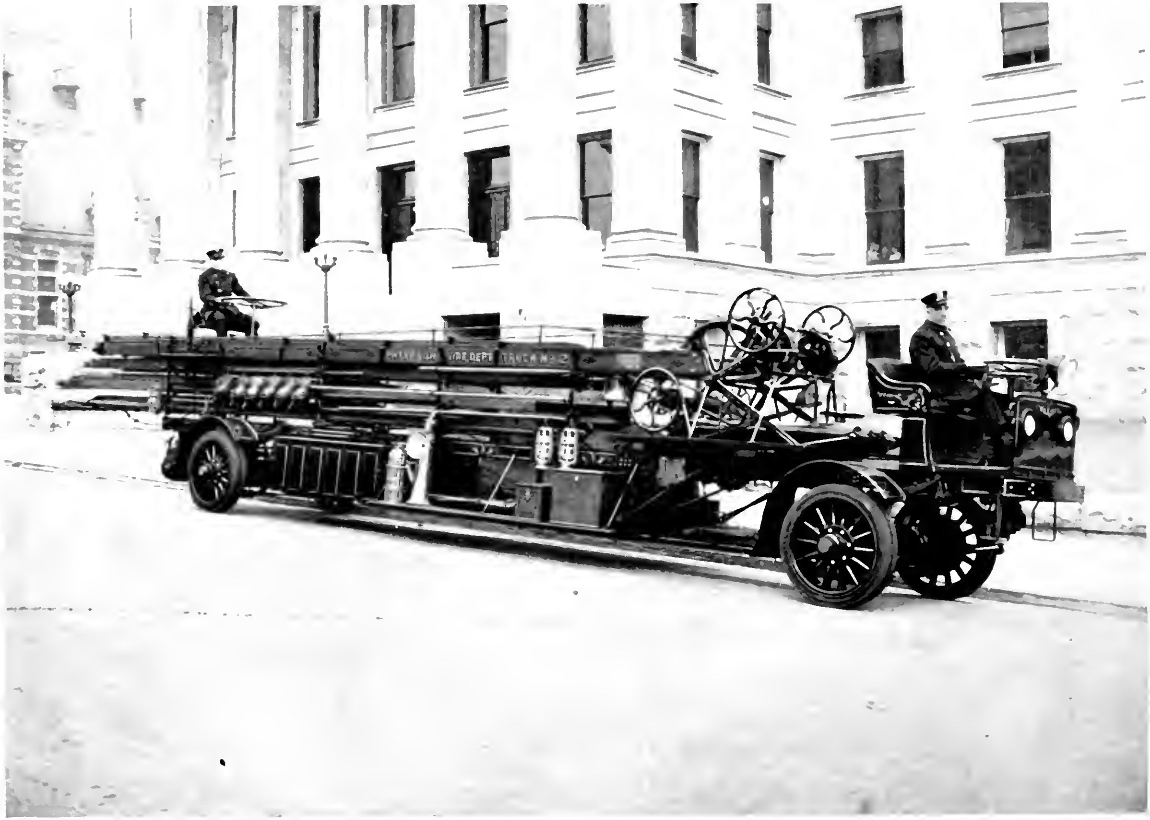

This Electrically-driven Aerial Ladder Truck, Weighing Nine Tons, Wrested from a Very Powerful Piece of Motor-driven Fire Apparatus the Hill Climbing Speed Record on the Famous Temple Hill, Paterson, N. J. (See Article, p. 275)

GENERAL ELECTRIC REVIEW

THE MASTER BUILDER AND HIS BRICKS

We think there is no excuse needed for often reiterating in these columns the imperative necessity for the engineer (using the term in its broadest sense) having an understanding of the task that is before him during this reconstruction period. To make good the waste and loss of war and to carry us still further in the evolution of our civilization is his task and duty, and, at the same time, his privilege and pleasure. An understanding of the task is a prime requisite to a sound beginning.

Physical research can and has done wonders for industry, but the first work of the physicist and chemist is research and the application of these discoveries and developments is in the province of the engineer. The engineer cannot keep up to date unless he keeps himself familiar with the progress made in science.

To keep informed on these developments is very hard in an age where education has run so far in the direction of specialization. To educate many men at an early age as specialists may be useful to fulfil an immediate need, but it lays no foundation on which later to build a broad understanding of the many phases of engineering work which must be appreciated and understood if the modern engineer is to make intelligent use of the tools that the scientist is preparing for him.

The work that was done in the research laboratory yesterday must be understood and put to practical use by the engineer today, and must be used and understood by the man in the street tomorrow. Sound progress depends upon this.

It is with these thoughts in mind that we constantly try to include in our columns some account of the research work in progress and also some account of the new scientific theories as they are evolved.

Nothing stimulates the imagination more than reading of successful research work, and an engineer above all things needs imagination, as he can hardly carry on the creative work which lies in his sphere, if he fails to cultivate his imagination.

Are there any stimulants to the imagination which can equal a study of Mendelejeff's periodic table, the spectrum and crystallography? The first shows us the majestic order of Nature in her arrangement of the elements and has enabled man to form a picture of the whole order of "things"—where previously he only had a haphazard collection of fragments which told no story until they were pieced together.

The spectrum is the very holy of holies of creation, through which we have learned so much—since the immortal genius of Newton first revealed to man the octave of visible light—to which we have added so many octaves of other radiations from time to time. These discoveries have literally illuminated the paths of men—and crystallography tells us what we know of the bricks with which the Master Builder has built His worlds and must still tell us more and more if in the future we are to build as we should build.

We hope that many engineers will read Dr. Fonda's article in this issue on "Crystal Growth in Metals." It is a poor builder that does not learn all he can about his bricks. The picture that Dr. Fonda draws of the crystallization of metals as they cool and the factors which enter into and determine their shape and size should start many an engineer wondering. The way in which the "working" of metal can change these shapes and sizes is just as important to the engineer as is the strength of any building material to the man who would build a building on a foundation that shall last.

Much as we have learned about crystals and useful as this knowledge has been—how much more have we still to learn? They are verily the bricks of the Master Builder. A German scientist recently announced the profound discovery that the tiny cotton fibre, of which there are some millions in the shirt on your back, is crystalline in nature. What new realms of thought does such an announcement open up to the speculative imagination of man? Cotton fibres are vegetables! Vegetables are a form of life! If one grows as a crystal—why not more—why not all?

If you pick an acorn and lay it on a shelf, it does not grow. If you plant the acorn in the soil, it does grow. Why? Is it only waiting for a saturated solution of "something" to start the process? Is the mighty oak tree started on its life's journey when the first crystal forms? If we could prove this of the oak—how long before we ask if it is not true of other forms of life—of animal life—of man? Anything is only a mystery or a miracle so long as the cause is not understood. It is not the engineer only—but all men—who should learn all they can about His bricks with which His worlds are built.

J. R. H.

Standardization

By E. W. Rice, Jr.

President, General Electric Company

The following is the substance of Mr. Rice's remarks before the Electrical Manufacturers' Council on January 26th. Mr. Rice was one of the real pioneers of our industry and we often wish we could hear more from such pioneers. What he says about standardization is both interesting and instructive.—Editor.

Standardization as a subject for an after dinner talk seems, I admit, rather dry—very dry in fact. Rather uninspiring and uninteresting. It suggests limitations in human effort, rigidity, boundaries, rules, stone walls, and fences; "the straight and narrow way." All unpleasant suggestions to most healthy individuals. Certainly the last thing that one would associate with the development of the electrical service and industry.

Anyone who has seen the growth of "things electrical" for the past forty years and considers also the present diversity of application and its inseparable relation with everything in our modern civilization, large and small, near and far, would affirm that there had been no setting of "metes and bounds" to electrical development and expansion. What are the facts? Well, I think we can say that whatever of standardization there has been in our industry, it apparently has not limited our development or the scope of our activities. Our slogan of "do it electrically" seems to have been more in evidence than any promulgation of standardization.

I think that, on the whole, electrical development has been guided by a rare combination of imagination and horse sense; science and research, invention and experiment have gone hand in hand with orderly engineering, systematic manufacture, good business practices and sound finance.

From the beginning, electrical work has been naturally attractive to the bold spirit of youth. Its leaders without exception were mere youngsters or relatively young men. It was a case of "love at first sight" with a devotion and constancy that only death could end.

Whatever standards or rules were found necessary, or thought desirable, for the industry were made by these young men, grown a little older, aided by a countless host of other young spirits, better trained in formal science, but no more enthusiastic than the early pioneers. I think we have here the reason why these rules or standards have not cramped and paralyzed the industry, but have rather aided it. They were made by those who were busily engaged in developing the same industry. Care was taken that the rules should guide development, not restrict it. The standards were made by those who were to obey them, they were made by, with and for the benefit of those who had created and were using the products of our great scientific industry. This I submit is as it should be, and I firmly believe that any other method would have been unfortunate, if not disastrous.

Our industry is more firmly based upon science perhaps than any other and electricity could not have become the important branch of scientific endeavor without the early work of those greatest of all standardizing committees—the International Electrical Committees which between 1863 and 1900, at different places, determined and defined our fundamental and practical electrical units, the ohm, volt, ampere, watt, henry, coulomb, etc.

Many of us remember the electrical meeting at Chicago in 1893 at the time of the World's Columbian Exposition, which was composed of delegates or members from different countries and included such names as

Von Helmholtz of Germany,
Ferraris of Italy,
Mascart and Hospitalier of France,
Preece and Sylvanus Thompson of England,
Elihu Thomson, Dr. Nichols, Prof. Carhart
and Elisha Gray of our country.

This meeting was called the International Electrical Congress or the International Congress of Electricians.

It was at this meeting that the units already in use were again defined and corrected and finally adopted as International units. We were all especially gratified that the unit of inductance was given the name of "henry" after our great physicist, Joseph Henry.

It is impossible to exaggerate the importance and value of this work. It was fortunately adopted as standard by the whole world—a true international standard. So that all those engaged in electrical work think and talk (so to speak) the same language.

We suffer no such handicap as has existed in other fields as, for example, the different monetary units, the variety of standards of weights and measures, the use of which waste time and energy that should be saved.

In the beginning of our industry, back in the 80's of the last century, there was of course no need for commercial standards, as no industry existed. It is very interesting, however, to remember that very soon after the electric arc light began to be used for commercial purposes, the need of a standard current for the series arc circuit was felt. Early in 1881, 9.6 amperes was selected by Prof. Elihu Thomson of the Thomson-Houston Company and continued to be the standard of the industry for many years.

It had the great advantage of ensuring uniformity of candle-power for each arc lamp and also enabled arc lamps to be used interchangeably in all such circuits. This was of benefit to the user and to the public as well as the manufacturer. Certain sizes of dynamos were also by common consent adopted as standards, for example: 1-3-10-16-20-40 light, etc.

Edison also adopted about the same time a standard of 110 volts for his incandescent lamp, which has remained one of the standards to this day.

The organizations represented here tonight have, I believe, been doing a most useful and valuable work along many lines and none better than in the field of standardization.

No one could read the book of the Power Club, its guiding principles, its actual rules and standards without being impressed in the thoughtful care and great practical wisdom which have been displayed. The same principles and sensible methods have also apparently actuated those who have formulated the practices and standards of the A.M.E.S.

I am informed that a committee of the Power Club in co-operation with a committee of the N.E.L.A. adopted standards which have effected, in the case of transformers, large reductions in the number of listed specialties, odd ratings, voltages, sizes, etc. The elimination of such apparently useless variations has been estimated at between 50 per cent and 60 per cent of the total listed units. Such action must increase the effectiveness of the engineering and sales personnel and improve the quality and reduce the cost of the service rendered by the manufacturing companies to their customers and to the public.

Naturally, I am an enthusiastic user of the many electrical devices which have been developed in recent years, such as percolators, fan motors, vacuum cleaners, toasters, etc., but as these various devices were introduced into my home, I found that each one required the use of a different type of attachment plug; each different plug representing, I was informed, a great advance in the art. Unfortunately, the new plugs did not fit any of the types of wall receptacles already installed in the house.

I understand that the A.M.E.S. has co-operated in the standardization of the attachment plug and wall receptacle now known as "convenience outlet" and this work of standardization has my profound respect. It will add to my comfort and peace of mind in my declining years.

It is also gratifying to note that it has been fully recognized by our manufacturing organizations that in many instances the field of standardization is so broad that co-operation with other organizations and societies was necessary and that a spirit of good sense and friendly co-operation has been displayed in all such cases.

I trust that no one will imagine that because I am stressing the value of standardization that I am not alive to the necessity and desirability of progress and that this involves increasing complexity. I believe it is essential to guard and preserve individuality. Variety is still the spice of life. Electricity has made its enormous progress because of its ability to meet the infinitely varying conditions of our industrial, city and home life. It can transport matter, transmit thought and transfer energy in its most useful form with maximum economy and almost without limitation. New methods, new ideas, new devices are therefore to be encouraged and are the life breath of our industry.

However, variety which is the result of haphazard methods of growth; variety based upon ignorance or prejudice, or which merely exists for the sake of itself, such variety is of doubtful economical value at best and may easily become a source of great economic loss. It is a useless "by-product" of our advancing industry.

When your president asked me to speak tonight upon this subject of standardization, I had in mind urging consideration of the importance of reducing the variety and sizes of many of our electric devices such as motors, transformers, etc.

However, after considering very carefully the work which has already been done by the Power Club and the A.M.E.S., I concluded that my views had been largely anticipated and that about all I could do was to voice my satisfaction with what had been done and to suggest that we keep right on and not "become weary of well doing." "Well begun is half done" and we have certainly made a good beginning.

I think that it is obvious that we of the electrical manufacturing industry and those we serve have not obtained the benefit which should follow the increased volume of our business, for the reason that the variety of sizes and number of different units have increased generally more rapidly than either the increase in total number of units or (dollars) volume of business.

The inevitable result has been to increase the "overhead" or the cost, not only of manufacture, but of distribution of the units of industry. I believe that if our industry is to continue to grow and increase its service to the public as it could and should, that our costs must be reduced. I am sure that we will all agree that if the number of separate units could be reduced that the total cost of production and distribution would be materially lowered. This would redound to the benefit not only of the manufacturers, large and small, but to all those connected with the distribution of our product and be of equal benefit to our real employers, the public. I believe that a large reduction in the number of sizes and varieties can be made, not only without sacrifice of real service to the public, but with an increase in the value and improvement in the character of our service. I cannot take the time to develop this suggestion this evening and it is probably not necessary, as I am sure that your own experience and thought have brought you to the same conclusion. It cannot be done by any manufacturer alone; it can only be brought about through the co-operation of all interested parties.

Full success will require a sympathetic attitude on the part of our Governmental authorities at Washington which apparently now happily exists. All these, our organizations, have a great opportunity and an equal responsibility. Splendid work has already been done, but we should, in my judgment, patiently but vigorously continue the work to the end that our profession and business may render that full service to man which we all visualize, but which so far with all its importance is but a promise of a greater and more useful future.

Calorizing and Calite

By G. H. Howe and G. R. Brophy

Research Laboratory, General Electric Company

"The rust that doth corrupt" is man's eternal enemy. The oxidization of materials when subjected to intense heat has caused huge losses to those engaged in the mechanical arts, in the same way as rust or oxidization causes enormous losses at ordinary temperatures. Mr. T. Van Aller discovered the process of calorizing to prevent oxidization of materials at high temperatures, and this process was developed to a commercial basis in the Schenectady Research Laboratory. This same Laboratory has now developed a material called calite, which is an alloy, to make cast parts which will not corrode or oxidize when subjected to intense heat. The process of calorizing and the alloy calite should lead to many advances in the arts and industries and we feel that our present article should be of great interest to our readers.—Editor.

CALORIZING

A freshly cut surface of aluminum, in common with all metals, shows a bright lustrous surface which becomes dull after a short time, due to oxidization. On longer exposure little change takes place in this strongly adherent coating of oxidization. In other words, the coating of oxide forms a protective surface. When aluminum is alloyed, in solid solution, with other metals it still retains this property and serves as a protection. It is this property that has been taken advantage of in developing the process of calorizing. In other words, calorizing consists of the formation of a surface alloy of aluminum on ferrous and nonferrous metals. There are now two methods of calorizing, namely, by the powder and the dip process.

The Powder Process

In the powder process the parts to be treated are placed in an air-tight receptacle partly filled with the calorizing mixture which consists of finely divided metallic aluminum suspended in aluminum oxide. Hydrogen gas is admitted into this container and it washes out all the air and provides a reducing atmosphere. When heated to a high temperature the particles of aluminum, which are kept separate by the alumina, make contact with the material being treated, infusing into the exposed surfaces. The depth to which the aluminum penetrates is governed by varying the length of the treatment and the composition of the mixture. When parts thus treated are subjected to high temperatures in air, a thin but impervious coating of oxide forms, which protects them from deterioration by scaling.

The Dip Process

What is known as the dip method was developed by C. Dantsizen, of the Schenectady Research Laboratory. It consists of properly fluxing the parts, which are then immersed in a molten bath of aluminum. This method has the advantage of being very rapid and is well adapted to the treatment of small parts in large quantities which do not warrant much added expense. Although the dip method gives a lighter coating than is obtained with the powder method, it gives a thoroughly reliable coating of aluminum alloy and is particularly well adapted to parts of small cross section. Where the usage is not very severe, parts of greater thickness may be adequately protected by this process. Some of the products already successfully treated in this way are iron wire, heating units, grids, stove burners, lighting fixture parts, gas engine exhaust mufflers, oil burner shields, miscellaneous stampings, etc.

General

Calorizing is frequently mistaken for sherardizing or galvanizing, both of which are processes for applying zinc to prevent rust. Zinc is a corrosive and strongly electropositive metal. When applied to iron or steel and exposed to dampness a slight galvanic action takes place, corroding the zinc only, so long as any is left. For such purposes zinc is considered the best protective medium, but it should be noted that it offers no resistance to the action of intense heat. Calorizing protects against the ravages of heat and although there are many instances where it has been used to prevent corrosion, such, for instance, as the corrosion of copper condenser tubes in seaboard towns, it is not generally recommended for such purposes. In calorizing, instead of forming a soft coating which can be readily scraped off, the aluminum makes intimate contact with the base metal and will withstand a considerable amount of abrasion.

It is interesting to note the piece of calorized metal shown in Fig. 1. After being treated it still has the appearance of metal, but not the appearance of metal subjected to oxidization. Just after calorizing the coating consists of a thin alloy layer, which is very rich in aluminum, but on being subjected to heat, under service conditions, this coating of alloy penetrates deeper, as shown in the right-hand piece of metal in Fig. 1. The right-hand specimen is of the same metal as that shown to the left, but has been fired at 900 deg. C. (1652 deg. F.) for 100 hours. In the right-hand specimen the aluminum has diffused further, forming a larger amount of homogeneous aluminum-iron alloy and a layer of oxide which is the protective coat. The coating produced in this manner is rather brittle, but, as previously stated, it will withstand ordinary abrasion. Should the layer of oxide become removed by severe use, when the specimen is subjected to intense heat it will be renewed by the oxidization of the alloy exposed.

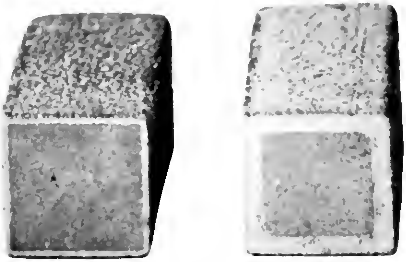

Fig. 1. Calorized Steel Showing Action of Heat in Diffusing Aluminum

The life of calorized material is chiefly dependent upon the proportion of the cross section affected by the alloying and the percentage of the aluminum content. For example, if two steel rods, one having half the diameter of the other, were treated to the same depth, the smaller specimen would be affected to a greater depth than the larger, thereby having a greater aluminum content than the piece of larger size. It is therefore obvious that the smaller piece of steel would have the greater resistance to prolonged heat.

In some cases, owing to the size and quality of the product, calorizing cannot be used to good advantage. One example is where an ample amount of protective medium cannot be applied because of very heavy walls. Low grade ferrous castings poured from the bad end of a heat sometimes contain slag, blowholes, sand inclusions and other imperfections which break up the continuity of the surface. These imperfections, together with the fact that the penetration seems to be retarded correspondingly with the amount of free carbon, are the chief reasons why cast iron is a poor subject for calorizing. Also the characteristic growth of cast iron on repeated heating and cooling tends to break up a surface alloy of aluminum, and leaves unprotected areas as it continues to grow. Excellent results have been obtained with good grades of steel castings. Calite, which will be dealt with in the latter part of this article, was designed to meet conditions where calorizing was not applicable. The protective quality of calite as a resistor of scaling is effective up to nearly its melting point.

Fig. 2. Calorized Steel Showing Oxidization of Unprotected Section

Innumerable comparative tests have been made in determining the value of the calorizing process. The maximum temperature which a piece of treated metal will stand depends upon the nature of the coating and the service to which it is put. If sufficient aluminum is applied to a piece of metal to allow a total impregnation, resulting in an alloy of from 12 to 14 per cent of aluminum, the breakdown will not occur below the melting point. Ordinarily 900 to 1000 deg. C. (1652 to 1832 deg. F.) is the limit to which calorizing should serve. In the case of pieces of heavy cross sections the aluminum, if not applied thickly, will continue to diffuse and will eventually result in an alloy too weak in aluminum to form a satisfactory oxide. The oxide coating on the surface will still act as a protector, but, if it becomes injured by abrasion, it will not renew itself but will allow the underlying metal to scale. The diffusion proceeds slowly at temperatures up to 900 deg. C. (1652 deg. F.) and becomes rapid at 1000 to 1200 deg. C. (1832 to 2192 deg. F.).

Fig. 2 shows two calorized specimens prepared so as to expose unprotected portions to oxidization. The firing of these specimens was done at a temperature of 800 deg. C. (1472 deg. F.) for one hour which was not enough for appreciable diffusion. The two pieces of calorized copper tubing shown in Fig. 3 were heated to the melting point and have a tough coating.

Characteristics

As is the case in judging the resistance of a piece of calorized metal to scaling, the properties of strength, and electrical and heat conductivity, vary with the cross section affected by diffusion. Physical tests made on steel tubing calorized by the powder method have shown that the treatment has an effect much like a hydrogen anneal. It has been found, however, that any change in the physical characteristics of the average application does not require serious consideration. The quality of homogeneity has been revealed by microscopic examinations of samples subjected to crushing tests. Both heat and electrical conductivity are somewhat lowered. Calorizing is not suited for work above 1000 deg. C. (1832 deg. F.), due to the rapid diffusion of aluminum and the consequent lowering of the surface aluminum content to the point where breakdown occurs.

Commercial Aspects and Other Uses

In manufacturing plants many special instances have been found where calorizing serves purposes other than the primary one for which it is intended. Calorized nonferrous metals, such as copper, brass, and nickel, are resistant to atmospheric conditions and certain acidulous liquids. Treated ferrous metals have resisting qualities to the effect of carbolic acid, hot tar, and pitch. Sulphur dioxide and carbon monoxide, as present in furnace gases, have a very wasting effect on iron or steel furnace parts, which may be corrected by calorizing.

Fig. 3. Calorized Copper Tubing Heated to Its Melting Point

Whenever metal is deteriorated by heat, subjected to some forms of corrosion or the wasting effect of certain gases, either dipped or powder calorized material or calite is valuable. There are other metals which serve the same purposes, but, owing to the expense, difficulty in machining or other working, very extensive applications have not been developed.

Consistently good results have been obtained by calorized material up to 925 deg. C. (1697 deg. F.) in the following uses:

Annealing containers and equipment
Pipes and tubes for tool steel, alloy steel
Pipes for continuous wire annealing
Pipes and tubes for needles, fish hooks, umbrella frames or special work
Pipes and tubes for rotary furnaces for rivets, bolts, screws, lock washers
Tubes for annealing incandescent lamp bulbs
Parts of rotary annealing furnaces
Parts of continuous furnaces
Link chains in continuous furnaces
Saddles for continuous furnaces
Case hardening boxes
Parts of tunnel kilns
Hardening plates
Furnace skids for light work
Pyrometer protection tubes

Thermostat fire ends
Burner nozzles for oil or gas furnaces
Steam superheaters
Air preheaters
Heat exchangers
Coils for household water heaters
Producer gas filter chambers
Calcining tubes and retorts
Carbon and bone black retorts
Pottery racks
Muffles
Bolts and rods for supporting top stone in glass melting furnaces
Mantle rods for glass furnaces
Diesel engine spoons and combustion plates
Vaporizers and coils for steam automobiles
Molten sulphur containers
Carbolic acid lines
Tubes for pressure stills for oil and tar refineries
Tubes for condensers for oil and tar refineries
Soldering irons
Gas mantle rings and supports
Oil burners for household furnaces
Small annealing and case hardening boxes
Stove linings
Wire mesh

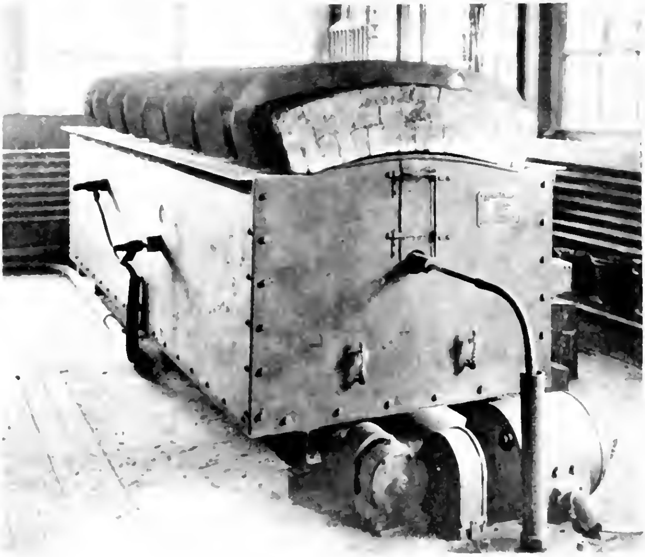

Fig. 4. 100-kw. Experimental Powder Calorizing Furnace

Electric Furnace

Like most metallurgical processes, calorizing requires careful technical supervision. This is particularly true in the operation of furnaces if absolute uniformity of product is to be maintained. To eliminate the human element from this phase of the work, an automatically controlled electric furnace, illustrated in Fig. 4, may often be useful. An experimental furnace has been constructed and, with three or four minor changes, gives remarkable results in the quality of work produced and the cost per unit of work treated, as compared with a fuel fired furnace. The units are so arranged as to give an even distribution of heat over the entire length of the retort. Any temperature can be attained and maintained by setting a recorder controller used to actuate the automatic control panel.

In connection with the dip method, electrically heated furnaces have proved superior to furnaces heated by gas combustion. It is probable that electric furnaces will be used altogether for the commercial production of calorized material in the near future. The development work done in heating along this line opens up new applications for the new types.

CALITE

As stated previously, calite is a material which has been developed in the Schenectady Research Laboratory for making cast parts which will resist the corrosive action of intense heat.

Development of Calite

A homogeneous alloy made by melting aluminum with iron will naturally show no diffusion on subsequent heating, and, provided the aluminum content is sufficiently high, the alloy will resist oxidization at temperatures nearly up to its melting point. Unfortunately, subsequent heating and rapid cooling or uneven heating causes such alloys to crack badly and no homeopathic doses of any third metal that has been tried up to the present—and nearly all of the metals were tried—helped to remedy this condition. If the hot metal is touched with the least amount of moisture it flies to pieces, acting like glass under the same conditions.

The low expansion of high nickel steel, together with the fact that aluminum and nickel form a compound with a very high melting point, led to the investigation of the promising ternary alloys of aluminum, nickel, and iron.

By keeping aluminum at a minimum and substituting nickel for iron in various percentages, a series of alloys was obtained which showed increasingly good properties. However, when the nickel reached a given percentage the alloy was extremely soft and resisted oxidization little better than pure iron. This was probably due to the formation of the high melting point alloy nickel-aluminum, which, while highly resistant to oxidization itself, robbed the iron of its protection and permitted the alloy to scale badly. Further additions of aluminum and nickel finally gave an alloy which was strong, which would stand shocks when either hot or cold, and which could be quenched repeatedly and was highly resistant to oxidization. A few further changes gave the alloy which was finally adopted and which is now known as calite.

Effect of Impurities

Manganese and silicon both tend to decrease resistance to oxidization, and carbon increases brittleness. Therefore, these impurities are kept as low as possible. On account of the ease with which silicon oxide slags with aluminum the melting must be done in a basic furnace. and the ladle must have a basic lining.

Physical Properties

Calite resists oxidization up to 1300 deg. C. (2372 deg. F.), but 1200 deg. C. (2200 deg. F.) is recommended for indefinite service. The protective oxide formed is tight and does not snap off even on quenching from high temperature. Calite, when quenched after 100 hours at 1200 deg. C., lost only 0.03 gram per square centimeter of surface while the best heat resisting base metal alloy other than calite lost 0.56 grams under the same conditions. When the same samples were run at 1300 deg. C. for an additional 25 hours calite lost 0.003 gram and the other alloys lost 0.09 gram per square centimeter exposed. From these figures it is apparent that calite is twenty times as resistant at 1200 deg. C. and that it is the only base metal alloy to stand up at higher temperatures. At 900 deg. C. or at ordinary operating temperatures the loss per square centimeter was measured in 1/10 mgs., or, for all practical purposes, it may be said that there was no loss.

Fig. 5. Two Small Calite Annealing Boxes After 1500 Heat-Hours. Large box shows characteristic scaling of steel

Calite is, practically speaking, non-corrosive. Samples have been polished and placed in a spray of saturated sea salt solution at 100 deg. F. for 200 hours and at the end of this period still retained the perfect polish. The so-called "stainless steel" will last but a few hours when subjected to a similar test. Calite should prove an excellent material for fittings exposed to salt atmospheres.

A 25 per cent solution of sulphuric acid dissolves calite rapidly. Hydrochloric acid dissolves it slowly and nitric acid hardly affects it. After 48 hours in 25 per cent nitric acid the metal lost 0.00042 gram per square centimeter exposed. Acetic acid has no effect on calite.

Molten chlorides, cyanides and sulphur and sulphur vapor do not attack calite. Fluxes such as cryolite and borate and silicates attack calite rapidly.

In general, the physical properties are as follows:

Melting point	2777 deg. F.
Softening temp.	2500 deg. F.
Working temp.	2200-2370 deg. F.
Sp. Gr.	7.03
Wt. per cubic inch	0.25 lb.
Brinell (standard hardness)	286 annealed
Scleroscope (hardness)	40 annealed
Thermal conductivity	25% of iron
Tensile strength	36,800 lb.
Transverse strength, 4250 lb. 1 in. bar, 12 in. supports	

Calite cannot be machined in cast condition, nor cut with oxy-acetylene. Any change of dimension or finish must be done by grinding.

Calite is more resistant to oxidization at high temperatures and will stand higher temperatures than any base metal alloy tested. The boxes shown in Fig. 5 have been run for 1500 heat-hours and, as will be seen, are in perfect condition. Measurement of these boxes shows no warpage nor growth. The oxide coating is no heavier now than after the first heat.

New Outdoor Substation of the Chee Hsin Cement Company, Ltd., Tongshan

By Graham Kearney

Engineer, Tientsin Office, Andersen, Meyer & Company, China

This is a short, but interesting, account of some up-to-date electrical equipment installed in China. The use of outdoor substation equipment in such remote regions is an eloquent tribute to the high state of development that has been reached in this class of apparatus.—Editor.

One of the most interesting electrical developments in China in point of novelty and utility is now almost completed at the plant of the Chee Hsin Cement Company, Ltd., at Tongshan. Tongshan may well be considered the industrial center of North China and its industries have always been noted for their pioneer work, leading the way in the adoption of the most modern ideas in industrial development. It is a matter of history that Tongshan was the birthplace, in 1881, of the "Rocket of China," the first standard gauge locomotive to operate in China, and from Tongshan started the first system of Chinese Government Railways. It is logical therefore that Tongshan should see the first application in China of one of the most modern ideas in electrical engineering, the high-tension outdoor substation. American outdoor transformers and high-tension switching apparatus are rapidly replacing the more elaborate and expensive indoor substations, and have proven thoroughly reliable under the most severe climatic conditions, more severe indeed than are ever encountered in this part of China.

The present cement plant has an annual capacity of 700,000 barrels; the cement making machinery is practically all electrically driven, most of the power being obtained from the Company's own steam plant of 1250-kv-a. capacity.

The Chee Hsin Cement Company's products have found such a ready market that the Company have seen the necessity of greatly increasing the capacity of their plant to take care of the future expansion of their market. Accordingly, they have during the past two years undertaken the installation of an additional plant which is now nearing completion, and which, when completed, will add 1,000,000 barrels annually to their output. The total capacity of 1,700,000 barrels will, it is believed, place the Company in a position to take care of the requirements of the market for some years to come, although the plant is so designed as to permit further extension if necessary.

The new cement plant is electrically driven throughout, and power for its operation is being purchased from the Kailan Mining Administration. One of the most important factors which led to the purchase of power was the advantage of having an extensive generating system as a source of supply, as against an isolated plant this giving practically complete insurance against possible shut-downs from failure of the power supply. The Kailan Mining Administration furnish power from the 30,000-volt transmission line joining their generating stations at Linsi and Tongshan; power is stepped down to 2200 volts, the operating voltage, through an outdoor transformer and switching station, consisting of two duplicate transformer and switching units of 1000 kv-a. each.

Each unit consists essentially of a high-tension steel switching tower, underneath which is set a bank of three single-phase, 333-kv-a., 30,000-volt (star) primary, 2200-volt (delta) secondary, 25-cycle, self-cooled, outdoor type transformers, and a 2200-volt steel switching house. The high-tension switching and protective devices, one of which is mounted on top of each switching tower, consist each of a 35,000-volt combined disconnecting switch, choke coil, and expulsion fuse. The three elements of the disconnecting switch are operated simultaneously by means of a special mechanism, which permits of their being opened or closed by an operator standing on the ground, and so arranged that they may be locked in either position. With the disconnecting switches open, the expulsion fuses are easily reached for inspection or replacement from a wooden platform extending along the side of the tower.

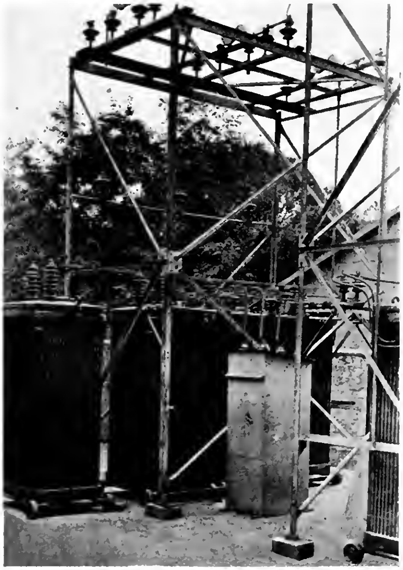

Fig. 1. One 1000-kv-a. Unit Showing Spare Transformer and 2200-volt Switch House, Chee Hsin Cement Company, Ltd., Tongshan, North China

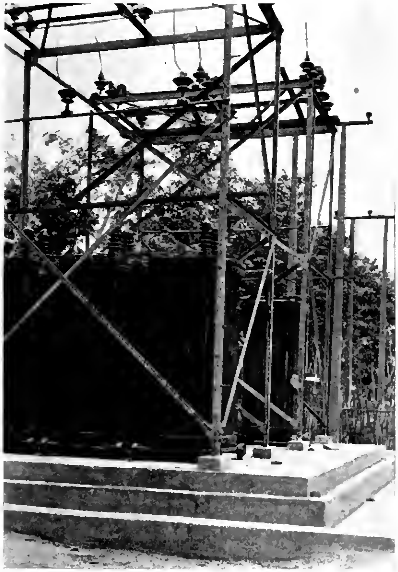

Fig. 2. Complete 2000-kv-a. Station Showing 30,000-volt Transmission Line, Chee Hsin Cement Company, Ltd., Tongshan, North China

The low-tension power is led from the 2200-volt delta through special roof entrance bushings into the steel switching house; each switching house contains a standard unit slate panel, on which are mounted an automatic oil circuit breaker and a polyphase watthour meter, with the necessary relays and potential and current transformers. The switch house is designed with weatherproof doors in front, which are opened for switching and metering operations, and a removable panel at the back, for inspection and repairs. The doors and panels are provided with locking devices. The two substation units are set face to face on a concrete slab, alongside of which is built a depressed track running to the works. All of the transformers are mounted on wheels, so that in case of trouble any transformer can be run quickly onto a specially designed truck and transferred to the shops for inspection and repairs. One spare transformer, which can be used in either unit, is kept standing by in such a position that it can be run quickly in on its own wheels to replace any one of the transformers in case of break-down.

The high-tension disconnecting switches are connected directly to the transmission line, but further protection is afforded by a disconnecting switch placed on the nearest transmission tower on each side of the substation. The transmission system from Linsi to Tongshan consists of two lines, forming a loop, so that in case of failure of either line one of the disconnecting switches in the line can be opened and power fed through the other one only.

Fig. 3. 37,000-volt, 3-phase, Outdoor Type Oxide Film Lightning Arrester, Chee Hsin Cement Company, Ltd., Tongshan, North China

Protection from lightning and surges is given by a 37,000-volt oxide film lightning arrester, which again is the first of its type to be installed in China, and represents the latest development in lightning protective equipment. This arrester is admirably suited to outdoor installations, and while it gives protection of the highest order, is not affected by climatic conditions, and requires no attention other than an occasional inspection.

The above mentioned generating and transforming equipments are, however, still inadequate for the Company's immediate power requirements, so to tide them over until the final installation is completed, the Company have purchased a complete 1500-kv-a. steam turbine-generator plant which is now in the course of erection. This, together with the original steam power plant, will eventually be replaced by an additional outdoor substation unit of approximately 4000-kv-a. which is now on order.

This unit will, in general, be similar to the present unit, but on account of the increased capacity an automatic outdoor type 30,000-volt oil circuit breaker will be used instead of the expulsion fuses as used in the smaller units. Also, on account of the necessity of distributing the power through several feeders, one of which will feed the new Wah Sing Cotton Mill, now under construction, the 2200-volt switching and metering equipment will be somewhat more elaborate, and will be housed in a simple brick structure close to the transformers. The leads for the transfer of power, from the 2200-volt delta to the switchboard busbar, will be placed underground.

All of the outdoor substation equipment is designed and built by the International General Electric Company, Inc., Schenectady, N. Y., U. S. A., and furnished through their Agents—Messrs. Andersen, Meyer & Company, Ltd., Tientsin.

The Electric Truck—Why It Is What It Is

By E. R. Whitney

President, Commercial Truck Company

We regret that the pressure of other business prevented the author from preparing this article in time for our including it in our special Electric Vehicle Number (April, 1922), for which it was intended. However, the article is by no means misplaced because it summarizes in a very able fashion the many facts and features that were brought out in our Electric Vehicle issue to show the superiority of this type of carrier in the field of service for which it is designed. In particular, the author treats of the general engineering excellence, economy, simplicity, speed, battery location, and low center of gravity of the electric truck.—Editor.

A great deal has been written on the electric truck, setting forth its many virtues, its simplicity, its economy, its reliability, and proclaiming its pre-eminence in its field, and still its real merits have been appreciated and taken advantage of by a comparatively few; but the period of economy, reduction of profits, prices and costs that we are now in is causing the addition of a great many prominent concerns to the list of electric truck users.

The purpose of this article is to present and discuss some of the features of the electric truck and some of the problems that confront the designers and the manufacturers and to explain why the modern electric truck is constructed as it is.

Engineering

The modern electric truck is an outstanding example of good engineering design. Practical engineering in most lines is a process of determining the best compromise. The popular impression of the electric truck is, or was not so long ago, a frame, springs, axles, wheels, a battery, a motor, just gathered together and assembled in a more or less unrelated fashion. Some of the earlier trucks were in fact not much more. The electric truck of today, however, is a highly developed product and the factors that are given consideration and weighed one against the other in determining the best all around compromise to meet the commercial demands are more numerous than are found in most engineering problems.

For instance, careful consideration must be given to keep the weight down to a minimum, as this affects a number of other features, including mileage, size of battery equipment, wear on tires, etc.

Strength must be given full consideration providing a large factor of safety and with great resistance to fatigue. Alloy steels and the art of heat treating have come to play a very important part in the construction of the modern electric truck.

Efficiency of all parts is of extreme importance as this will not only affect the cost of current, but what is of greater importance, the amount of work that can be done with a given battery capacity.

The selling price must be kept sufficiently low to meet competition, and the design must be such that the cost of construction will leave a net profit, without sacrificing in any way the strength, reliability or durability of parts.

Why the Electric Truck

I have often been asked why the electric truck is manufactured, as the gasoline truck will do all of the work of the electric truck. While admitting this, it can be consistently stated that there is a very important place and a very large field for the electric truck where it will work more reliably and economically, and its place has been made to a large extent by reason of its extreme simplicity.

There are a number of advantages in the electric truck, only a few of which I will enumerate, including its quiet operation, absence of odor, low fire hazard, short over-all length (therefore small garage space required), as well as the feasibility of garaging at the loading platform in many cases, etc.; but of course in the last analysis and summed up in a single word, the real reason for the existence of the electric truck is economy.

Simplicity

Contrary to the popular impression, there is opportunity for display of real engineering ability in the very maintenance of the all-important simplicity which is in such large measure accountable for the success of the electric truck.

A great many attempts have been made during the last twenty years to introduce innovations, such, for instance, as arranging the brakes so that when applied the current circuit from the battery is opened; or, for instance, regeneration; that is, so designing the motor characteristics that by strengthening the field or when coasting down hill the motor will be converted into a dynamo and recharge the battery.

It has been quite conclusively proved a number of times that if full account is taken of the increased weight and expense necessary to produce regeneration, and this same weight and expense added to increase the battery capacity or to improve the motor efficiency, the added mileage over the straight, simple, series wound motor with its rugged windings is very slight and not enough to warrant the added complication and increased maintenance cost.

Other automatic devices have from time to time been tried out, but invariably in the end the manufacturer eliminates the automatic or innovation devices and gets down to the simplest form of construction and then devotes attention to improving efficiency and the design and construction to make a better truck and to bring maintenance cost to a minimum.

The construction of the gas car is so familiar to the average person, and the extreme simplicity of the electric truck is so little appreciated, that a prospective buyer will quite frequently ask an electric truck salesman for information as to the type of clutch or transmission with which his truck is equipped, or other similar questions, and it is necessary to explain that the electric truck has none of these devices and has no need for them.

During the last fifteen years I have received proposals from three or four independent inventors who had conceived the idea of a transmission for use on electric trucks, the transmission being equipped with either one or two gear changes, the idea being to reduce the current demand on the battery when ascending grades and to permit of the use of a different type of motor than that ordinarily used.

In considering with the inventor the merits of his device, and after carefully obtaining his ideas as to the limit of current demand, minimum speed permissible on a given grade, etc., in every case it has been possible to demonstrate that the same or higher speed, with no higher current demand, and other advantages can be obtained with a fixed gear ratio, from the simple, sturdy, series wound motor with its automatic characteristics, producing rapidly increasing torque with increasing load and corresponding speed reduction.

Speed

It seems to be the popular impression that the electric truck is a slow moving vehicle. This belief undoubtedly came from the old type electric trucks which were invariably designed to operate at a relatively low speed.

Proper speed is an extremely important feature, and I wish to point out that the electric truck does not operate at a low or moderate speed because this is a necessary and inherent feature of the electric truck. The modern electric truck in fact does not operate at a low speed but at a considerably higher speed than the older type, the average speed being $2\frac{1}{2}$ to 3 times the speed of the horse. The electric truck can be designed to operate at practically any speed within commercial limitations.

The hill climbing speed record on the famous Temple Hill in Paterson, N. J., that was previously made by a very powerful motor-driven piece of fire apparatus, was quite materially lowered in 1912 by an electrically-driven aerial ladder truck,* having a total weight of 9 tons, and by an electrically-driven combination chemical and hose wagon.† The new record still stands. This apparatus was designed to operate at a speed of between 20 to 25 miles per hour on the level. It may be of interest here to note that the City of Paterson has been relying entirely for a number of years for its protection against fire on the electrically-driven fire apparatus.

The standard electric truck is designed to operate at the speed at which it runs—a moderate speed—not because this speed is necessary but because it is the most economical speed for hauling freight or delivering parcels.

If the speed were increased more goods might be delivered, but the maintenance cost would go up and the cost per mile or per ton-mile would be higher.

If the truck speed were reduced less work could be done and without a material reduction in maintenance cost, and again the cost per mile or per ton-mile would be higher.

In fixing the speed of the electric truck it has not been done by hit or miss, but the designer has, as illustrated above, selected the speed that long experience and many hard knocks in service have indicated as the most economical.

What is said above applies to the standard electric truck. There are exceptional

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* See frontispiece of this issue of the REVIEW.
†See cover illustration of the April, 1922, issue of the REVIEW.

Fig. 1. High Body Mounting is Possible with Low Center of Gravity in the Electric Vehicle. (Commercial Truck Company)

Fig. 2. A Small Electric Delivery Wagon. (Commercial Truck Company)

Fig. 3. An Electric Moving Van. (Commercial Truck Company)

Fig. 4. Five-ton Electric Trucks in Heavy Hauling Service. (Commercial Truck Company)

conditions where a somewhat higher speed can be used to advantage and with economy, and there are still other conditions where a speed lower than the standard speed will give better results and lower costs. Most truck manufacturers are equipped to satisfactorily meet the demand for these special cases.

Battery Location

I have often been asked why the battery is always located under the frame and between the wheels, there being various suggestions for improving the performance, appearance and other features of the electric truck by mounting the battery in another place or in a different way.

Fig. 5. An Electric Lamp Trimmer's Wagon with Center of Gravity so Low as to be Perfectly Stable When the Bridge is Raised and Offset. (Commercial Truck Company)

During the past 15 or 20 years a great many trucks have been built with batteries located at various places, and, in fact, in certain special types of trucks the battery can be placed in a different location to advantage, as for instance in the 2-wheel steamer tractor, Fig. 6, where half of the battery is under hood in front, resulting in a shorter tractor and a balance around the axle. But for the general run of standard trucks there is just one best location for the battery, and that is below the frame in the center of the truck where it is in the most guarded position and where it is very unlikely to be damaged by collision.

There are other important considerations for this location. For instance, a lower center of gravity is obtained, which is of great assistance in producing a truck that is stable and not likely to skid on slippery streets. This location also enables the designer to obtain the proper weight distribution without excessive length of wheel base, and what is of equal importance and a feature which is often overlooked, proper weight distribution for the truck both loaded and empty. If, for instance, 67 per cent of the total is the correct weight to be carried on rear wheels this should not change when load is put on or removed.

It is also important that the battery be located all in one compartment where the compartment can be built to provide ample ventilation for warm months and can be properly enclosed to hold the temperature during the winter months.

Another important feature obtained with this location is that any spilling of electrolyte usually falls directly to the floor or the ground instead of dropping on some part of the mechanism or structure of the chassis.

Special Advantages

By taking full benefit of the simple, sturdy construction of the electric motor, with its single rotating part, low center of gravity, unvarying weight distribution and other features, a few of which have been outlined above, it is entirely feasible to obtain results with the electric truck that cannot be accomplished with any other type of truck. For instance, the motor can be located forward with the advantages that go along with this arrangement or with equal facility built into the rear axle as an integral part of the rear construction, thus in turn taking advantage of types of gearing and methods of drive that could not be used were it not possible to mount the motor in this way.

It is also possible to mount the motor directly in or adjacent to each driving wheel, making an independent drive for each wheel, thus eliminating the differential gear and effecting other incidental advantages.

The connection between the control and the driving mechanism is usually in the form of copper cables and thus the need for accurate alignment or fixed relation between the two is entirely eliminated. Fig. 1 illustrates a type of construction which takes advantage of the low center of gravity of the electric truck chassis as referred to above.

The lamp trimmer's tower wagon, Fig. 5, with the bridge swung to one side, is perfectly safe and stable.

The coal truck, Fig. 1, takes advantage of the low center of gravity of the chassis, and the body, which has a capacity of six tons, is raised considerably higher than is customary or feasible with motor trucks of other types or with horse-drawn trucks. Still the truck as a whole has a relatively low center of gravity and is entirely safe and stable, although the truck when seen on the street looks as tough it were not safe and might tip over, while as a matter of fact it is more stable than the ordinary horse-drawn truck with body mounted much lower.

It will be noted that the body is mounted on the chassis in a fixed position, the discharge chutes being sufficiently high to handle a large percentage of the bulk delivery of anthracite coal to office buildings, stores, hotels, etc., entirely by gravity.

Without taking advantage of these features the body would be mounted considerably lower. This arrangement on trucks of other types is necessary for stability, making necessary a power hoist of some kind and materially increasing the weight, and reducing the net carrying capacity of the truck and at the same time adding other mechanism to be maintained.

The body on this electric coal truck, as shown in Fig. 1, weighs about one ton less than the type of body and hoist as ordinarily used. This difference in weight is available for carrying capacity, with the result that this truck is designed to handle six long tons as against about five long tons with the ordinary type of body and hoist The low center of gravity makes it permissible to haul more coal per load and entirely eliminates the hoist with its cost and troubles.

Fig. 6. Two-wheel Steamer Tractor with Special Battery-mounting, Half on Each Side of the Front Driving Axle

A number of other instances might be cited as illustrative of the adaptability and serviceability of the electric truck in special applications, and which would probably make more interesting reading if space permitted than a description of the trucks that in hundreds and hundreds of applications, and without special equipment of any kind, are quietly, sanely, and at low cost doing a large amount of the trucking and still only a fraction of the ultimate volume that will be handled in our larger cities by the electric truck when its real merits are fully appreciated.

What the Trolley Car Has to Learn from the Automobile

By H. L. Andrews

Railway and Traction Engineering Department, General Electric Company

Many of the people now using automobiles for daily transportation were formerly trolley patrons. The reasons for their choice of transportation and the price they pay for it are made the subjects of careful analysis in the following article. The conclusions from this experience with public preference are that the street railway companies can recover a large percentage of the lost patronage by installing safety cars on existing rail routes and trackless trolleys on streets traveled by competing gasoline buses.—Editor.

The automotive industry has attained a remarkable growth in a comparatively short time. It now occupies second place in this country's industries, being surpassed only by the steel industry. In 1912, there were approximately 1,000,000 automobiles registered in the United States. In 1913, there were approximately 240,000 more which represented an increase of 25 per cent. This production of new cars has more than held constant since that time, reaching a maximum of 50 per cent in 1916 which corresponds to an increase in new cars of approximately 1,120,000. At the end of 1921 there were approximately 10,500,000 automobiles registered, 8,800,000 of which were passenger cars, or one passenger car to every 12 persons. In addition to this enormous number of passenger cars, there are more than 1,000,000 gasoline buses and trucks.

As a consequence, there are many communities now served by the automobile as well as the trolley car. In them the private car and the public bus are not only active competitors of the trolley car but are selling transportation to the public at a higher fare. The automobile in many instances is even threatening the existence of trolley lines.

Apparently, therefore, there is something wrong with the usual trolley equipment or the manner in which the system has ordinarily been conducted. Community interest naturally requires that this condition be remedied. Accordingly, an analysis will be made first of the cost of providing transportation and second of the class of transportation provided by both the automobile and the trolley car to determine just what are the features which give popularity to the service offered by the automobile and to find means of bringing the trolley service up to the same or a higher standard.

There are but few car owners who know the actual cost of operating their pleasure cars, and there are few business men who have analyzed the relative cost of transportation by automobile and by trolley car. Consequently, emphasis must be laid on the fact that in estimating the cost of operating the automobile the figures should be worked out with the same thoroughness as is used by the railway operator in estimating the cost of operating a street car.

For the purpose of such an investigation there have been selected 15 standard makes of pleasure cars, varying in weight from 1560 to 4750 lb. and in price from slightly under $400 to over $7,000. The gasoline and oil consumptions assumed are based on the experience of operators of each of these types of cars. With gasoline at 30 cents per gallon and oil at 65 cents per gallon, it is a simple matter to calculate the cost of gasoline and oil per automobile-mile.

The tire cost has been computed on the basis of the present retail price, to which has been added 25 per cent to cover the cost of repairs. The life of the tires has been taken at the guaranteed mileage, which probably represents average conditions.

To obtain any definite information on maintenance, painting, and miscellaneous expenses of a pleasure car is very difficult as each car owner has a materially different estimate of the amount spent annually on his car for these items. In the calculations, these charges have been set at $75 for the lighter and lower price cars and at $100 for the heavier and larger cars.

Based on these assumptions, and an annual mileage of 5000, the operating costs per mile and per year are shown in Fig. 2. These costs vary from a minimum of 5.5 cents per car-mile for the lighter cars to a maximum of 10.5 cents per car-mile for the heavier cars. In other words, the combined cost of gasoline, oil, tires, and maintenance varies from $275 per year for the smaller cars to $525 per year for the larger cars.

In addition to this operating charge, there are certain fixed charges which must be made against the passenger car in order to obtain the true cost of operation. These fixed charges are as follows: (a) Interest on the investment, which should be taken as 7 per cent, the amount of which will of course vary with the price of the car. (b) Depreciation, which is of questionable value, but probably the average is represented by dividing two-thirds of the first cost of the car over a life of five years. This too will vary with the selling price. (c) Garage rent, as this is chargeable against the cost of operation even though the garage is the property of the car owner. This has been assumed at $50 per year for cars of all types. (d) Taxes and insurance have been taken at the present price and include protection against fire, theft, and liability, and vary with the type of car.

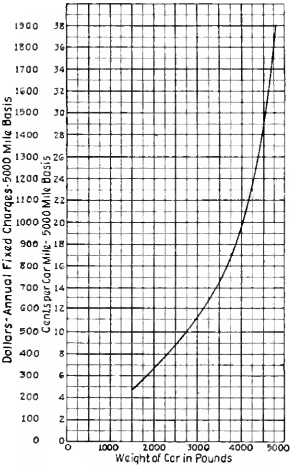

Fig. 1. Annual Fixed Charges of Automobile Passenger Cars

Considering these items and assuming 5,000 miles per year or 25,000 miles in five years the curve in Fig. 1 shows that the fixed charges per mile become a minimum of 4.3 cents for the lower price cars and a maximum of 38 cents for the higher price cars, or vary from a minimum of $215 annually for the lighter cars to a maximum of $1,900 for the heavier cars.

By combining the curve in Fig. 2, showing the operating costs, and that in Fig. 1, showing the fixed charges, the total cost is obtained and is represented by the curve in Fig. 3. This cost varies according to the weight from a minimum of 9¾ cents per mile for the cheap and light automobile to a maximum of 48.5 cents per mile for the more expensive and heavier car, or on a 5,000-mile annual basis, the total cost to the owner of a private car varies from $487 annually for the light car to $2,420 for the heavy car.

Probably few automobile salesmen would agree that the actual cost to the car owner is as great as these curves show, but nevertheless when all factors are considered it is believed that the values represent the true cost. A great many car owners in estimating the cost of operation do not consider the fixed charges. Only recently a prominent automobile magazine referred to a long-distance run of a well-known car as being made at a cost of 4.6 cents per mile. An analysis of this charge showed that it included only gasoline, oil, tires, and miscellaneous expenses. In other words, the cost was the actual operating cost and did not include any fixed charges.

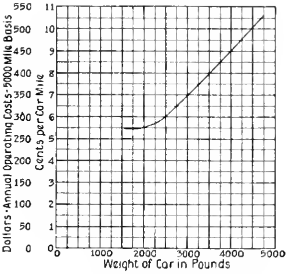

Fig. 2. Operating Costs of Automobile Passenger Cars

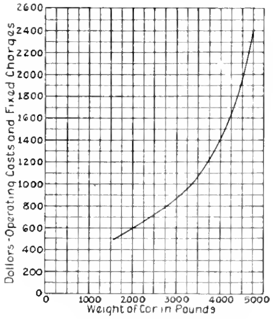

Fig. 3. Annual Operating Costs and Fixed Charges of Automobile Passenger Cars

From the curve of total cost, Fig. 3, further assumptions can be made and the cost of transportation by automobile compared to that by trolley car. Assume that an individual owns a car purchased primarily for pleasure and that this car is of average price and weight, having operating costs of 5.8 cents per mile, fixed charges of 8.45 cents per mile, or a total of 14.25 cents per mile. These operating costs correspond to a car weighing approximately 2,400 lb.

The fixed charges on this machine are $423 per year, and will not vary whether the car is operated 1,000 miles or 10,000 miles annually. Assuming 5,000 miles annual operation, the operating cost at 5.8 cents per mile for gasoline, oil, tires, etc., is $290, to which must be added the fixed charges of $423, making a total annual operating cost of $713. In making the assumption of 5,000 miles annually, it is proposed to divide them into 3500 miles for pleasure and 1500 miles for traveling between the owner's home and his place of business, which latter is equivalent to an average round trip of 5 miles for 300 working days per year.

Assuming the owner operated his car for pleasure only and used a trolley car to and from work, operating the automobile only 3500 miles per year, the cost to the owner for actual operating expenses would be 3500 miles at 5.8 cents per mile, or a total annual charge of $203 for actual operating costs, to which must be added the fixed charges of $423, making a total annual charge of $626, which represents a reduction of $87 per year over the cost of using the automobile exclusively. From this saving of $87 there must be deducted the cost of transportation by trolley. Estimating the average fare at 7 cents, or 14 cents per day, for 300 days, makes a total annual charge of $42, leaving a net saving of $45 annually over the automobile transportation, or 6 per cent of the total operating cost of the private car.

To look at it another way, the cost of operating an automobile 1500 miles per year, corresponding to a round trip of 5 miles per day for 300 days, exclusive of fixed charges, is 29 cents per day or $87 annually. The corresponding cost for the transportation offered by the trolley car is 14 cents per day or $42 annually. In other words, the cost of transportation by the privately owned automobile is more than double that of the trolley car.

This is a minimum saving. In many of our larger cities, the average distance from a car owner's home to his place of business would be more than 2½ miles. Under such conditions assume that he travels 10 miles daily. The cost of this transportation by a private automobile would be 58 cents per day, or $174 annually; while the cost by trolley car would be 14 cents per day, or $42 annually; or the use of the trolley car would effect an annual saving of $132; or to put it another way, the car owner is paying more than four times as much for transportation by automobile than he would by trolley car.

Even with this enormous difference in the transportation cost, there are millions of car owners daily using automobiles to obtain transportation, the equivalent of which is offered by the trolley car at a much lower cost. It is evident that the competiton offered by the privately owned automobile is not a matter of economy, as the trolley car is capable of giving the same transportation at a saving of 50 to 90 per cent cost.

It can therefore be concluded that the competition offered by the automobile is simply a matter of service, the car owner being perfectly willing to pay considerably more for the quick, clean, and comfortable transportation which the trolley car does not offer him, even though it does offer transportation at a lower cost. The traveling public does not appear to object to paying a higher fare, or a higher cost, for a superior method of transportation.

The matter of saving time is a large element. The private machine is able to avoid making numerous stops. It can maneuver in traffic, can select its route, and consequently can operate at a higher schedule speed. If the trolley car is to compete successfully with the private automobile, those responsible for trolley car operation must study the service rendered by the automobile and must profit by the lessons gained from such a study and from daily experience and contact with this type of vehicle.

The rapid advancement of the automobile bus in the last few years is largely traceable to insufficient progression on the part of those responsible for the trolley car and for its method of operation. The gasoline bus, like the smaller privately owned pleasure car, is offering the public something in transportation which the trolley car does not furnish. The bus possesses advantages over the trolley car which attract the public to it; more comfortable riding is provided, it picks up and discharges its load at the curb, but the principal factor is that the bus has the ability to maneuver in traffic, thereby preventing a great many delays to which the trolley car is subjected, and consequently is able to provide a much higher schedule speed.

For this reason, the operators of the gasoline bus are able to secure a higher rate of fare than the trolley car because they are providing something which the public desires and is willing to pay extra for. They are providing a higher schedule speed and effecting a saving of the traveler's time; and for this saving, however slight it may be, and possibly for the privilege of being more comfortable and of being assured of a seat and better ventilation, the public is willing to pay a considerably higher fare.

The statement has often been made by trolley car operators and others interested, that the gasoline bus cannot compete service for service with the trolley car. Operators who have had large experience with the gasoline bus and the trolley car state that buses are excellent vehicles for feeders, lines of light traffic, and for connecting up rail routes, but that they are totally inadequate for handling peak loads. It is altogether likely that these opinions are correct. However, the buses are successfully competing with many of the trolley lines for the reason that the trolley car is not providing the best service it can offer. Where the trolley cars are in poor condition, and the headways are long, and delays are encountered, the automobile bus is making rapid headway.

With all this competition from the private passenger car and the automobile bus, the trolley company—no matter how badly pressed by pleasure cars or automobile buses—should be able successfully to meet any competition from these sources. The remedy lies:

(1) In improving the service given by the trolley car, and when this has been done, in going to the public with the story and demonstrating to them that a faster, more comfortable, and higher class service has been provided. After such a clean, quick, and reliable service has been established, there is no question but that the public will show their appreciation by an increase in riding.

(2) In meeting the gasoline bus on its own stamping ground. If the bus is allowed to operate over the paved streets of the city and compete with established rail routes, those responsible for the trolley car operation should compete with the bus by the establishment of trackless trolley routes.

Concerning the first section of the suggested remedy, the operator of the trolley car cannot afford to overlook the safety car and the immense possibilities offered by it for improving service. There are in operation in the United States several thousand of these cars, and they have made an excellent record. The cars in operation today have increased the net receipts of more than 200 railway companies approximately $12,000,000 annually. Wherever they have been operated they have improved public relations to a marked degree; they have given thousands of platform men better paid and more interesting work; and they have materially reduced all accidents. Against this splendid record there are no offsetting disadvantages. Some operators have criticized the construction of the car, the seating arrangement, the door arrangement, etc., but there has not been a single definite criticism which can be pointed out as unfavorable to the general plan of the safety car. The method of operating these cars is very simple. They are smaller, lighter, are operated by one man, and consequently make a material saving in operating costs. Roughly, the operating cost of two safety cars is little more than that of one large double-truck car. By using two cars instead of one, the headway is cut in two, the cars are able to make a higher schedule speed, and the result has been the attraction of the car rider and a growth in revenue nearly in direct proportion to the amount of increased service given. On a great many lines where the safety car has been operated, providing a greatly improved service, owners of private automobiles have abandoned the use of their cars to and from their places of business and make use of the transportation offered by the safety car. A great deal has been published concerning the operation of this improved type of trolley car and also of the results obtained by their use. With all of this information and with the proof that these cars handle all kinds of traffic, that they reduce operating costs, that they increase gross receipts, and that they improve public relations, and are successfully competing with the private automobile and the jitney bus, there are operators who still are of the opinion that their local conditions are such that they cannot use the safety car.

It is a practical certainty that such local conditions exist only in the operator's mind, because observations of a large number of safety car installations convincingly demonstrate that there is no city in the United States which cannot use a large number of cars of this type. Furthermore, it can be said with confidence that the safety car will do all and more than is claimed for it toward improving public relations and will give the trolley car operator a most useful tool with which to meet the competition of the privately owned passenger car and the automobile bus.

This car enables the trolley company to offer the best possible service, it provides an increase in frequency of service, improves schedules, and makes attractive to the public the one product which the trolley car has to offer; viz., good transportation at low cost.

As to the suggested plan for competing with the automobile bus, the use of the trackless trolley unquestionably gives any trolley company a positive means for the purpose. The automobile bus operates on the paved streets on rubber tires. Put the trolley car on the same basis, adopt automobile construction, and operate it over the same streets as the gasoline propelled bus. The trackless trolley will operate at a cost two-thirds that of the gasoline bus; it will provide the same service—better in many respects; it can maneuver and dodge traffic; it can run at a higher schedule speed at a greater convenience to patrons; and it can discharge and pick up passengers at the curb. In other words, the trackless trolley can do everything a gasoline bus can do, and more, it offers a cleaner, quieter, quicker, and more attractive service at a lower cost.

The gasoline bus is out to fight for the patronage of both the urban and interurban trolley car and is doing this with no small measure of success. The automotive industry has discovered that the public utility field is well worth invading and the trolley car is faced with very keen competition.

The automobile bus can be defeated, however, if the operator of the trolley line will adopt the trackless trolley on new routes and the safety car on existing rail routes.

Consider the operating costs of the gasoline bus and the trackless trolley. The bus with one operator has a minimum operating cost of 31 cents per mile. The trackless trolley with one operator has a maximum operating cost of 20 cents per mile, or a saving of 11 cents per mile, equivalent to a saving of $3,000 to $3,500 annually. To offset this reduction in operating costs there are certain interest and fixed charges which must be made against the trackless trolley. The cost of the overhead construction is approximately $5,500 per mile of double set of wires. Fixed charges covering interest, taxes and depreciation on this investment in overhead line will not exceed 15 per cent, and the total cost of operation including these fixed charges will be materially lower than that of the gasoline bus—except where headways are 60 minutes or longer.

For instance, a 4-mile route can be operated with trolley buses on a 15-minute headway at a total cost, including fixed charges, of $33,500 per year. To give the same service with gasoline buses would cost $46,000 per year. With 10-minute headway the saving, by use of trolley buses, would be $19,000, and on shorter headways still greater.

The trolley car has much the better of the argument in both cases of competition. In the case of the privately owned automobile, the trolley car at a lower figure can produce equivalent transportation. In the case of the automobile bus, the trackless trolley at a lesser cost can produce better transportation. The trolley car has therefore a big undisputable point in its favor, that is lower cost of producing transportation. The success of the trolley car in meeting the competition of the private automobile and the bus lies with those responsible for its operation.

The management of a railway property should improve the service by operating cars on short evenly spaced headways, minimizing all traffic delays, improving the schedule speed, keeping the cars clean, well ventilated, and comfortable and otherwise catering to the traveling public the same as the owner of any retail business caters to his trade. After these improvements have been made, the management should go to the people and tell them its service offers the best, quickest, cleanest, most reliable, and cheapest transportation in the world, should tell them of the economy of using the street car rather than the automobile and should show them the difference in cost of operation. The railway company should not put the trolley car on the street and leave the public to take it or leave it.

The trolley car has one product to sell—transportation—and that product should be made good and then advertised. The automobile at present offers a superior method of transportation, charges a higher price and gets it.

The trolley car has a lower cost of transportation, and can offer a better service in many respects than does the automobile. The safety car and the trackless trolley are the tools with which to provide a quieter, quicker, cleaner, and more reliable service, and if they are employed the trolley company will not only be able to meet the competition offered by the automobile but will attract many riders who are now using a more expensive method of transportation.

An Abstract of the Report of the Commission Appointed to Consider the Choice of a System of Electrification for the Netherlands' Railways

By W. D. Bearce

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The attention that has been given to railroad electrification in Europe is of special importance to American manufacturers. The independent and exhaustive studies that have been made in many cases give highly valuable data. The decision in the Netherlands' report in favor of high potential direct current should be gratifying to those who were the pioneers of this system in this country.—Editor.

In January, 1920, the Minister of the Department of Buildings and Roads and the Board of Managers of the Netherlands' Railways appointed a commission to report on the relative desirability of the different systems available for the electrification of railroads.

The Commission consisted of the following members: Mr. L. M. Barnet Lyon, Member of the Board of Trustees for Railway Service, Chairman; J. J. W. Loenen Martinet, Chief of Electric Traction for the Netherlands' Railways, Secretary; H. Doyer, Consulting Electrical Engineer; H. J. Lessen, Chief of the Bureau of Buildings of the Netherlands' Electric Railways; Prof. I. Van Dam and G. J. Swaay, Advisors to the Government in the Inspection of Electric Current Supply.

It was particularly specified that this commission should take into consideration only such questions as concerned the relative importance of the different systems. Furthermore, the commission was to base its decision upon the gradual electrification of the entire railway system, so that the system selected was chosen with regard to the qualifications of the railway system as a whole. This point was considered of special importance because of the relatively small area covered by this country, and the confusion that would be caused by the installation of different systems.

At the time this commission was formed only two countries could be said to have officially selected a uniform system of electrification; these were Switzerland and Germany, both of which had selected single-phase alternating current. In Sweden this system was also tentatively chosen, but later, on account of the certainty of interference with communication lines, a new investigation was started of the direct-current system.

In England, France, Belgium and Italy, commissions were appointed which have made their reports since the Netherlands' commission was first appointed. The following are recommendations made by these several commissions:

England, 1500 volts direct current; France, 1500 volts direct current (with 3000 volts for some lines); Belgium, 1500 volts direct current; Italy, three-phase in North and direct current in South.

During the period from February to September, 1920, the members of the commission visited various countries, inspected the several railway systems and interviewed railway and electrical experts. Visits were made to England, Switzerland, Germany, Sweden and the United States. The question of system was studied, both from the point of view of the general electrification of railways and industries, and from the point of view of electrifying the roads alone. Naturally the first point to be settled was the question of frequency. It is pointed out that in case the railways were electrified with the single-phase system it would be necessary to provide current for this purpose at a frequency of 16⅔ cycles. Studies were made as to the relative desirability of using steam turbines with generators of two frequencies on the same shaft or the employment of frequency changer substations for all of the railway service. It was the opinion of the commission that the double frequency generation scheme was impractical, and that the most satisfactory solution required the transmission of all current at one frequency and over the same transmission lines.

The report then proceeds to make a careful analysis of the factors entering into the choice of system in the following order:

1. Influence of stray currents on communication lines.

2. Electrical arrangement of the locomotives.
    (a) Motor.
    (b) Complete electrical arrangement.
3. Power and substations.
4. Overhead distribution.

INFLUENCE OF STRAY CURRENTS ON COMMUNICATION AND SIGNAL LINES

In view of the well-known difficulties caused by the disturbing influence of railway circuits on neighboring weak current conductors, an exhaustive study was made of this phase of the question. This is of particular importance because of the highly congested situation in the Netherlands, where large numbers of telephone and telegraph circuits are carried along the railroad right-of-way. In some cases as high as 100 conductors per pole are within the influence of the proposed distribution system for electric traction. The "safest and most often used solutions," namely, the relocating of these lines at a distance from the railroads, or the more expensive method of placing them in underground cables, were found to be abnormally expensive. In fact, in the Netherlands, owing to the great congestion in densely populated districts, a relocation of lines, even at a distance of 15 meters, would hardly be considered possible. Furthermore, the traffic on these lines would be so much heavier than on any existing single-phase lines that the disturbance would be even more embarrassing.

It should be noted that the conclusions of the Swedish commission were not sufficient to entirely eliminate the uncertainty with regard to possible disturbances from these sources. In fact, the funds for the electrification of the Gothberg-Stockholm line were loaned to the Government on the condition that "the cost of overcoming the disturbances in communication lines shall first be established beyond doubt as being not excessively high." The matter was thereupon given to a new commission for research

The Netherlands' commission then cites the expedients used on the various single-phase lines concerning which data was available, including the Midi lines in France, the London, Brighton and South Coast in England, proposed electrification in Austria, Federal lines in Switzerland, Federal Railways in Germany and several American lines. The general conclusion reached was that the remedy for inductive interference from single-phase was not only very expensive, but uncertain of accomplishing the desired results.

In this connection studies were also made of the interference of direct-current lines and the possibilities of corrosion from electrolysis. The commission was repeatedly convinced that telephoning along wires near the direct-current trolley wire takes place without any difficulty and cites tests made for the French Commission.

As regards electrolytic corrosion, the experience gained on lines in the Netherlands and the systematically applied precautions ordinarily adopted led the commission to the conclusion that less trouble will be experienced from this cause than is found in many foreign cities. In both England and the United States none of the experts whose opinions were asked foresaw any difficulties on this account.

With regard to the use of a three-phase motor, it was decided that this piece of apparatus would not be suitable for the requirements of the Netherlands' schedules. The traffic requirements, however, could be handled either by the high voltage direct-current or the single-phase motor. It is the opinion of the commission that direct current at 1500 volts is the best proposition for a combined locomotive and motor car traffic such as the Netherlands' Railways handle, because of the excessive weight of the alternating-current equipment as well as its higher cost.

Under the heading of power and substations, it is pointed out that generation of current at a frequency of 16⅔ cycles entails the disadvantages of limitations on the turbine speed. For this frequency it is only possible to operate at 1000 r.p.m. with a limit of from 6000 to 8000 kw. per unit. With a frequency of 50 cycles, turbines can be operated at 3000 r.p.m. with capacities of 15,000 kw. and above. For this reason 50-cycle current could be generated for approximately 15 per cent less cost than the low frequency. With regard to the possibility of using geared turbines, it is stated that this type of unit is not available above 5000 kw.

Concerning the question of overhead distribution as compared with third rail, the commission concluded that the third rail is not desired in the Netherlands and, therefore, this question is not pertinent.

Comments are also made on the great value of synchronous motor-generator sets for maintaining a high power factor and therefore insuring a uniform transmission voltage.

It is also pointed out that since 1500 volts direct current has been selected by so many countries in Europe the possibility of securing equipment, at a competitive price, is much greater than with other systems.

The great desirability of uniting the load demands of the railways, industries and lighting systems was discussed as highly desirable for the purpose of securing a greater diversity of load factor.

THE INTERIM REPORT

The following points are of especial interest as outlined in the "Interim Report":

1. The three-phase has more advantages for mountainous countries, but has the disadvantage of requiring two trolley wires while the three-phase motor is less adaptable to the demands of railroad service.
2. The combination of a National Electric Supply system with distribution of power to the railroads offers more advantages with direct current than with single phase.
3. The question of overcoming the disturbances in communication lines caused by single-phase supply has not been answered satisfactorily; therefore, it cannot be decided in advance what protective measures (assuming a minimum cost) will be sufficient to insure the operation in a manner satisfactory to all reasonable requirements.
4. It was the unanimous opinion of the commission that the direct-current motor was more simple and reliable than the single-phase type, especially at moderate direct-current voltages. This opinion was strengthened by inspection of foreign roads, although the single-phase motor has been much improved in recent years.
5. The commission, therefore, is of the opinion that for the Netherlands the direct-current system must be recommended. The potential to be selected lies between 1500 and 3000 volts. So far as can be seen at present a potential of 3000 volts will not be necessary, in view of the short distances between feeding points and the weight of trains to be handled.
6. The commission, therefore, comes to the conclusion that the electrification of the Netherlands' Railways must take place by use of the direct-current system with a 1500-volt trolley potential.

FINAL REPORT

The general comparisons cited in the conclusions between the two available systems are as follows:

1. The influence on the weak current lines is of special importance in view of the limited space on the railroad, the large number of wires and the difficulty of finding another place for them in a thickly populated district.
2. The comparatively small distances between the junctions would not give the possible high tension single phase the proper advantage.
3. In connection with these short distances and the density of traffic at time of electrification, the difference in cost of construction and operation will not be very great.
4. According to the judgment of the commission the direct-current motor is better adapted to traffic than the single-phase motor.
5. The development of the automatic substations and the use of mercury rectifiers offers more probability for improvement to the entire direct-current system than to the single-phase system.
6. With the direct current a greater possibility exists in general that a considerable part of what is necessary can be manufactured in the Netherlands.

What has been quoted above in points 4, 5 and 6 may be regarded as sufficient reason for the decision reached.

The following summarizes the conclusions reached:

1. While it is uncertain whether or not a National Electric Supply system will be established, the commission believes that in any case the generating of current will have to take place at a frequency of 50 cycles.
2. If a National Electric Supply system is not established, the Holland Railways must be electrified with direct current having an operating potential of 1500 volts.

The commission is convinced that the choice of 1500 volts direct current is the proper solution for the electrification of the Netherlands' Railways. While future developments may indicate that a higher voltage could have been chosen, since a decision had to be made at the present time it could not be otherwise than 1500 volts.

The Control of Blower Motors

By Henry G. Issertell

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That there is one correct motor to use for each class of service is as true in the case of blowers as it is in railway work and in industrial applications. The author has devoted his article to showing how to select the right motor and the right form of control for paddle wheel, centrifugal and multi-vane types of blowers for the ventilation of buildings.—Editor.

The control of motors for operating blowers and exhaust fans is so clearly related to the selection of the right motor characteristics for this service, that the two must be considered together. This article is devoted to the selection of motors and their controls for driving enclosed fans of the paddle wheel, centrifugal, or multi-vane type for the ventilation of buildings. While the same characteristics apply more or less to other fan applications, such as disk or propeller fans, mine fans and positive pressure blowers, these applications are not here considered.

The basic conditions on which motors and controls are selected are as follows:

1. The characteristics of the current, whether alternating current or direct current.
2. The character of service, which involves the question of whether the fans are to run continuously or intermittently.
3. Whether it is possible to predetermine the horse power requirements with accuracy.
4. Whether the requirements of air delivery involve a change in the quantity of air and the pressure from time to time.
5. The location of the fans and the personnel available for their operation.
6. The circumstances determining the running of the fan—that is, whether the operation of the fan depends on the judgment of the building superintendent for different weather conditions, use of the rooms, etc., or whether the fan is automatically controlled under predetermined conditions of temperature or pressure by means of thermostatic or pressure control independent of any manual direction.

These conditions involve again:

1. Constant-speed motors—manual-control, d-c. circuit.
2. Variable-speed motors—manual-control, d-c. circuit
3. Constant-speed motors—remote-control, d-c. circuit.
4. Variable-speed motors—remote-control, d-c. circuit.
5. Constant-speed motors—manual-control, a-c. circuit.
6. Variable-speed motors—manual-control, a-c. circuit.
7. Constant-speed motors—remote-control, a-c. circuit.
8. Variable-speed motors—remote-control, a-c. circuit.

Remote Control

The remote-control equipment can each be subdivided into:

(A) *Push-button control*, where the service switch is left closed and the motor started and stopped by push buttons from a remote point, under control of the building superintendent or other authorized person. This control may be either for one running speed (constant speed) or for any of several running speeds predetermined by the setting of the controller handle, or dial-switch-arm as it is technically called (predetermined speed control), or any one of several speeds obtained from the push-button station (full automatic control).

(B) *Thermostatic control*, where an electric relay, responsive to temperature variations, acts at a predetermined minimum or maximum temperature to start or stop the fan motor through an automatic controller.

(C) *Pressure control*, where a diaphragm or piston responsive to air pressure (or vacuum) acts through a relay to start or stop a fan motor. This type of control is more frequently used with pump motors than with fan motors, the pump starting and stopping with variations in open tank level or closed tank pressure. Pressure control is used with variable-speed, constant-running fans which are started and stopped manually to change the speed to meet varying air-delivery requirements, as for example, in fans supplying air for forced draft to furnaces.

(D) *Line-switch control*, which is a form of control intermediate between *hand control* and *push-button control.* This may be applied to either a constant or variable-speed motor which need be stopped or started from one point only. The controller functions to accelerate the motor automatically on closing the line switch. It is limited to small motors usually 5 h.p. or less.

General Conditions

The general conditions to be met by control apparatus applying to all types are under-voltage release, under-voltage protection, overload protection, and enclosure of live parts.

Under-voltage Release.—This means that if the voltage fails, thereby shutting down the motor, the sudden restoration of voltage *shall cause no damage.* The motor may automatically start up again, but it must start up through its regular steps to insure keeping down the current inrush, and to prevent jarring the fan. A d-c. motor with remote control of the *line-switch* type is thus protected. An a-c. motor that is normally started by being thrown across the line is obviously also self-protected. If there is no objection to a fan starting up automatically when voltage is restored after failure, under-voltage release alone is sufficient on small motors.

Under-voltage Protection.—This means that if the voltage fails, thereby shutting down the motor, the motor can only be restarted by intentional action of someone operating the controller (if manual control) or pressing the start button (if remote push-button control). In the case of pressure or temperature control, shutting down the motor usually brings about a minimum condition which will cause the relay to act to start up the motor as soon as voltage is restored to the relay terminals.

In the case of controllers for variable speed, a-c., two- or three-phase, slip-ring motors, under-voltage protection is accomplished best by a magnetic main-line switch or contactor which is opened or closed by a push-button station. In such motors the speed control is obtained by resistance in the rotor or secondary circuit which is entirely independent of the primary circuit. It is this primary circuit which must be closed to start the motor, and opened to stop the motor. Therefore, fitting the speed-controlling handle with a spring return and holding coil, as in a d-c. hand starter or controller, would require a multiplicity of extra and insulated contact segments which would produce a very complicated and expensive control handle.

In Fig. 1 is illustrated an a-c. control for slip-ring motors with line contactor giving under-voltage protection. The push-button station outside the case has a start and a stop button. The controller handle must be all the way back to the left before the start button will function. This insures starting with all resistance in. The stop button is fitted with a pivoted clip which may be locked in place over the button if desired When so locked the equipment cannot be started.

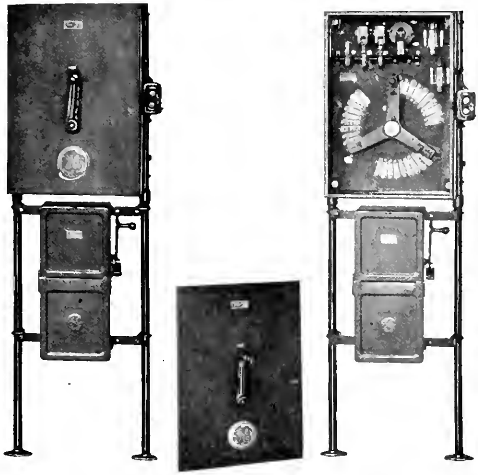

Fig. 1. Enclosed Manually-operated Controller for Alternating-current Slip-ring Type Blower Motor Fitted with Under-voltage and Overload Protection

Overload Protection.—Underwriters' requirements in most sections of the country require insertion of fuses in the motor circuits or a circuit breaker, regardless of whether a separate overload relay is installed on the control panel. Hence the use of *overload release* is generally superfluous where overloads are of infrequent occurrence. In the case of hand-operated starters and speed regulators for d-c. circuits which have an under-voltage release magnet which holds the controller handle in place and lets it fly back to the *off* position in case of voltage failure, the usual *overload release*, which operates to open or short circuit the under-voltage coil and so let the handle fly back to the *off* position, is usually unreliable and of little value.

In the case of controllers fitted with a magnetic main-line switch, which is the case with the larger d-c., manually-controlled panels (above 50 h.p.), or with d-c., remote-controlled, push-button-operated panels, or with a-c. panels having low-voltage release, whether manual or remote control, a type of overload relay is available which is very reliable and can be set to close limits.

Fig. 2. Old Style Open Panel with Controller, Switch and Fuses Mounted Together

There exists considerable difference of opinion as to the relative merits of a fused switch and a circuit breaker. If no other overload protective device is installed, and if overloads are of frequent occurrence, the circuit breaker is better because it eliminates fuse renewals. As pointed out below, if overloads are of infrequent occurrence in fan application, and if a magnetic main line switch or contactor is part of the control, the addition of an overload relay, in connection with a simple fused switch of the enclosed type, is quite as effective and less expensive to install than a circuit breaker of a type that will really meet all requirements. On a-c. blower-motor panels especially, it makes a better combination.

Fan motors if properly selected are very seldom overloaded. If the calculations are incorrect and the duct resistance too high, there may be a permanent condition requiring more power, but the function of the overload relay is for protection against unusual overloads, which in the case of motor-driven fans can come only from seized bearings, grounds in the windings and similar accidents which the fuses can take care of at very little expense because of infrequent occurrences.

There has recently been developed a *thermal relay* which functions in a most reliable and truly logical manner under overloads. The damage to a motor due to overload results chiefly from heating. The thermal relay is subjected to the same effects. Too frequent or too long continued heating causes the relay to operate and open the motor circuit through its magnetic contactor. Sudden overloads do not affect the relay. The more familiar time limit relay delays action on sudden brief overloads (which the motor readily handles), but its action does not follow the effect of the overload on the motor as truly as does the thermal relay.

Enclosure of Live Parts.—A growing appreciation of the right of both the competent electrician and the unsuspecting layman to be protected against accidental contacts with live parts of electrical apparatus, and reduction of fire risk, is bringing about a general adoption of totally enclosed controllers.

The illustrations given show the evolution of the enclosed controller. Fig. 2 shows an open controller. The service switch is also exposed.

Fig. 3 shows a controller mounted with switch and fuses and all mounted in a cabinet.

Fig. 3. Panel with Controller Segments, Switch and Fuses, Flush Mounted and Enclosed in Cabinet

This has been until recently looked upon as an ideal arrangement. However, when the door is open, the controller is alive and even when the switch is pulled, the incoming line terminals are alive.

Fig. 4 shows the ultimate in safety devices. The controller is in a separate cabinet with a locked cover. The service switch is in a separate cabinet so designed that its cover cannot be opened to remove fuses unless the switch is opened by moving the handle forward; and when the fuse cover is open, the only live terminals are at the top where they cannot be reached without unscrewing the cover. When the service switch is open every part of the controller, including the incoming leads, is dead.

Enclosed controllers may be of two types: one in which the cover must be open to operate the controller handle, if it is a manual controller (Fig. 4) or to set the speed if it is a predetermined-speed remote controller, and the other type in which the controller handle is operable from the front of the case by an insulated handle. In the case of remote, predetermined-speed controllers, this externally-operated handle is simply a speed-setting device. The second type, with the insulated external handle, is in a sense the safer of the two, because it is theoretically possible to open the cabinet door of the first type before opening the service switch. For control of fans in buildings, the former type is preferable, because once the cabinet door is closed and locked the motor cannot be started and stopped or the speed changed by an unauthorized person, or a tenant of the building. This is especially important in schools. In industrial establishments, factories, etc., the type with external handle is preferable.

Safety Requirements

The Electrical Safety Conference* has compiled a safety standard for industrial control equipment which architects and engineers would do well to follow in their specifications and manufacturers in their designs. The organizations co-operating in this conference are the *Associated Manufacturers of Electrical Supplies, The Electric Power Club, The National Workman's Compensation Service Bureau*, the *Underwriters' Laboratories* and the *Bureau of Standards*.

Selection of Motors

Next the selection of motors according to the eight main divisions given above will be considered. If direct current is available, d-c. motors will inevitably be used. If alternating current is available, a-c. motors may be used, or a motor generator or rotary converter installed and d-c. motors used. Frequently on a-c. circuits, both types are employed; d-c. motors on the variable-speed blowers and a-c. motors on the constant-speed blowers and on pumps.

Motors, either alternating current or direct current, may be of the open or semi-enclosed type. There is an increasing tendency towards the latter. Open motors are, however, entirely satisfactory in most cases and, located as they are in remote and seldom-reached portions of buildings and well protected from the weather, the fire or personal injury risk is very slight, and the extra cost of semi-enclosed motors, including the cost of the larger frames frequently needed because of the restricted circulation of air through the motors, is seldom justified. Totally enclosed motors would seem never to be justified for such applications, though of course, in the case of disk fans where the motor is directly in the air stream, and hence subject to damage from foreign particles and moisture, enclosed motors are necessary. So are they in some pump applications.

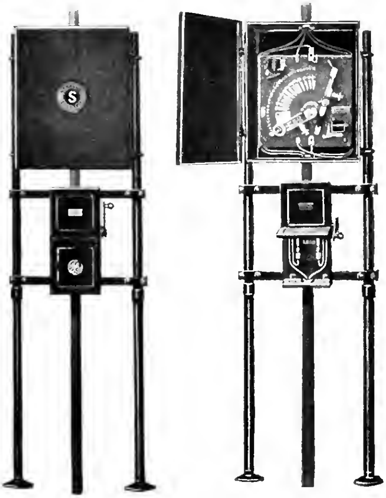

Fig. 4. The Latest Development in Manual Control. Doors open and closed. Enclosed direct-current speed regulator (all field control) with under-voltage and overload protection and with separately mounted safety-first type fused switch

The question as to the selection of 40 and 50 degree motors often arises. There is a good deal of confusion existing in the minds of many engineers on this topic. So far as the ability of the motor windings and other parts

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* Electrical Safety Conference, 25 City Hall Place, New York, N. Y.

to stand a temperature of 50 deg. C. above the temperature of the surrounding atmosphere (usually taken at 25 deg. C. or 77 deg. F.) as compared with 40 deg. C. is concerned, that is for average cases an actual temperature of 75 deg. C. (167 deg. F.) as compared with 65 deg. C. (149 deg. F.), it may be said that 75 deg. C. is well below safe limits for ordinary insulation and therefore a 50 degree motor is just as suitable for fan service as a 40 degree motor and is usually less costly and more efficient. Especially is this true of low speed motors, either direct current or alternating current.

This distinction is really one of overload capacity. Most commercial 40 degree motors will stand a continuous overload of moderate amount in which case they virtually become 50 degree motors. As stated above, fan motors are seldom overloaded unless the calculations are wrong. So far as the sudden or brief overloads are concerned, either type of motor will stand up if the controller protection functions properly. The selection of one type or the other is largely a question of prejudging the proper horse power for the application.

Horse Power Determination

Now it is ordinarily customary to take the brake horse power as given by the fan builders for the size fan and speed required for the given air delivery and duct resistance, this being a list value obtained by repeated trials, and add a safety factor for contingencies. This is usually 25 per cent. This factor in most cases is more than ample, especially as the figures are usually rounded out to the next highest. Thus assume the fan table gives 11 h.p., adding 25 per cent gives 13.75 h.p. and the engineer may call for a 15 h.p. motor. To insist then on a 40 degree motor virtually means a motor good for about 18 h.p. continuously at 50 degrees, or a safety factor of 63 per cent over the theoretical brake horse power—surely this is a wide margin. Such a motor would be likely anyway to run a good part of the time at low speeds and greatly underloaded and hence inefficiently.

Direct-current Motors

Direct-current motors should be of the shunt type. If compound windings are used, they are for stabilizing purposes on a weakened field and the motor has shunt characteristics or fairly constant speed at different loads.

Whether d-c. motors for fans are of the commutating-pole type or not depends rather on the individual design than on the requirements of the application. The larger motors will be practically always of the commutating-pole type whether for constant or variable speed. The smaller motors may be of the non-commutating-pole type even for variable-speed service by field control if properly designed.

Speed Control

In the case of d-c., variable-speed motors, the method of varying the speed demands attention. The question of method involves the size of the motor, the amount of speed control desired, per cent of time operated at low speeds, and the cost of power. The normal speed of a d-c. motor in the language of the designer is the speed for which it is designed to run under full load, without resistance in either armature or field circuit The speed may be reduced below normal by resistance in the armature circuit down to ½ of normal speed, or it may be increased by inserting resistance in the field circuit. The amount of this increase varies, but for fan work the maximum is usually 1½ to 2 times the normal speed.

Fan manufacturers frequently refer to the normal speed as that at which the fan is usually operated. This may be the maximum fan speed or the minimum fan speed, or a point between. It may coincide with *normal* motor speed or it may not. It might cause less confusion, when speaking of fan speeds, to refer to the minimum, average and maximum speeds, and leave *normal* to the motor manufacturer.

When a motor speed is reduced by armature resistance, some power is wasted in the resistance and the motor consumes more power than is actually needed to run the fan and for the unavoidable or fixed motor losses. This fact has very properly led most engineers to specify field control on d-c. motors. But it is quite possible to overdo this.

The power required to drive a fan varies with the cube of the speed. At ½ maximum speed, the power required is only ⅛ minimum. Therefore, the power wasted in driving fans at low speeds on armature control is very little. For these reasons, the use of field control should never be carried beyond the point where the saving by elimination of the power wasted in the resistance is offset by reduced motor efficiency resulting from a larger motor frame size and by increased interest charges due to greater first cost.

There is also involved the first cost of the controller. This is greater for armature control or for combined armature and field control in the larger sizes than for straight field control, but the increase in motor cost for all field control is greater than the increase in controller cost for combined armature and field control.

It is impossible to give rules which cover all cases, but the following are representative of a number of conditions: under 5 h.p. use all armature control unless cost of current is high (over 3½ cents per kw-hr.) and the motor is to operate practically all the time at low speeds; above 5 h.p., use all field control if the total speed range is from a maximum fan speed down to ⅔ of maximum. (This means 50 per cent increase over motor *normal* speed by field.) As the decrease from maximum diminishes, the field-control motor more closely approaches the armature-control motor in cost, and on the other hand, the loss of power in resistance if armature control is used diminishes.

If the conditions of the installation are so unusual as to require a total speed range of 2:1 or from maximum to ½ of maximum, the combination of field control and armature control, using 50 per cent field control (full speed down to ⅔ of full speed), and 25 per cent armature control (⅔ of full speed to ½ of full speed) will be found lower in first cost. This combination is to be preferred in place of the all field control whenever the cost of power is less than 3 cents per kw-hr., and where the equipment will be operated at the lowest speed approximately 25 per cent of the time. An average case would show 25 per cent of the time operated at minimum speed; 75 per cent at ⅔ of maximum or above, that is, on field control with no power wasted. With such a combination, with power costing 3 cents per kw-hr., the combination of armature and field control will be decided by the lower first cost even if the motor is operated every day in the year. If the cost of power is less than 3 cents, or the motor is operated only occasionally or less than 25 per cent of the time on armature control, then the selection is all the more justified.

Alternating-current Supply

Where a-c. supply is available, the question comes up as to whether to use a-c. motors or to put in a motor-generator set and use d-c. motors. If the number of motors is small, or if the individual horse powers are low, or if constant speed is acceptable, there is no question but that a-c. motors should be used.

In the case of larger buildings needing from 10 to 30 fans, taking from 10 to 50 h.p. and requiring variable speed, the use of a motor-generator set may well be considered. All elements have to be considered in each case; the overall cost, interest on the cost, overall efficiency, and the cost of power. The losses in a motor generator are from 20 to 30 per cent at average working conditions, and an equivalent saving by using d-c. motors with field control over a-c. motors with armature control must be realized to offset this. A rotary converter will usually be preferred to a motor-generator set if it is possible to use alternating current for the lights, and constant-speed machinery. The somewhat decreased flexibility of voltage adjustment is offset by higher efficiency (losses 10 to 15 per cent instead of 20 to 30 per cent), as compared with a motor-generator set.

The question of elevators enters into this problem as the d-c. supply may be desired for elevator operation in addition to variable speed blowers. A-c. motors, whether polyphase or single-phase, are at a decided disadvantage compared with d-c. motors when it comes to direct connecting them to low-speed blowers and exhausters. Such low-speed motors have a very poor power-factor, that is, a large *wattless* or non-power current, which means installation of larger transformers and cables and causes a serious disturbance to power companies' lines. There is a tendency for power companies to penalize low power-factor installations and this will tend to decrease rather than increase the cost of such motors.

If low-speed motors are not used, speed reduction between motor shaft and fan shaft is obtained by belt, silent chain or gears. The belt drive is, of course, the cheapest but the least satisfactory. Chain drive is perhaps the best. Gear reductions using silent enclosed worm gears have found favor in some cases.

Alternating-current Motors

Alternating-current motors are normally rather noisy compared to d-c. motors, and special design must be resorted to if this noise is to be eliminated entirely. This noise, which is due to the alternating magnetic hum, is rendered unnoticeable in most cases by properly insulating the motor base and coupling against transmission of sound vibrations.

The so-called multi-speed, a-c. motor is frequently pointed to as a means of obtaining efficient operation without waste of power on a-c. circuits. The objection to such motors is the lack of flexibility.

Taking the case of a 60-cycle, belted or chain-driven motor, two speeds, 1200 and 600 r.p.m., can be obtained without very great increase in motor cost over a constant-speed motor. But these speeds are too far apart for blower work. 1200 and 900, or 900 and 720, or 720 and 600, can be obtained only by two independent windings, one of which is inactive while the other is working, thus increasing the motor frame to a great extent. Three speeds, 1200, 900 and 600, can be obtained with a motor rather larger than a slip-ring motor for the same job, and with a more complicated control. With slip-ring motors, or d-c. motors, just the right speeds can be had.

Fig. 5. Direct-current Remote-control Self-starting Speed Regulator for Blowers, Combined Armature and Field Control. Automatic self-starting type for remote operation by push buttons. Controller arm can be set for any desired predetermined speed

Alternating-current Commutator Motors

A type of motor which is rapidly coming into use is the commutator type, a-c., brush-shifting motor. In this motor the speed is varied by shifting the brushes. When the speed is reduced, there is no waste of current in resistances. This type of motor is therefore more efficient at low speeds than slip-ring motors, and is nearly as efficient as d-c. motors with field control. Any number of speeds can be obtained and the flexibility is therefore as great as a d-c. or a-c. slip-ring motor and much greater than the a-c. multi-speed motor.

In the smaller sizes, the speed is varied by manual operation, and this means by going to the motor to change the speed. For such applications, however, it is possible, unless extremes of speed change are needed, to leave the brushes set on a predetermined speed and start and stop the motor from a remote point just as with any of the remote-control devices described above.

With the larger motors, either hand control or automatic control is possible. With automatic control a small pilot motor is mounted on the motor and geared to the brush rigging. This pilot motor is controlled from a remote push-button station from which any speed can be obtained.

The brush-shifting motor is made in single-phase types up to 7½ h.p. and in polyphase types from 5 h.p. and larger. The single-phase, brush-shifting motors, 3 h.p. and smaller, are no more expensive than polyphase, slip-ring motors and are more efficient. The larger motors cost more than slip-ring motors of corresponding horse power, but in many applications the increased carrying charges on the first cost will be more than offset by decreased cost of power, if the motor is operated any large part of the time at low speeds. Commutator motors are as a rule more noisy than induction motors and this point must be considered in many building applications.

Remote Control for Variable-speed Motors

Remote control for variable-speed fan motors has many advantages over manual control and may in time come to be generally applied as the standard method, with manual control confined only to a few of the smaller and simpler installations.

Fig. 6. Push-button Station for Starting and Stopping. The motors are equipped with remote control. A latch can be carried over the stop button and this latch held in place with a padlock. When this lock is in place the *feed circuit* is open and the equipment cannot be operated from this or any other station

A typical remote-control installation, whether for d-c. motors or a-c. slip-ring motors, will consist of an automatic, self-starting controller containing a handle or switch arm which can be set to any desired operating speed, the whole self-contained in a cabinet with cover which may be locked to prevent unauthorized persons from altering the speed. Safety requirements will dictate the use of a separate, enclosed service switch and fuses. Fig. 5 shows such an equipment. A push-button station located at a suitable point gives control of starting and stopping. This may be in the building superintendent's office. In addition to this push-button station, additional stations can be used at other parts of the building if advisable. These additional stations may be both starting and stopping stations, or for stopping only. The push-button station may be fitted with a lock to prevent operation by anyone except those in possession of the key. See Fig. 6.

At a very slight additional cost, the remote control can be provided to give two different speeds from the push-button station: (1) a low speed, the minimum; (2) a maximum speed which is the speed for which the dial-switch handle is set. This arrangement enables the superintendent to slow down the fan to a point where the air delivery will be at a minimum, but without entirely stopping the fan, and then speed it up again later as requirements may dictate. Then for a change in the regular high speed, a man is sent to the controller to change the setting of the predetermined speed arm. This may be required only occasionally with changes of weather conditions, etc.

At a somewhat greater cost, the control may be arranged to give several different speeds, 4 to 7, let us say, from the push-button stations and with an indicator to show the speed obtained. At a still greater cost, the control can be of the full-automatic type, in which the speed-controlling arm is operated by a pilot motor or magnets under control of the push buttons so that any speed or any change of speed within the motor range can be obtained. The chief value of full-automatic control is realized when the control is made responsive to changing conditions, that is, to temperature, pressure, etc. A special type of automatic control is shown in Fig. 7 for a forced-draft fan in which the speed is controlled from the steam pressure in the system.

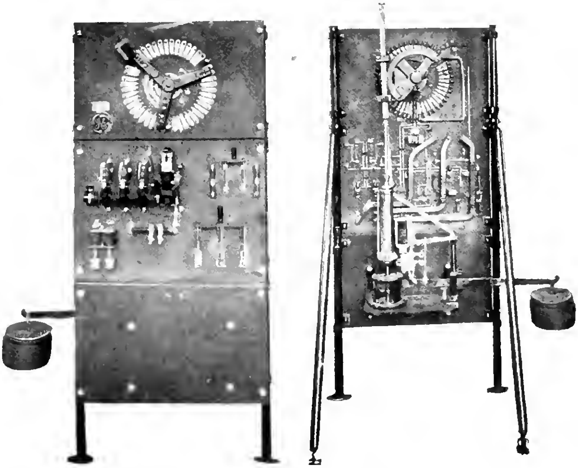


Fig. 7. Automatic Speed Controller for A-c. Slip-ring Motor for Forced Draft Fans Controlled by Vacuum Regulator. Through this regulator the speed is automatically adjusted to the requirements of the boiler as controlled by the steam pressure

Electric Auxiliaries on Motor Ship *Harper*

By C. H. Giroux

Marine Engineering Department, General Electric Company

In recent months we have published several articles on Electricity in the Merchant Marine. The present contribution is of special interest as giving specific data for a special vessel where the requirements are unusually severe. If the electrical auxiliaries plan out well for an oil cargo boat they can certainly meet any requirements of vessels of less specialized type.—Editor.

The fact that ship owners are beginning to realize the benefits to be obtained by the use of electricity for all auxiliary power purposes on merchant ships is again illustrated by the tanker *H. T. Harper*, recently completed by the Moore Shipbuilding Company for the Standard Oil Company of California.

The electrical equipment of this ship is a splendid example of how great economy of operation and highly reliable performance can be obtained by the use of the diversified electric products built to meet marine requirements.

The *Harper*, which is used to carry oil between Pacific Coast ports, was designed so as to take full advantage of the characteristics of the electrical apparatus and to reduce to a minimum the fire risk which is always a matter of great importance in the transportation of petroleum products in bulk.

The short voyages, incident to the trade in which the ship operates, means that cargo is loaded and unloaded very frequently. The low fuel consumption effected by the use of Diesel engine driven generators and electric auxiliaries while in port is therefore of even greater importance than on vessels running to foreign ports.

Propulsion Equipment

This vessel which has a deadweight capacity of 4697 tons is propelled at a speed of approximately 12 knots by two Workspoor Diesel engines of 850 b.h.p. each, built by the Pacific Diesel Engine Company. These engines are direct coupled to the propellers and run at a speed of 135 r.p.m.

Auxiliary Generating Plant

Two 150 and one 100-kw. direct-current, 240-volt, 250-r.p.m. generators are provided. These are driven by Diesel engines manufactured by the Dow Pump and Diesel Engine Company.

In addition to the main plant, a 10-kw. oil engine driven emergency set is installed above the water line.

A balancer set is used to obtain 120 volts for lighting. This balancer is rated at three kilowatts, but is only required to handle the unbalanced load and is therefore of sufficient size to fulfill the needs of the lighting system of the ship.

Fig. 1. The Motor Ship *H. T. Harper* Under Power

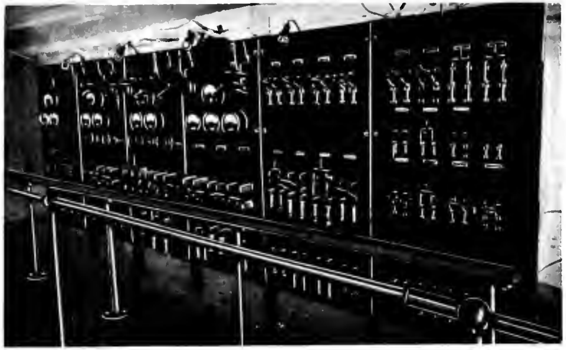


Fig. 2. Main Switchboard for the Control of the Auxiliary Generators and the Distribution of Power

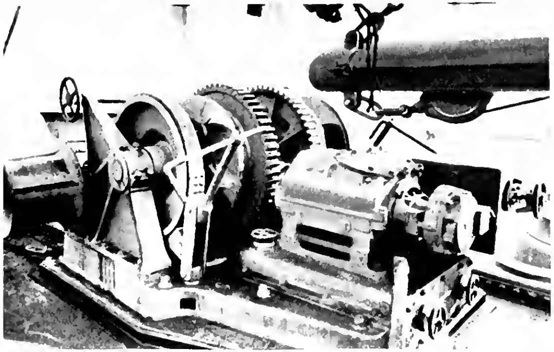


Fig. 3. Electric Anchor Windlass Driven by 25-h.p. Direct-current Marine Motor

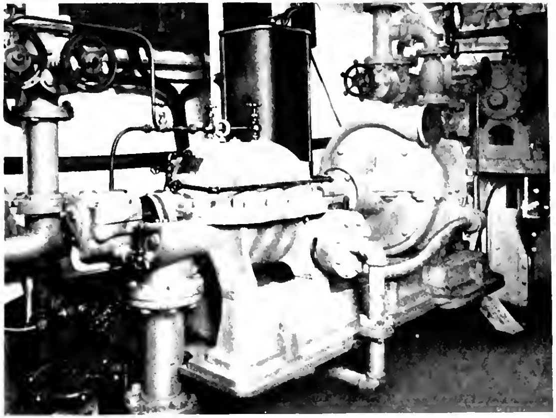


Fig. 4. Electric Centrifugal Fire Pump Driven by 40-h.p., Direct-current Marine Motor

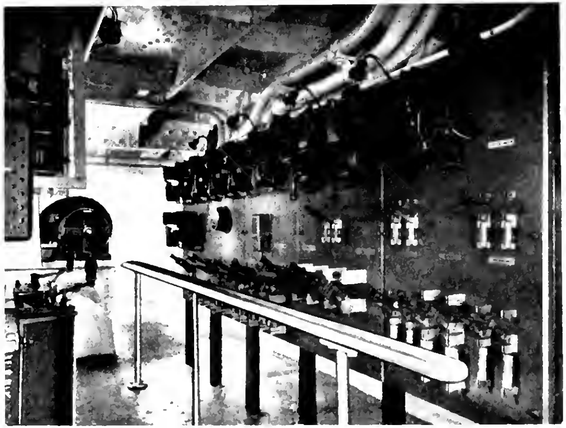


Fig 5. Pump Control Room Showing Auxiliary Distribution and Control Board for Cargo Oil Pumps. Pump motor controllers, resistance grids, and ventilating motor at the left

Engine Room Auxiliaries

The auxiliaries listed in Table I and installed in the engine room are driven and controlled by electrical apparatus manufactured by the General Electric Company.

Cargo Oil Pumps

A great deal of discussion has taken place regarding the danger of explosions if direct-current motors were used for driving cargo oil pumps. All likelihood of such an occurrence seems to have been eliminated by the system employed on this ship.

All motors in the pump room are enclosed, with air openings at each end for ventilation. These openings are connected to a ventilating system and fresh air from above deck is forced through the motors by means of a small electrically driven fan located in the pump control room. As the interior of each motor is under positive air pressure there is no possibility of oil fumes entering and igniting.

Great care was taken in the construction of these machines so that all dead air spaces, where gas could collect when the motors were idle, were eliminated.

For furthur protection, interlocking is employed in order that the pump motors cannot be started until the blower has been in operation for a sufficient length of time to insure that the system is filled with fresh air.

TABLE I: ENGINE ROOM AUXILIARIES

No.	Auxiliary	Type	Manufacturer	Motor
1	Fire Pump	Centrifugal	Alberger Pump and Condenser Co	40-h.p., 1700-r.p.m., 230-volt
1	Cooling Water Circulating Pump	Centrifugal	Alberger Pump and Condenser Co	20-h.p., 1700-r.p.m., 230-volt
1	Sanitary Pump	Centrifugal	Alberger Pump and Condenser Co	15-h.p., 1700-r.p.m., 230-volt
1	Fresh Water Pump	Centrifugal	Worthington Pump and Mach. Corp.	5-h.p., 1700-r.p.m., 230-volt
1	Engine Room Bilge Pump	Horizontal Duplex	Worthington Pump and Mach. Corp.	7½-h.p., 1150-r.p.m., 230-volt
1	Fuel Oil Service Pump	Rotary	Kinney Mfg. Co	2-h.p., 1150-r.p.m., 230-volt
2	Lubricating Oil Pump	Rotary	Kinney Mfg. Co	7½-h.p., 1150-r.p.m., 230-volt
1	Air Compressor		Rix Compressed Air and Drill Co	50-h.p., 1075-r.p.m., 230-volt
1	Booster Air Compressor		Rix Compressed Air and Drill Co	5-h.p., 1700-r.p.m., 230-volt
2	Engine Turning Equipments	Worm Gear		7½-h.p., 1200-r.p.m., 230-volt

TABLE II: PUMPS

No.	Pump	Type	Manufacturer	Motor
3	Cargo Oil	Rotary	Kinney Mfg. Co	90-h.p., 900-r.p.m., 230-volt
1	Forward Bilge	Horizontal Duplex	Worthington Pump and Mach. Corp.	10-h.p., 1150-r.p.m., 230-volt
1	Fuel Oil Transfer	Rotary	Kinney Mfg. Co	20-h.p., 1150-r.p.m., 230-volt
1	Ballast	Rotary	Kinney Mfg. Co	20-h.p., 1150-r.p.m., 230-volt

All control apparatus for the motors in the pump room is installed in a well ventilated room above deck.

The pumps listed in Table II are driven and controlled by General Electric apparatus and installed in the pump room.

Steering Gear

The steering gear is of the electro-hydraulic type built by the Hyde Windlass Company. It is driven by a 12-h.p., 600-r.p.m.,

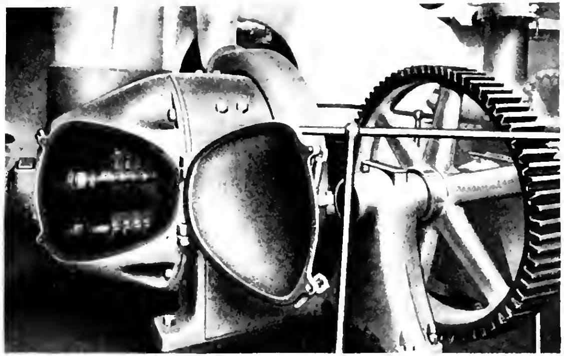


Fig. 6. Electric Cargo Oil Pump Driven by 90-h.p. Force Ventilated Direct-current Marine Motor. Inspection door open

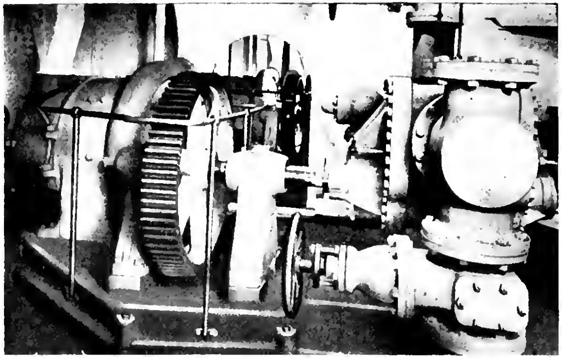


Fig 7. Same as Fig. 6 Showing Pinion End of Motor

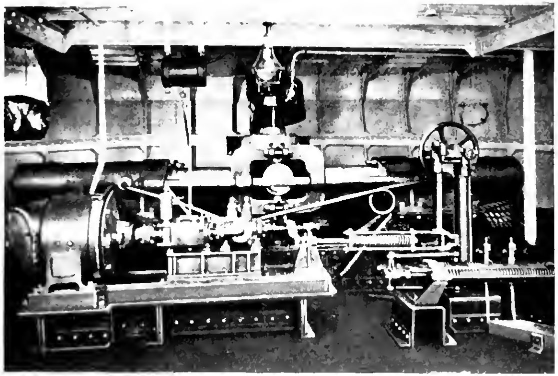


Fig. 8. Electro-hydraulic Steering Gear Driven by 6 h.p. Direct-current Marine Motor

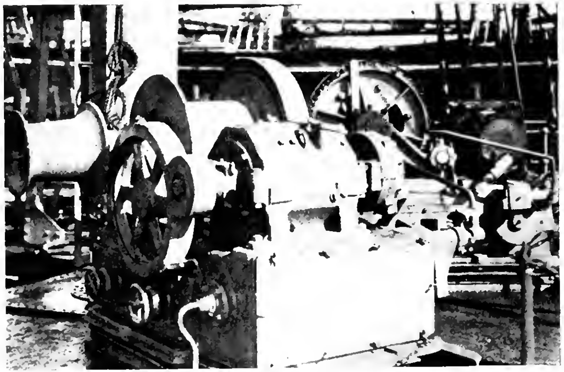


Fig 9 Electric Cargo Winch Driven by 15-h.p Direct-current Marine Motor

TABLE III: DECK AUXILIARIES

No.	Auxiliary	Manufacturer	Electric Equipment
4	Deck Winches	Allan Cunningham Co	15-h.p., 600-r.p.m., 230-volt Motor Disk Brake Dynamic Lowering Control
2	Capstans	Allan Cunningham Co	10-h.p., 700-r.p.m., 230-volt Motor Rheostatic Control
1	Anchor Windlass	Allan Cunningham Co	25-h.p., 550-r.p.m., 230-volt Motor Disk Brake Rheostatic Control

230-volt shunt wound enclosed ventilated motor. A hydraulic telemotor controls the operation of the gear from the bridge.

Deck Machinery

From the photograph of the ship it may be seen that there is very little freeboard when the ship is loaded. As a consequence the deck machinery, especially that located on the well decks, is entirely submerged very frequently when the ship is at sea.

The experience gained on similar vessels has enabled the manufacturers to produce equipment which successfully meets these severe conditions.

The deck auxiliaries are listed in Table III.

S. S. *Bessemer*, 7000-ton Tanker, Equipped with Electrically Driven Cargo Oil Pumps

The Maneuvering of Electrically Driven Merchant Ships

By J. L. Booth

Marine Engineering Department, General Electric Company

The experiences at sea with an electrically driven merchantman will naturally interest marine engineers. The author gives some interesting facts about the maiden voyage of the *Eclipse* which reflect great credit on her equipment. He also recites some experiences of the *Invincible* which prove what electric control can do in an emergency.—Editor.

The first of the contracts for electrically driven machinery for merchant ships, which were placed by the Emergency Fleet Corporation with the General Electric Company, has now been completed for some considerable time, the last vessel having successfully completed her trial trips in November, 1921. This order was placed during the war with the intention that the machinery should be installed in new hulls. On the conclusion of the war, however, the number of equipments was greatly reduced by cancellations, and in 1920, when some of the early war emergency gears had reached the end of their life, it was decided by the Shipping Board to use the electric drive equipments for replacement purposes.

The machinery consists of a 3000-h.p. turbine-generator set having an eight-stage Curtis turbine, direct connected to a 2300-volt alternating-current generator, driving an induction motor. The control apparatus is capable of being operated either electrically or by hand. The contract was for five sets of machinery which have now been completed and installed on a group of sister ships of approximately 15,000 tons displacement, named *Eclipse*, *Invincible*, *Archer*, *Independence* and *Victorious*.

Unfortunately, owing to the severe shipping depression, all of these vessels have not been running in regular service, but sufficient operating data have been obtained to give a good indication of the performance of electric drive machinery under the ordinary conditions of the merchant marine.

There are certain characteristics possessed by electric drive machinery, the value of which have been demonstrated on the vessels in service, and which probably have not been fully appreciated by those who have had no experience of an electrically driven ship.

One of the most important of these characteristics is the ease with which the ship can be maneuvered. This is due not only to the fact that the main motor can be reversed in direction in a very much shorter time than a reverse can be effected by any of the other forms of propulsion machinery, but, also, because there is the same power available when going astern as ahead. With a reciprocating engine, although in a case of emergency

Fig. 1. S. S. *Cuba*, the First Electrically Driven Passenger and Express Freight Steamer

the link motion would be put over into the reverse position without closing down the main stop valve, there is the possibility of stopping on a dead center, and though high pressure steam may be admitted to the top or bottom of the intermediate or low pressure cylinder to turn the engine over, there is the possibility of doing the wrong thing in an emergency, causing some delay in reversing. With a marine geared turbine there is usually a reverse element incorporated in the same casing as the ahead element, steam to the two elements being controlled by two valves which are interlocked in such a way that only one can be open at a time. Although this reversal can be effected very rapidly, and the arrangement is practically fool-proof, it is the usual practice in marine turbine work to give an astern power of about 70 per cent of the ahead, and there is, therefore, not the same power available when going astern. In this respect the electric drive is superior, and, although no case has been reported in which troubles have occurred on a geared turbine ship from this arrangement, the very rapid handling which is possible with electric drive machinery has already proved of great value on several occasions.

Fig. 2. The Maneuvering Platform of an Electrically Driven Vessel. The ship is held under perfect control by the two small levers near the bottom of the panel

On the *Eclipse* and her sister ships the mechanism for maneuvering consists of two levers about 16 in. long mounted at a convenient height on the panel containing the group of control contactors. One of these levers regulates the speed of the turbine generator, the other operates the master controller which governs the contactors for ahead or astern. There are thus three permanent positions for this lever, ahead and astern being at the extremes of its travel, with "Stop" at the mid-position of the lever.

The electrical meters and indicators showing the speed of both the turbine and propeller are mounted on the panel directly in front of the engineer. When reversing from full speed ahead, the speed lever is brought back to about $^1/_3$ speed by the right hand, and the electric or direction lever, which is operated by the left hand, is moved to the astern position before the turbine is again brought up to full speed by the speed lever. The personal factor is eliminated to a great extent, as indicators showing exactly what each part of the machinery is doing are always directly in front of the engineer.

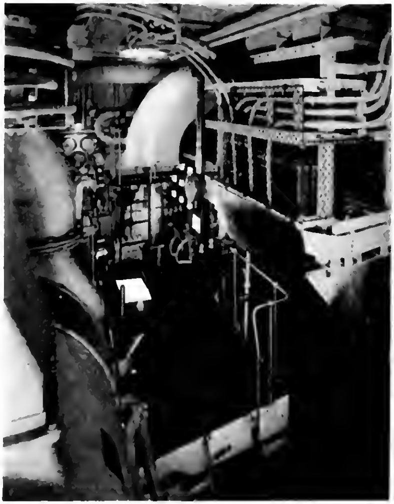


Fig. 3. The Control Platform of One of the U. S. Coast Guard Electrically Driven Cutters. Note the convenient arrangement of all gauges, indicators and maneuvering levers within easy reach of the operating engineer

So quick is the response of the motor to this maneuver, that the usual time taken to go from full speed ahead to full propeller speed astern is from 10 to 15 seconds. The adoption of a substantial design of control levers, very similar to what a marine engineer has been accustomed to, has disassociated his mind from the idea of push button or street car controller methods of control for the ship. This, together with the ease with which these ships can be handled even by engineers who have had only reciprocating or turbine experience previously, is doubtless responsible for the popularity of the electric drive with operating engineers.

A still further development, namely, bridge control, will naturally suggest itself as being capable of being carried out very simply with electric drive machinery. While this is unnecessary on ordinary cargo vessels, there are special vessels, such as ferries operating in very crowded waters, on which it offers great advantages.

The first vessel, the *Eclipse*, ran her trial trip in October, 1920, and immediately on her completion took on a cargo at New York for the Far East. She sailed on November 12 for Singapore via the Suez Canal. When crossing the Atlantic she maintained a good deal better speed than is usual for ships of her class and passed Gibraltar ahead of time. The following extract from a letter written by an engineer, in no way connected with the makers of the equipment, who accompanied the ship as far as Port Said is of interest:

> "The trip was the most interesting in all my sea experience, making 5,122 miles without a single stop, although we have had very heavy weather and a poor grade of fuel, we maintained excellent speed for the entire trip.
>
> "The main turbines and motor gave excellent service, the control gear was very easily and efficiently operated by the new personnel, not the slightest trouble of any kind was experienced during the run.
>
> "The Chief Engineer was very well satisfied with the performance of the entire equipment and especially so with the simplicity of its operation.
>
> "The writer has had many years of seagoing experience in different types of vessels with various equipments, but has never been on any vessel which showed such marked steadiness and entirely devoid of vibration."

The vessel passed through the Suez Canal and Red Sea and proceeded to Singapore, Batavia, Samarang, Surabaya, and Bombay, running for many weeks through tropical seas without incident.

On the return trip when passing through the Suez Canal an incident occurred which showed the value of the better control of the ship which is possible with electric drive. The engineer reported as follows:

> "At about 7 a.m., April 7, while passing through the Suez Canal the ship's rudder refused to answer the telemotor and the ship was to starboard by about 5 degrees to the channel which is about 250 ft. in width at this point. The pilot gave full speed astern and managed to overcome the ship's headway before the bow came within 50 ft. of the bank. The ship was making about 6 knots at this time and the propeller action was so prompt that the pilot signalled slow speed ahead within a minute from the time he gave full speed astern. The pilot remarked that he had been a pilot for 35 years and that the S.S. *Eclipse* with its electric drive was under better control than any other ship with different type drive."

After passing through the Suez Canal into the Mediterranean, the *Eclipse* went through the Black Sea to Constanza, Roumania, and Galetz, for cargo and fuel oil. A very forcible demonstration of the value of her maneuvering qualities occurred when leaving these ports. The following is extracted from the report of her voyage.

> "Another good piece of maneuvering was effected when we left Constanza, Roumania, where the ship was detained for fumigation. The sea walls enclose a very small harbor where there was very little room for maneuvering so that the ship had to be turned astern about with its own power almost within one ship's length. The S.S. *Eclipse* was the largest ship which had called at Roumanian ports up to the time of our arrival and apparently the pilot at Constanza did not know how to handle it as he used 67 minutes trying to swing it on a long anchor; but made no headway up to the time the skipper took over the ship and maneuvered it out to sea. This was on the afternoon of April 13, 1921, at 5:10 p.m. and we were turned about face and out to sea by 5:19 p.m. by making six full power reversals with anchor up.
>
> "The Danube Canal authorities demanded that we use a tug to assist us in maneuvering around the three hairpin turns in the river just below the Kilia mouth. We were able to maneuver quicker than the tug and found it of very little assistance."

After leaving the Mediterranean the ship proceeded to New York and completed a seven months' voyage in foreign waters during which time she had made 26,500 miles without any difficulties or troubles, and as far as the electric machinery was concerned she could have turned around for another voyage without any repairs being necessary.

The second voyage of the *Eclipse* was to Mediterranean ports, and at Bizerta on the north coast of Africa the value of her electric control was shown again.

> "August 17. Arrived pilot station Bizerta 9:44 a.m. Took on 300 tons fuel oil and 100 tons water. Left pilot station, Bizerta, for New York

at 8:13 p.m. On leaving Bizerta ship was almost rammed into breakwater wall but considerable trouble narrowly averted only by the instant response of electric propelling equipment.

"We received two successive instantaneous emergency bells on telegraph from 'slow ahead' to 'full astern' and responded immediately going from slow ahead to full astern in approximately 4 seconds. Steering engine was reported out of order as partly cause of trouble."

The experience of the second electric drive ship, the *Invincible* has also demonstrated to an even greater extent the value of rapidity of control. When proceeding from New York to Philadelphia to take on cargo after her trials, the *Invincible* was in collision with the Army Transport *Madawaska* in a heavy fog.

The following account of the incident is taken from the daily press:

"Electric control of the steamship *Invincible*, rammed off Barnegat, N. J., Tuesday night by the army transport *Madawaska*, is said by Shipping Board officials to be responsible for averting a serious catastrophe, according to word received by the General Electric Company yesterday. The *Invincible* is the second electrically driven merchant ship belonging to the Shipping Board. Due to the flexibility in operation of her electric apparatus, which was furnished by the General Electric Company, she was able to reverse to full speed astern in about four seconds. This fact, according to H. P. Taylor, chief turbine engineer of the Shipping Board, and Commander V. V. Woodward, Manager of the Repair Department, both of whom were aboard the *Invincible*, was responsible for lessening the force of the collision, saving greater damage to both vessels and probably loss of life. Mr. Taylor was on the bridge when the collision happened.

"The *Invincible* was proceeding at half speed when, according to his description, the *Madawaska* loomed up hardly a boat's length ahead. In less than four seconds after the signal for full speed astern was given, the *Invincible* was reversing at top speed.

"There is no question but that the maneuvering qualities of the *Invincible* were greatly enhanced as the result of her electric drive, and it is gratifying to note that the flexibility of her control proved itself so well in an emergency, Mr. Taylor said."

The experience gained so far with these replacement installations has been very satisfactory. The original steam driven deck and engine room auxiliaries, however, have been retained on these ships. Irrespective of whether the propulsion machinery is a geared turbine, or electric drive, the greatest possibilities for an improvement in economy lie in the electrification of the auxiliary machinery, and the maximum advantages from the general application of electricity on merchant ships will only be obtained with the adoption of electrically driven auxiliaries on a geared turbine ship, or when the first "all electric" merchant ship is placed in service.

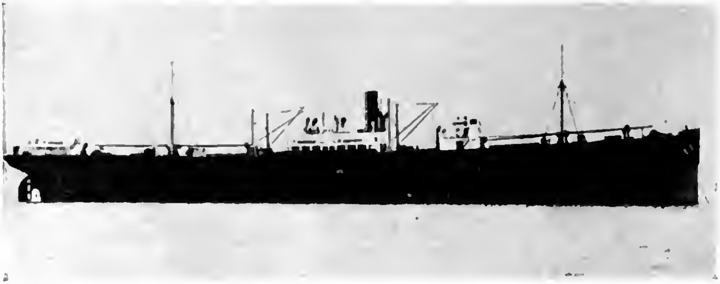


Fig. 4. S. S. *Eclipse*, the First Electrically Driven Sea-going Cargo Vessel of the Merchant Marine

Crystal Growth in Metals

By G. R. Fonda

Research Laboratory, General Electric Company

Crystallization in metals is of such fundamental importance to engineers that we feel our present contribution should prove as useful as it is interesting—crystals are built up from the bricks of the Master Builder. Any one who is ambitious to build anything is foolish not to know all he can about his "bricks." The crystals spoken of in this article, although they are the small entities interlocked to form the coherent mass, are similar in nature and structure to those large crystals which are so beautiful to see and about which most of us know something. The author shows how these crystals vary in size and form according to the strains the metal is subjected to and according to how the metal is "worked."—Editor.

The size of crystals in a metal has long been recognized as of influence in determining its properties and of late years much has been written about its control by variations in the extent of the working and in the temperature of the anneal.

An attempt is made here to cover the more important investigations and to show how their results are in accord with current atomic views. A series of papers of similar nature has just been published by Jeffries and Archer[1] since this present review was completed.

Crystallization

A metal, despite its compact, coherent form, is in reality a mass of crystals of the same structure as the crystals of a salt. When a metal is polished and etched, its surface becomes marked off by boundary lines into patches of irregular shape, frequently so small that they can be seen only under a microscope. These patches are sections of crystals despite the absence of definite geometrical shape. Their irregularity is due to their method of formation.

Whenever a molten metal solidifies on cooling, the first crystals start growing from germs just as in the formation of crystals in a salt solution. The growth of these germs is most rapid along the lines of the crystal axes, so that the crystal as first developed in the molten metal is of the same tree-like shape as the frost crystals which collect on a window pane.

The further progress of crystallization is shown by the diagrams in Fig. 1, taken from Rosenhain.[2] The pioneer work of Laue and the Braggs on crystal structure, as exhibited in X-ray spectroscopy, has demonstrated that the atoms of a crystal occur in regular, geometrical arrangements on lattices which are in the form of a mass of bodies, frequently cubes, regularly packed together like building blocks in a box. Each block in Fig. 1 represents therefore a configuration of atoms. Those which have assembled together in (a) are the germs—crystalline aggregates of a few atoms about which crystallization has started. The blank spaces between represent material still molten. As shown in the successive diagrams each germ grows by the addition of further cubes having the same orientations. Growth is at first most rapid along the main axes of a crystal, but, when these have extended so far as to butt against neighboring crystals, further growth serves to fill in the unoccupied spaces between, as in (c) and (d). Eventually a state is reached as in (e), with the crystals grown to such an extent as to be in close juxtaposition. There are still spaces between, too small to be occupied by the cubes of unit crystalline structure. On complete solidification these spaces become filled up, as Rosenhain has assumed, with whatever metal remains, as a thin, amorphous film. The final "crystalline" structure therefore will be as in (f).

The sequence of these diagrams illustrates the conditions which determine the irregular outlines of crystals in a solid metal. Actually, of course, all three axes of a crystal make different angles with those of its neighbors, so that when they are etched their outline is shown, not only by the development of boundary lines, but also by differences in shading, due to variations in orientation.

The crystal growth of particular concern here is that which can be made to take place in metals after solidification, and yet considerable illumination is thrown upon its mechanism by the process of solidification as pictured above. In both cases the number of germs formed determines the final crystal size. A rapid cooling of the melt throws down many such germs and yields a finely crystalline solid. In an extremely slow cooling on the other hand their number is restricted because atoms on the point of solidifying have time to arrange themselves upon the germs and large coarse crystals result as in the slow cooling of a salt solution. It will become evident later how the number of germs in a solid metal may be varied.

In the case of a metal which melts at such a high temperature that it cannot conveniently be cast, the finely divided powder may be pressed together and heated for a short time near its melting point, as is done in obtaining tungsten filaments for incandescent lamps. The particles of powder coalesce, fitting together into a compact lattice of regular geometrical shape, and form a crystalline structure identical with that of a casting, as is well illustrated in a paper by Jeffries.[3]

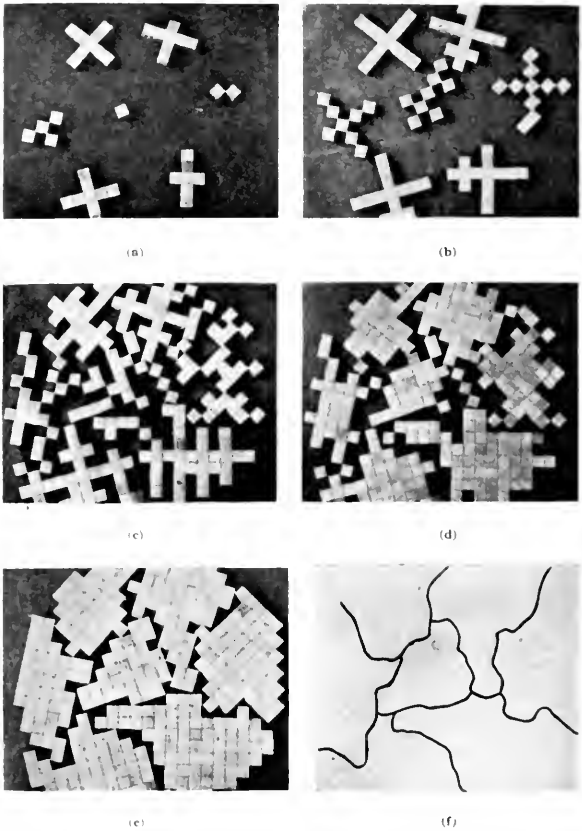

(a) (b) (c) (d) (e) (f)

Fig. 1. Diagram Illustrating Crystallization from a Molten Metal (From Physical Metallurgy, by Rosenhain, p. 62)

Effect of Cold Working on Crystalline Structure

These crystallized structures are known as "equi-axed," from the approximately equal lengths of their crystal axes. If such a metal is mechanically worked, as by hammering, rolling or drawing, further changes in the crystalline structure are brought about which may be made such as to lead either to smaller or to larger crystals on annealing.

The tendency of any one of these working operations is to elongate the crystals. The temperature at which it is done is important—it must be below the "equi-axing temperature" above which crystals remain equiaxed. The more a metal is "cold-worked" in this sense, the greater is the elongation of the crystals until eventually a fibrous structure results. This has been shown for various metals by many metallurgists, such as Sauveur,[4] Chappell,[5] Mathewson and Phillips,[6] Jeffries,[3] Hanson and Archbutt[7] and Carpenter and Elam[8]. Fig. 2 shows a series of photomicrographs of aluminum taken by the last, demonstrating the progressive changes in elongation.

These elongations result from a slipping over each other of the planes of atoms which made up the original crystal. This is a change similar to that produced in a regular pile of blocks by pushing on one side. As the working continues, the changes necessarily become more disorderly—distortions arise even of the same plane of atoms. The lattice becomes more and more strained and deformed, so that further slip becomes increasingly difficult. Hull[9] has pointed out how these effects lead to the hardness associated with cold working, for hardness denotes essentially a resistance to further strain.

The extent to which these distortions go has lately been demonstrated by means of the X-ray spectrometer. If X-rays which have been made monochromatic by filtering are allowed to impinge upon a large crystal, reflections are obtained from each atomic plane which at certain angles reinforce one another. These are of such an extent that, as the crystal is rotated, lines of variable intensity will be exposed upon a photographic film placed so as to receive the reflected rays. At other positions of the crystal, their intensity will be so low that no exposure will result. The distance apart of the lines in the pattern formed is a function of the distance between atomic layers in the crystal.

A similarly exposed film is obtained by using, instead of the one large rotating crystal, a powder made up of tiny crystals which present all possible orientations and yield therefore the same pattern on the film without rotation—a method developed by Hull.[10]

If the large crystal had not been rotated, there would have been no regular pattern formed on the film. Depending upon the angle which its surface chanced to make with the X-rays, there might have been one or two haphazard lines or there might have been nothing whatever.

Distinctions such as these have in fact been found by Bain[11] between coarsely crystalline wire, in which only one crystal received the X-rays, and finely crystalline wire—so fine that it was comparable with a mass of finely crystalline powder.

Use has just recently been made of these effects by Bain and Jeffries[12] in demonstrating the disordered state of the planes of atoms in a large crystal after cold working. An X-ray spectrogram obtained from a large crystal of aluminum gave a blank exposure on the film except for a couple of random dashes. After the sample, however, had been severely worked by rolling, it exhibited virtually the full pattern of lines obtained from the finest powders. This shows very clearly how the original parallel planes of atoms had been distorted into interlocking folds.

Recrystallization

The first effect of heat on a worked metal is to relieve these strains and to allow each distorted element to separate itself from the bonds of the original lattice and to become an independent entity.

When, for instance, the sample of severely worked aluminum shown in Fig. 2f was heated at 200-300 deg. C., the first visible structural change from its fibrous condition was a blurring of the original boundaries of the flattened crystals and the appearance of a granular structure, as exhibited in Fig. 3. This denotes the liberation of numerous minute grains, each an aggregate of atoms in crystalline arrangement. This sample had now lost the hardness developed by cold working and had become virtually as soft as the original metal before working. Brislee[13] in 1917 and Anderson[14] in 1918, working with somewhat less pure aluminum, found also that the annealing of severely worked samples made them dead soft, to within one point of the original material, although the structure still remained granular.

In this condition the aluminum represents then a mass of fine grains, resembling strongly the pressed rods of tungsten powder already referred to. If its heating is now continued at any temperature above 250 deg. C., it behaves likewise just the same as closely packed masses of powder-agglomeration of the grains takes place, and an equiaxed structure results, with crystals that can readily be recognized as such, as shown in

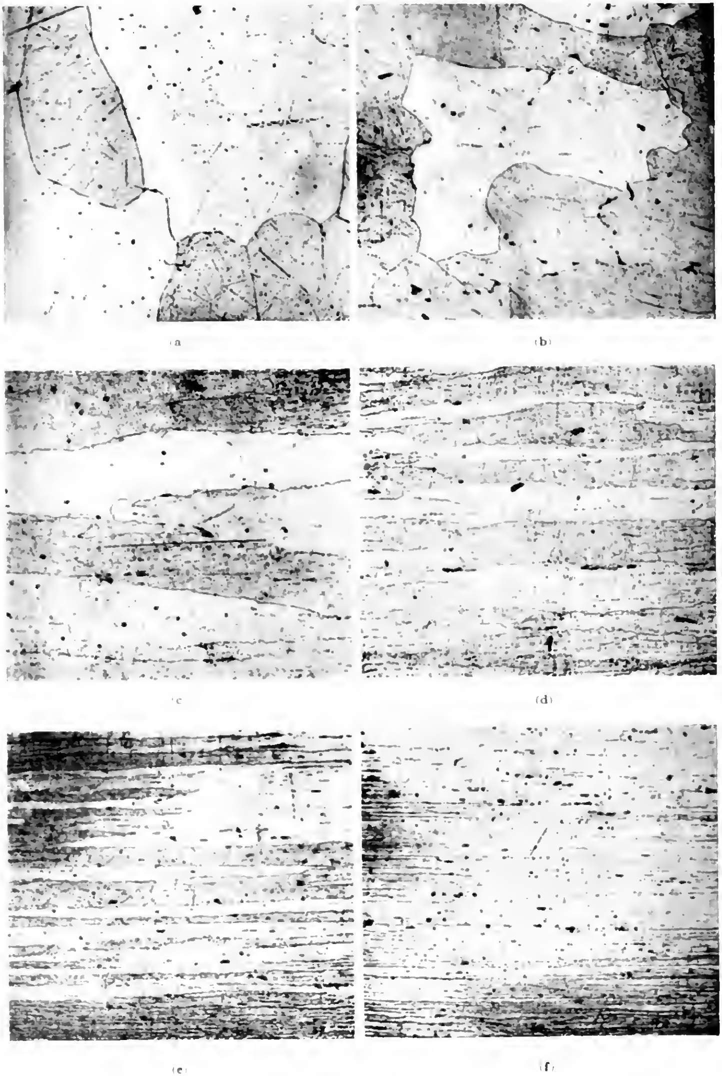


Fig. 2 Flattening of Crystals in Aluminium Sheets During Rolling. Magnification 100 dia. Reduced by $\frac{1}{6}$. (From Recrystallization of Aluminium Sheet on Heating, by Carpenter and Elam. Jour. Inst. Metals, Vol. 25, p. 272, Plate XIV, 1921)

Fig. 4. These crystals are smaller than in the original unworked sample, Fig. 2a, but they are obviously many times larger than the minute grains of Fig. 3. They represent what is referred to as the recrystallization of a worked metal.

This phenomenon, which is the same as the crystallization of a mass of powder, seems to be allied to the formation of large drops of liquid at the expense of small ones by reason of the greater vapor pressure of the latter, or to the growth of large crystals in the precipitate of a solution at the expense of the smaller particles. In both cases surface tension is the active force. The latter case was investigated by Hulett[16] and he showed that small particles have a considerably higher solubility than large. In the presence of small and large particles together in a solution, the small ones tend to dissolve, forming a solution which is supersaturated with respect to the large ones. The latter consequently must grow to reduce the concentration of the solution down to the normal value corresponding to their size. Such differences were found for very small particles only—in the case of calcium sulphate it did not become measurable until a fineness of 0.0003 mm. was reached.

Such a condition exists also in a worked metal after the initial stage of anneal. The crystals are broken up into minute grains, of the same order of magnitude as the particles of a chemical precipitate. Many experiments indicate that they are surrounded by amorphous material similar to a colloidal variety of the metal. Beilby in 1911 asserted that it was formed during cold working and Rosenhain has suggested that it is present normally between the crystals of all metals. It is probably not made up of individual atoms, but rather of groups of atoms, much smaller than the grains but each with the regular lattice arrangement characteristic of the metal and in fact a tiny crystal—as found by Scherrer[17] for colloidal particles of silver and gold so small as to be below the limit of ultra-microscopic visibility. This suggests that the so-called plasticity of the amorphous phase at high temperatures, the existence of which has been demonstrated by Rosenhain and Humphrey,[18] is due to a loosening of the bonds between these minute crystals as a result of increased molecular vibration which always accompanies increases in temperature. At low temperature the amorphous phase would be stronger than the crystalline because of the interlocked condition of these tiny crystals, a condition rendering them more resistant to slip than the planes of atoms in a crystal of normal size.

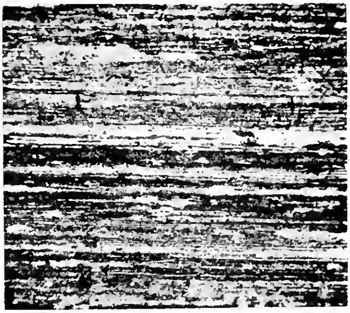
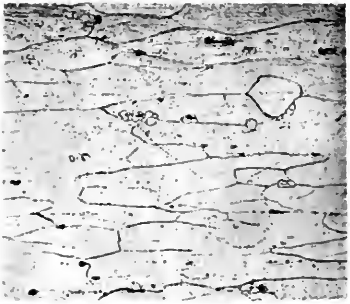


Fig. 3. Recrystallization of Severely Rolled Aluminium at 250 deg. C. Magnification 100 dia. Reduced by 1/6. (From Recrystallization of Aluminium Sheet on Heating, by Carpenter and Elam. Jour. Inst. Metals, Vol. 25, p. 272, Plate XVIII, 1921)

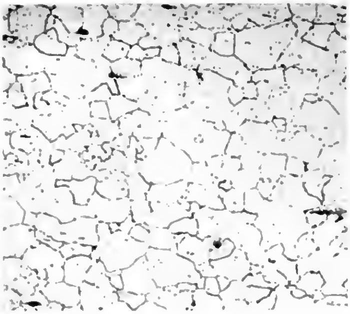
Fig. 4. Grain Growth of Severely Rolled Aluminium After 10 Weeks at 350 deg. C. Magnification 100 dia. Reduced by 1/6. (From Recrystallization of Aluminium Sheet on Heating, by Carpenter and Elam. Jour. Inst. Metals, Vol. 25, p. 272, Plate XVI, 1921)

At the elevated temperatures of anneal particles of this amorphous material during their molecular movements acquire at some moment the same orientation as the atoms in an adjacent grain and are then rapidly annexed by it, providing it is sufficiently large as to approximate a plane surface, a condition which allows surface atoms to be held with strong bonds. The surface atoms in the smaller grains, on the contrary, are so

(a) Original after Rolling



(b) 3 hr. at 250° C.



(c) 65 hr. at 250° C.

Fig. 5. Stages in Recrystallization of Strained Aluminium Zinc Alloy. Magnification 150 dia. Reduced by 1/6. (From Recrystallization of Aluminium Sheet on Heating, by Carpenter and Elam. Jour. Inst. Metals, Vol. 25, p. 272, Plate XX, 1921)

loosely held by reason of the high curvature of the surface that they readily break loose and become part of the amorphous phase.

This is a physical interpretation of the chemical phenomenon of solubility, in which the amorphous phase plays the role of the solution and serves as the medium of transfer of small to large particles. Differences in solution are accordingly thought of as differences in the magnitude of the bonds on surface atoms.

It is noteworthy in view of what is to be said later on crystal growth, that recrystallization does not take place simultaneously throughout the metal. As Rose[15] showed in 1913 for samples of rolled gold, it occurs first in certain particular grains. The location of these was later established more definitely. In 1914, Chappell[5] showed that the recrystallization of a worked metal begins at the boundaries of the old grains where the greatest disorganization of the lattice and most of the amorphous material would in fact be expected. This has recently been confirmed by Carpenter and Elam[8] with an aluminum-zinc alloy. Fig. 5a shows the original worked specimen with its elongated grains. In (b) minute crystals are evident along the boundaries, the first effect of heating, and after the heating had been continued for a long time complete recrystallization took place as in (c).

If any insoluble impurities are present in a metal which has been cold worked, they act as mechanical barriers between the grains when the metal is heated and check grain agglomeration into crystals. This was shown for aluminum by Carpenter and Elam[8] on samples which were annealed at the very low temperature of 200 deg. C. after having been worked down to the 97 per cent reduction shown in Fig. 2f. Recrystallization is of course very sluggish at a temperature as low as this, but nevertheless it became developed in the sample of 99.6 per cent aluminum after 18 months. In the 98.9 per cent aluminum, however, containing more of the insoluble oxide, there was no evidence of it after 3.23 years, in fact, the fibrous structure was still so pronounced as to denote a resistance even to a breaking-up of the strained lattice into grains.

When such a sample is heated to a higher temperature, recrystallization develops, but the crystals are never as large as in a pure metal unless the temperature is so high that the growing grains acquire sufficient energy to burst through the barriers of impurities.

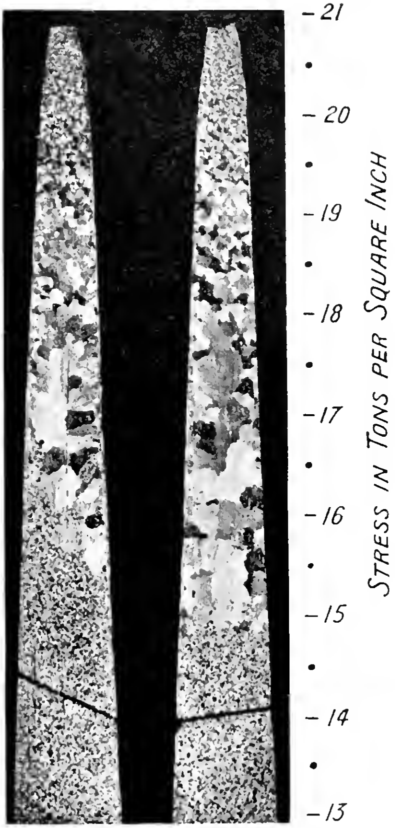
For this reason an impurity may be purposely added in order to maintain small crystal size. Such was done by Coolidge in adding thoria to tungsten to prevent "offsetting" of the filaments.

These effects are similar to the action of protective colloids. As Alexander[19] has pointed out, 0.1 per cent gelatin in plaster of Paris prevents the formation of crystals and 1 per cent even prevents setting.

Growth of crystals in a casting has never been observed even on long continued heating unless the material is first strained. A particularly convincing experiment was performed by Carpenter and Elam[20] on a piece of cast aluminum containing 0.17 per cent iron which forms the compound $FeAl_3$, insoluble in the aluminum. During solidification such an impurity is shoved ahead by the solidifying crystal, so that on complete freezing it has necessarily become segregated at the crystal boundaries. The sample was annealed for ten weeks at 550 deg. C. and then etched until the crystal boundaries appeared. They were found to be outlined by globules, made up of the insoluble $FeAl_3$. The position of these globules represented the original boundary before the anneal, for crystal growth could not have moved them from their fixed positions. The coincidence of their location with the boundaries developed by etching after the anneal demonstrates the absence of growth.

Ewing and Rosenhain[21] in 1900 performed an experiment which demonstrated that growth does not occur in a cast metal even when extremely fine grain. By arranging for very rapid cooling from the melt, they obtained a specimen of lead with a minute crystalline structure not much larger than that of severely worked lead. Nevertheless annealing for nearly seven days at 200 deg. C. brought no change. When it was strained by crushing, vigorous grain growth took place at once.

This emphasizes the need of sufficient amorphous material between grains to serve as medium in growth. In his discussion of Carpenter and Elam's paper,[20] Rosenhain referred to another experiment which suggests that considerably more amorphous material is formed between grains during working than is present in the original metal. When a sample of beta brass was exposed to the action of mercury, the crystals were readily separated from one another if the metal had been cold worked, but not nearly so readily if the material had not been worked.



(a) 820° C. (b) 870° C.

Fig. 6. Crystal Growth in Iron Rod After Tensile Test Followed by Anneal. Magnification 4.75 dia. (From Recrystallization of Deformed Iron, by Chappell. Jour. Iron and Steel Inst. Vol. 89, p. 496, Plate XLVI, 1914)

Grain Growth

After the recrystallization of a strained metal has begun, the size of crystal depends directly upon the temperature of anneal, increasing with increase in temperature. It also increases with the duration of heating at any one temperature. In either of these two ways, crystals become larger, but they do not become abnormally large unless conditions are such that the larger grains

Fig. 7 Crystal Growth in Aluminium Sheet After Various Elongations Followed by Anneal for 65 hours at 550 deg. C. One-third size. (From Crystal Growth and Recrystallization in Metal, by Carpenter and Elam. Jour. Inst. Metals, Vol. 24, p. 104, Plate IX, 1920)

may grow at the expense of the smaller, as was pointed out above. Fig. 4 represents what normally happens on the uniform anneal of a highly strained metal. Crystallization starts from a number of grain centers at the same time, and when the newly developed crystals have extended their boundaries so as to touch each other, the possibility for further growth is necessarily at an end, and a fine grained structure is the result.

There are several ways in which formation of a few germs may result, so that particularly large crystals may form from the absorption of all the other grains by these germs.

If, for instance, the working is not as severe as in the example above but is carried only far enough to shatter some of the crystals and leave others fairly intact, then it would be expected that these unchanged crystals, or at least the larger fragments of them, would serve as germinating centers on heating, and would grow at the expense of the granular fragments round about them.

Such a result was first noticed by Sauveur[4] in 1912 and led to his development of the "critical strain" hypothesis. He demonstrated that the deformation of low carbon steel, followed by annealing, led to the formation of coarse crystals at one critical strain, whereas smaller crystals resulted for higher strains. Similar results were obtained by Sherry[22] in 1912, Robin[23] and Ruder[24] in 1913, Chappell[5] in 1914, Hanson[25] in 1918, and Carpenter and Elam[20] in 1920.

A typical illustration of this effect is shown in Fig. 6, taken from Chappell. An iron bar tapered from each end toward the center was put under a tensile force until it broke. In the resulting half pieces, the stress in the metal increased progressively from the large end toward the small broken end. When these pieces were heated, very large crystals formed at an intermediate point, becoming continuously smaller for regions of higher stress. On the side of less stress, the structure remained in its granular form unchanged. It is typical of all such tests that the large crystals extended further into the region of lower strain in the sample which had been heated at the higher temperature, as in Fig. 6b.

The experiments of Carpenter and Elam are on pieces of sheet aluminum strained by stretching. The samples illustrating their results for three different annealing temperatures are shown in Figs. 7 and 8. They demonstrate that there is a certain stress necessary to start crystallization and that its degree becomes less as the temperature is raised. Recrystallization and grain growth become also more rapid with increase in temperature, but this greater rapidity prevents the formation of as large crystals. The largest crystals are developed by the minimum stress which is just sufficient to bring about the slightest recrystallization in the original fine grained metal. There is no change for instance at 500 deg. C. in the sample which had been elongated 2 per cent, whereas at 600 deg. C. large crystals are formed. As the stress is increased beyond this critical point, the crystals after annealing become smaller, until at the highest stresses they are no larger than those in the original metal, as shown in the sample elongated 21 per cent and annealed at 550 deg. C. The effect of using a higher temperature than that at which crystallization first occurs is to decrease the final size of crystal, because increase in temperature allows growth to start from more grain centers. In some cases, grain growth extended into the shoulders as far as the strain went, but in no case did it absorb the unstrained grains at the very ends, even on prolonged heating. This is further evidence denoting the need for the formation of amorphous material to serve as a medium for growth.

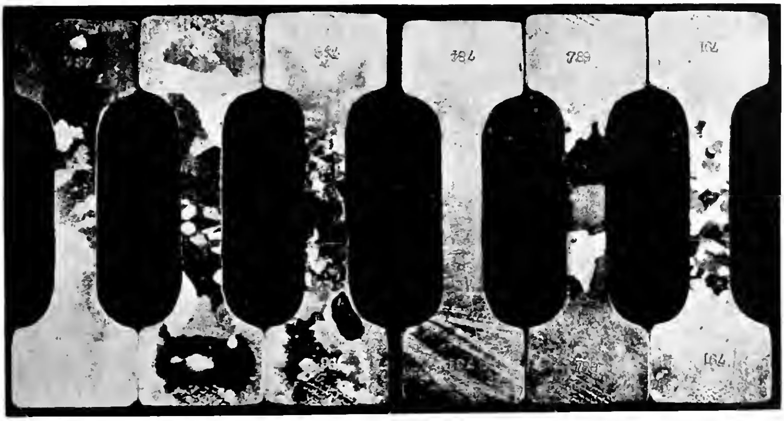


Fig. 8. Crystal Growth in Aluminium Sheet After Various Elongations Followed by Anneal for 65 hours. Left Three Specimens at 650 deg. C. Right Three Specimens at 500 deg. C. One-third Size. (From Crystal Growth and Recrystallization in Metal, by Carpenter and Elam. Jour. Inst. Metals, Vol. 24, p. 104, Plate X, 1920)

Under the influence of these small, critical strains, the old crystals are not visibly broken up first into granular masses when heated, but certain ones begin growing at the expense of their neighbors. Their growth proceeds by boundary migration, as was shown in 1900 by Rosenhain[26] for a sample of freshly cut lead. When it was heated for increasing periods at 200 deg. C. and etched after each anneal, certain crystals became progressively larger at a rate which was particularly rapid where their boundary was irregular.

The same thing was demonstrated in a noteworthy manner by Carpenter and Elam[20] in 1920 for an alloy of tin with 1.5 per cent antimony. It was polished, etched and then heated for several periods at 200 deg. C. to bring about crystal growth. The position of a

(a) After First Heat

(b) After Fourth Heat

(c) Same as (b) Repolished and Re-etched

Fig 9. Migration of Crystal Boundaries During Interrupted Heating of Tin Antimony Alloy. Magnification 100 dia. Reduced by 1/6. (From Crystal Growth and Recrystallization in Metal, by Carpenter and Elam. Jour. Inst Metals, Vol. 24, p. 104, Plate III, 1920)

new boundary was shown after each heating by the appearance of a line which really represented a difference in level. That such lines actually denoted the new boundaries was shown by photographing the sample, and then polishing, etching afresh, and photographing the same area again. The etched boundaries were found to coincide exactly with those previously denoted by the differences in level. Repeated heatings brought out fresh lines, the last one marking the furthest advance in growth. These changes are illustrated in Fig. 9. The first advance of grain boundary is shown in (a) and successive advances during the next four heat treatments in (b); (c) is taken of the same area after polishing and etching, and demonstrates the final complete absorption of the central grain, the successive steps of which are shown in (a) and (b).

In a paper published this year, Carpenter and Elam[27] have carried their experiments on growth still further, and have produced single crystals from sheets of aluminum of the same shape as pictured in Fig. 7, measuring 0.125 inch wide and 4 inches long, and also from aluminum bars up to a diameter of 0.798 inch and 3 inches long. The aluminum was particularly pure, 99.6 per cent.

The samples of sheet were first annealed six hours at 550 deg. C. to remove all strains and to produce normal equiaxed crystals of a size of 150 to the linear inch, and then elongated 1.6 per cent. A longer preliminary anneal gave too large crystals, which the authors state did not become uniformly strained on pulling. Another and perhaps more significant reason why large grains were unfavorable for final single crystal growth lies in the probability that the very slight deformation did not develop sufficiently small fragments on annealing. They were presumably not as small as would result from the straining of crystals already small. As pointed out above, the contrast between the large growing germ grain and the small grains which are absorbed is most effective when the latter are minute.

In the final anneal after straining, it was essential that the samples should be heated at the lowest temperature at which growth could take place. It was found to be 500 deg. C but in order to avoid any chance of overshooting such a point, the anneal was started at 450 deg. C. and raised 15-20 deg. C. a day up to 550 deg. C.; a final hour at 600 deg. C. completed the absorption of the small grains. In this way it was assured that grain growth would start from the minimum number of centers—in fact a single crystal, which resulted once out of every four trials, could form from the growth of a single germ only. The increase in temperature was for the purpose of accelerating the growth, once started.

The bars were given the same schedule except that they were elongated 2 per cent. Single crystals resulted in 8 out of 18 cases.

A second general method by which the growth of a few grains only may be favored and abnormally large crystals formed is to choose a temperature gradient such that some will be heated just enough to promote their growth at the expense of neighboring ones which are at too low a temperature to coalesce among themselves. This method may be used with severely worked material, as described by Jeffries[3] in experiments on tungsten.

Another instance of the same effect is an experiment of Ruder's on silicon steel sheet as cited by Jeffries[1] in 1918. A strip was annealed and moderately strained and then one end heated in an electric furnace while the rest was outside and cold. After a large crystal had developed in the heated end, the temperature was raised to a high value, and the strip slowly pulled through the furnace at such a rate that the large crystal absorbed with equal speed the adjoining grains of the cold portion as they came within the temperature zone. In this way the crystal grew continuously and could be made of considerable length.

A method similar to this was used also by Schaller[28] in the case of tungsten. A squirted filament 0.02–0.2 mm. in diameter of tungsten powder containing up to 4 per cent thoria was passed through a hot zone formed by a tungsten spiral at 2400–2600 deg. C. It was pulled through at a rate of 2½ meters an hour—the speed at which the particles of tungsten could be absorbed by the crystal formed at the elevated temperature. Here again is an instance of the growth of a favored crystal at the expense of minute grains. The purpose of the thoria, as already cited above, was to check the crystallization of the particles in the low temperature zone by serving as a boundary between them, so that no coalescence could take place till they were in a position to be absorbed by the growing crystal in the hottest zone.

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Ultra-Violet Light, Its Uses and Possibilities

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Ultra-violet light is an artificial light produced electrically, and as such should be of interest to the engineer as well as to the scientist. It has a different wave-length from the familiar visible spectrum, which means that it has different characteristics and applications from ordinary light. Some of these characteristics and uses are dealt with in the present article, but perhaps the greatest interest lies in the possibility of extending its known uses and of finding new ways to serve mankind.—Editor.

Modern theories treat radiation as a propagation of energy in the form of waves which have been shown to vary continuously in length from twenty to thirty thousand meters, in the wireless region, to the extremely short disturbances involved in X-rays. The visible spectrum covers only a very short range of these waves, extending from a length of 7600 to 3900 Ångström units.* In this article we are concerned principally with that part of the spectrum which is known as the ultra-violet region and only with the chemical and physiological properties of these rays, so we will not consider the physical and electrical aspect of the question in any great detail.

The study of the spectrum has had a powerful attraction for scientists since Newton's time. Scheele discovered, as early as 1777, that silver chloride not only darkened in sunlight, but also changed its color when exposed to the action of the invisible rays at the extreme violet end of the spectrum. During the last quarter of the eighteenth century there were a number of experimenters working along this line and many interesting theories about the character and structure of light were evolved. In 1800, Sir William Herschel discovered that the maximum heating effect in the spectrum was to be found in the region beyond the visible limit of the red end. In 1840, Sir John Herschel continued the investigation and proved that the spectrum actually did extend beyond the visible limits and that the Fraunhofer lines were continued into this region. Attention was drawn by Inglefield, in 1803, to Scheele's earlier observations on silver chloride and he suggested that an extension beyond the violet end of the spectrum might exist similar to the infra-red spectrum. The actual demonstration of the existence of ultra-violet light was made by Ritter and by Wollaston, who showed that silver chloride was readily blackened in the region beyond the visible portion of the spectrum in the violet.

Becquerel, in 1842, succeeded in photographing a long ultra-violet region which contained many Fraunhofer lines, which he labeled with the letters L to P. This meant the extension of the spectrum to the limit of about $\lambda = 3400$ Ångströms.

Photographic methods are convenient for investigating the ultra-violet regions, as silver salts are very active toward these rays. Since glass absorbs ultra-violet light when the wave-length is shorter than about 3300 Ångströms, more transparent materials must be used when these short rays are wanted, and the lenses and prisms must be made of quartz, Iceland spar, or fluorite. Iceland spar absorbs wave-lengths shorter than 2150 Ångströms. With quartz lenses and prisms, it is perfectly easy to reach as far as $\lambda = 1850$ Ångströms, provided no great air space is traversed by the rays, since a thick layer of air exerts a powerful absorption upon these rays. For the region beyond $\lambda = 1850$ Ångströms, the apparatus must be as free from air as possible, and fluorite lenses and a specially prepared photographic plate containing very little or no gelatin must be used.

Rowland, during his search for a source of monochromatic illumination, found that a good grating was necessary and conceived the idea of ruling gratings on a cylindrical mirror of speculum metal. With these concave gratings, lenses are dispensed with, as the grating itself, being ruled on a cylindrical mirror, focuses the rays and produces the spectrum. This has proved to be one of the greatest inventions ever made in spectroscopy. Schumann did excellent work in the extreme ultra-violet region and reached an estimated limit of 1000 Ångströms for hydrogen.

For photographing the region of shortest wave-length in the ultra-violet, where the gelatin interferes by absorption of the rays, a special very thin gelatin is prepared, or else the gelatin is replaced entirely on the plate by a pure silver salt. In Schumann's work on the absorptive power of gelatin, he employed films of thicknesses varying from 0.13 mm. to 0.00004 mm., which he prepared

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* An Ångstrom is one one-hundred millionth (10^{-8}) of a centimeter.

by allowing a definite quantity of gelatin solution of known strength to dry upon a glass plate. A film of 0.13 mm. thickness of gelatin on a photographic plate possesses an absorptive power which extends over the whole ultra-violet region, and reaches even into the visible spectrum. The absorption is practically complete beyond $\lambda = 2470$ Ångströms. A film of 0.01 mm. gave a total absorption beyond $\lambda = 2266$ Ångströms. The extreme case of 0.00004 gave a distinct weakening of the extreme ultra-violet rays, even as low as $\lambda = 2061$ and 2024 Ångströms. The best plates for ultra-violet photographs are made with a very thin coating of gelatin on glass and a very thin film of silver bromide deposited on the surface of the gelatin. The gelatin serves to bind the silver salt and glass together and it also increases the photochemical sensitiveness of the silver bromide. The negatives from these plates show some contrast, which is utterly lacking in negatives obtained with a pure silver salt.

Stokes introduced three new methods of observation in his ultra-violet work. He substituted a fluorescent screen for the daguerreotype plate of Becquerel, replaced the glass lenses and prisms by a system of quartz, and used the light from an electric spark instead of the sun as a source of the rays.

Lyman made another advance, by using a ruled grating in place of the fluorite prism, which allowed him to measure wave-lengths as short as $\lambda = 1030$ Ångströms.

Millikan in his splendid work has photographed the ultra-violet spectrum and determined wave-lengths down to $\lambda = 136.6$ Ångströms in the case of aluminum and down to $\lambda = 149.5$ Ångströms in the case of copper. This leaves a very short gap only between the shortest measured ultra-violet waves and the longest X-rays measured by the method of crystal-spectrometry, which stops at 13.3 Ångströms.

Ultra-violet light is produced in many ways, but few of them are sources of much energy. All artificial light contains more or less ultra-violet radiation. The sun emits a continuous spectrum of great intensity but wave-lengths shorter than 2950 Ångströms are absorbed by the atmosphere. Limelight, burning magnesium ribbon, the incandescent lamp, arcs between metals, spark-gaps and vacuum tubes are a few of the many sources of ultra-violet light. The mercury arc in a quartz tube and the magnetite arc are excellent sources of the radiations. Finsen in his work used an arc between iron electrodes, after having found that such an arc is about fifty times as powerful as an arc of the same wattage between carbon electrodes. The flaming arc has great possibilities, owing to the number of substances which can be incorporated in the electrodes. These are all most efficient commercial sources of ultra-violet energy.

With arcs, as well as with sparks, a disintegration of the metal of the electrode occurs, causing trouble. When mercury is used as an electrode, the vaporized metal, on condensing, flows back to the electrode container, if the arc is enclosed. The material used for enclosing the arc must be transparent to the ultra-violet rays, such as rock crystal in the natural or in the fused state.

Finsen's research work was not entirely successful at first because his arc was enclosed in glass which absorbed the greater part of the ultra-violet rays. About 1901 the Cooper-Hewitt mercury arc lamp was perfected. Later Schattner, Kuech, Heraeus and the Westinghouse-Cooper-Hewitt Co. built these lamps, using quartz instead of glass for enclosing the arc. The original reason for using quartz was because its melting point was about 1700 deg. C., which allowed the lamps to be run at a greater temperature than glass lamps, and which permitted them to be made smaller and less cumbersome mechanically. Quartz allows about 1000 times as much ultra-violet radiation to pass through it as glass does, so, naturally, quartz is used almost exclusively for the industrial production of these lamps.

Ultra-violet light is very reactive chemically and readily effects the decomposition of alcohols, aldehydes, organic acids, and ketones, and gives rise to condensations and to polymerizing effects in the case of acetylene, ethylene, cyanogen and oxygen, causing a diminution in volume.

In the photolysis of primary alcohols by ultra-violet light, there is a predominance of hydrogen gas formed, associated with carbon monoxide and an absence of carbon dioxide. The activity of photolytic decomposition decreases materially as the molecular weights of the compounds increase. The higher alcohols give from ten to twenty times less gas than the lower members of the series. Berthelot's work shows that this statement applies equally to aldehydes and acids. Cyanogen is oxidized practically completely to carbon dioxide and nitrogen, under the influence of ultra-violet rays, and a mixture of ammonia and oxygen yields nitrites, and nitrogen and water, but free hydrogen is apparently not oxidized by oxygen, at ordinary temperatures, under similar conditions.

Ultra-violet light has a stronger action in producing fluorescence and phosphorescence than the visible spectrum has, and some wave-lengths produce much stronger effects than others. When polished metals—zinc, for instance—are illuminated by ultra-violet light, they become positively charged, if insulated, and discharged, if already negatively charged. Under the action of the light rays negative electrons are discharged from the metals. This is known as the photoelectric effect, and the alkali metals are especially sensitive in this respect to visible rays as well as to ultra-violet, and the phenomenon is made use of in the photoelectric cell.

During our recent war, Dr. Louis Bell and Norman Marshall of Boston, attacked the problem of signaling by invisible rays. They used the rays in the region just beyond the visible spectrum and, contrary to precedent, worked with Mangin mirrors instead of quartz lenses. They found it possible to obtain a powerful beam in the region between $\lambda =$ 4000—3500 Ångströms of the spectrum from an ordinary gas-filled incandescent lamp, run at excess voltage. An ingenious combination of glasses was devised which cut out light of all wave-lengths except the one desired, and a receiving screen for the light was finally found in a "chemical eye" of barium platinocyanide, which fluoresced with the color of maximum luminosity value for very weak stimuli. Ordinary field glasses were fitted up with the fluorescent screen, for use at the front, and the device was used successfully in drizzling rain and in snow. The atmosphere showed very little absorption of these ultra-violet rays, which were absolutely invisible to the naked eye, and which appeared, in the receiving glass, as a small green disk flashing a code message.

Air is ionized by ultra-violet light and the breakdown voltage of an air gap is decreased when illuminated by ultra-violet rays. This light is especially destructive toward coloring media. Mott found the fading effect on dyes at a distance of 10 inches from a 28-ampere white flame arc to be several times greater than June sunlight. The chlorination of natural gas in the manufacture of chloroform is materially accelerated by ultra-violet light, and ozone, hydrogen peroxide and nitrous acid are produced in the vicinity of powerful sources of ultra-violet radiations. These radiations have a strong bactericidal action.

Marshall Ward gave us the first biologic spectrum analysis. He threw the spectrum on an infected agar plate, and the parts of the plate which were exposed to the violet end of the spectrum did not show any growth of colonies when incubated, while the parts which were exposed to the visible and red end of the spectrum developed growth. He sterilized the Thames water by exposing it in thin sheets to ultra-violet light.

To Finsen and his Institute, in about 1900, we owe the first real analysis of abiotic phenomena occurring under the influence of ultra-violet light. His work resulted in the therapeutic use of ultra-violet lamps and he has done some very effective work with ultra-violet treatment of skin diseases, such as lupus vulgaris. He found that the abiotic reaction became very powerful as soon as one reached wave-lengths shorter than those contained in sunlight, and he also proved that the abiotic action of the rays is independent of the presence of oxygen and that colloidal solutions have a very strong absorptive effect on ultra-violet rays. His pupil, Bangs, determined the relative resistivities of different germs to this light and found that young cultures were less resistant than older ones. Finsen's pupils proposed the use of ultra-violet rays for sterilizing liquids, such as milk.

Downs and Blunt studied the action of sunlight on different organisms and organic tissues. Considerable work was done in France about 1909 by Courmont, Nogier, Vallet, and others. Very elaborate researches were carried on in the Physiological Laboratory of the Sorbonne University by Henri, Helbronner, and von Recklinghausen, which led to considerable technical application of the rays. The industrial application is closely linked with the development of the means for producing the ultra-violet rays. In sterilizing water, it has been found that the abiotic power of the rays decreases as the square of the distance from the source of the energy. Bacteria do not vary as much in their resistivity toward ultra-violet light as they do toward heat and chemicals. Spores, which are often twenty times as resistant toward other agents, are only 1.5 to 5 times more resistant toward ultra-violet light than ordinary unprotected water bacteria are.

There are several theories as to how the ultra-violet rays act on living cells, but it is generally conceded, now, that the deadly action is due to some quality inherent in the rays themselves, and not to the action of some poisonous substance formed by them, such as hydrogen peroxide or ozone. The abiotic action is apparently independent of the temperature between 0 deg. C. and 55 deg. C., as shown by Henri, and it is the same in clearly frozen ice as it is in water.

The theory has been advanced that ultra-violet radiation kills bacteria by destroying the intracellular enzymes, due to the action of the short wave-lengths. Mr. Burge has shown, in his experiments on liquefying bacteria, that the bacteria themselves are killed, but that the liquefying action, which is due to the intracellular enzyme, is practically unimpaired, which would seem to indicate that the enzymes are not concerned in the killing of the bacteria. Burge next tried experiments to show that the destructive action is due to a coagulating effect on the protoplasm. He exposed a number of different kinds of bacteria to ultra-violet light and a similar lot to heat at 45 deg. C. and at 90 deg. C. Under the microscope those which had been rayed and those which had been heated to 90 degrees looked the same, and were evidently coagulated. When heated at 45 degrees for a long time, or when rayed with insufficient energy, the cells appeared to disintegrate without coagulating, but, nevertheless, the destructive action was apparently due to coagulation.

When egg white is exposed to ultra-violet radiations, it coagulates, and the micro-organism, paramecia, acts in the same way when accorded the same treatment. It would seem from these results that ultra-violet radiation kills living cells by coagulating, or rendering insoluble, the protoplasm, or living material, of the cells. In the egg white the coagulation does not become apparent until it has been placed in a solution of calcium salts, when the coagulated area becomes visible. The effect seems to be due to a precipitation of the protein of the egg white which has been chemically changed by the rays in such a way that it combines with the salts to form a coagulum.

This effect is shown in the action of these rays on the eye. With fishes living in water containing calcium salts and silicates, the action of the rays on the eye is quicker and more powerful than with fishes in tap water. Ultra-violet rays are readily absorbed by the crystalline lens in the human eye and also by the conjunctiva and cornea. A chemical transformation takes place with the formation of insoluble proteins, with consequent opacity, and a cataract is formed as a result of the absorption of the rays. The most effective abiotic region of the spectrum seems to be between $\lambda = 3000$ and 2500 Ångström units, although these rays have very little penetrating power as compared with the rays from $\lambda = 4000$ to 3000 Ångström units, and are absorbed by 0.1 mm. of human skin.

The consensus of opinion at present seems to be that ultra-violet radiation kills living cells and tissues by changing the protoplasm of the cells in such a way that certain salts can combine with the protein of the protoplasm to form an insoluble compound.

According to Benoit, ultra-violet light has a most beneficent action on wounds, even on those of long standing, and this light was used in treating the wounds of our soldiers in the World War.

That the visible rays of the spectrum have practically no abiotic effect on living organisms is probably due to the fact that the organisms have adapted themselves to the rays in sunlight, and these are very little absorbed by protoplasm. Ultra-violet radiations, on the other hand, render the protein of the protoplasm insoluble and retard the catalase action and the result is a general thickening and degeneration of the connecting tissue of the walls of the blood vessels.

Fluorescent bacteria (non-spore formers) are more resistant to ultra-violet light than non-fluorescent organisms. The suggestion has been made that the fluorescent bacteria are able to convert the short wave-lengths into longer ones and thus escape the protein coagulating effect of the short ones.

By experiments using various screens for the organisms, such as solutions of amino-benzoic acid, cystine, tyrosine, leucine, etc., Harris has found that the susceptibility of protoplasm to ultra-violet light is due to the absorption of the toxic rays by the aromatic amino-acid radicals of the proteins.

Dry pure cultures of certain bacteria were placed on cover slips and exposed to the action of ultra-violet light for periods of 5 to 200 seconds at a distance of 12 cm. from a mercury arc. Death of the organisms resulted, as they did not incubate in bouillon after treatment. Interposition of a quartz beaker containing a 1 per cent solution of tyrosine between the cover slips containing the bacteria and the arc exerted a protective action. Bacillus subtilis and staphylococcus aureus (normally killed at 150 and 90 seconds respectively) survived exposure for 40 minutes, and B. mucosus cap. (normally killed in 20 seconds) survived after exposure for 10 minutes. All three survived exposure for 3200 seconds when protected by a solution of amino-benzoic acid. These experiments led to the conclusion that aromatic amino-acid radicals are among the substances in bacteria affected by the action of ultra-violet light. Mercury arc radiations are not absorbed by tyrosine and phenylalanine and hence they are relatively non-toxic.

Radiations between $\lambda = 3000$ Ångströms and 2970 Ångströms have a destructive effect on certain hormones, enzymes and proenzymes. The cholagogic activity of bile is not affected by ultra-violet light. The bactericidal power of ultra-violet rays increases progressively as the wave-length decreases, and down to $\lambda = 2144$ there appears to be no optimum point of sensitiveness. The Schumann rays have a marked bactericidal action which is highly localized and makes them valuable for investigations in the experimental morphology and physiology of the cell, but below wave-length 1600 Ångströms the penetrating power is so slight that the rays may not penetrate into the organisms far enough to have much effect. In experiments with these rays on amoeba, only a part of the protoplasm was killed, indicating that the rays penetrated only a short distance.

Ultra-violet treatment of micro-organisms tends to favor an agglutinin response and diminishes the toxic effects of certain organisms. Eberson has shown that group relationships are brought out clearly in bacterial types when under the influence of a physico-chemical agent which alters the antigenic properties within the cell. The action of ultra-violet light on micro-organisms suggests a method for building up an immunity to disease in animals by injecting bacteria which have been exposed to the rays for constantly diminishing periods of time. There is evidence that perhaps a single strain of bacteria may suffice for immunizing against a heterogeneous group of organisms. It is possible that a single protein structure may represent the element common to groups of biologically related organisms.

In a hemolytic serum, shaking for a few hours inactivated the complement but had no effect on the hemolytic amboceptor, even when continued for several days. Ultra-violet rays, on the other hand, inactivate both the complement and the hemolytic amboceptor in a short time, especially when the amboceptor is used in a dilution ten times as great as the complement. X-rays do not modify either the complement or the amboceptor. The different actions of the two kinds of rays may be due to the fact that the ultra-violet rays are absorbed by the proteins, while the X-rays easily penetrate them.

After subjecting blood serum to the action of ultra-violet rays for 23 hours, Delbet found no changes in the colloidal state, although the hemolytic power was reduced one-half after being exposed to the rays for 75 minutes. Scott found that exposure to ultra-violet radiations reduced the precipitating power of the serum. The necrotizing action of epinephrine disappeared completely after one and one-half hours of irradiation. Ultra-violet rays have a most destructive effect on the active principles of normal and prepared serum. Experiments were tried by Baroni on these serums and on vegetable toxins. Dilution by reducing the number of colloidal substances favors the destructive action of ultra-violet rays. Alexins are destroyed more easily than other immunizing substances. Agglutinins and antitoxins are the most resistant to the radiations. The rays apparently act like heat. The vegetable toxins lose their agglutinizing power and toxicity at the same time. The radiations have an inhibiting action on enzymes. According to Delezenne, inactive pancreatic juice can be activated by mixing it with calcium salts, or by adding a diastase to it. Exposure of the juice for several hours to ultra-violet rays destroys its re-activating properties as regards calcium salts, but does not change its response to the action of diastase. The juice also loses its lipolytic power. Amylase showed the least susceptibility to the rays and trypsinogen was destroyed in four hours. Lemotte proposed a method for serodiagnosis of typhoid and paratyphoid affections. Ultra-violet rays kill the bacteria without destroying their diastatic and agglutinating properties. Lemotte proposed to use emulsions of these bacteria, killed by ultra-violet rays, and to add to tubes containing them, the diluted blood of the patient, noting whether agglutination occurred. The advantage claimed was that the handling of dangerous living bacteria was avoided, as well as the use of a microscope.

W. M. Baldwin has done some interesting work on the effect of ultra-violet light on the development of the frog's egg. It is known that proteins, carbohydrates and lipins are chemically altered by ultra-violet rays, so it is not unreasonable to infer that these substances may be susceptible to the influence of the rays while still in the living ovum. By raying certain restricted areas of the fertilized ovum of the frog with ultra-violet light, a constant type of defect is produced which seems to be due to an alteration of the superficially placed egg substance in the area rayed. The protoplasm seems to have been altered chemically to such a degree as to render it unfit for participation in the subsequent chemical ontogenetic processes of which it normally was a part, and in addition it acts as a hindrance to the developmental shifting of the primitive mass of cells in the embryo. There are apparently two types of defects caused by these radiations on frog's eggs, spina bifida, and the folded or U-shaped embryo.

Fauré-Fermiet has shown the effects of ultra-violet light on the segmentation of the eggs of ascaris magnalocephala. There is a slowing of pigmentation which is proportional to the intensity of the irradiation and a fragmentation of the chromosomes, especially if the rays are applied after segmentation is well advanced. Anomalies of segmentation manifest themselves at first by displacement of the lines of division, then by the arrest of the division of the injured cells and diffusion of the nuclear substance with the formation of metachromatic granules. The most active region in the ultra-violet for ascaris is about $\lambda = 2800$ Ångströms which is also the most active photochemical region. The action is proportional to the duration and intensity of the irradiation and consequently to the quantity of energy received by the egg.

Ultra-violet light varying in wave-length from 2144–2400 Ångströms has a penetrating capacity of but 0.02 mm. in the embryo of the tadpole. All of the energy is absorbed by two layers of ectodermal cells of the embryo. The energy absorbed produces intracellular reaction.

According to Raybaud, animals with a bare skin are much more sensitive to ultra-violet radiations than animals whose skins are protected by a layer of chitin. Snails were rayed and did not appear inconvenienced, although they died in 24 hours. Tadpoles, in about 2 cm. of water, became torpid after three hours' exposure and were dead in five. Flies, in spite of their chitinous envelope, were killed as rapidly as tadpoles, but evidenced some disquietude during the action of the rays. Young grasshoppers perished in two or three days; the adults lived a week without appearing incommoded. Beetles and spiders moved about in their wire cages for a fortnight with the same activity under the rays as the controls. White mice were exposed for eight days. Their eyes, of which the eyelids were inflamed, were the only parts attacked. They may have become blind. It is interesting to note that the eyes at the end of snail tentacles are not sensitive to colored rays.

As a result of the action of ultra-violet radiation on 24 species of yeast-like fungi, suspended in water in open Petri dishes, at a distance of 25 cm. from the source of the rays—one species survived a 10 minute exposure and 23 were killed in less than one minute. Yeast cells exposed for 10 seconds do not germinate, and exposure for three minutes kills the cells. It has been suggested that the fermentation due to malt cultures could be controlled in this way.

Henri has found in his experiments with small animals, like cyclops and daphnia, that each animal has a definite threshold value (minimum duration of irradiation). The reciprocal of this minimum period is a measure of the photo-excitability of the animal. This photo-excitability increases with the proportion of ultra-violet rays in the radiation There is a minimum value of intensity of irradiation below which the animal does not respond, regardless of the duration of irradiation. The period for producing excitation decreases as the intensity of ultra-violet radiation increases. When the intensity of radiation is increased, the energy of ultra-violet rays necessary to produce excitation passes through a minimum. Ultra-violet radiations of shorter duration than the threshold value produce effects which increase for some time after the discontinuance of irradiation and then gradually vanish. The rays cause photochemical tissue changes and diffusion of resultant products to sensitive nerve endings, causing stimulation of nerve centers and endings, and resulting in muscular contraction. Excitability is independent of the temperature at which the rays are applied. "Threshold time" rises considerably after prolonged exposure, but promptly falls to its original value. If sensory nerve endings are anesthetized by immersing the animal for a short time in a solution of cocaine, or if the nerve centers are anesthetized by ether, the same results occur. Phenomena of fatigue and reparation, after the application of the rays, have their seat in the peripheral organs.

"Threshold time" of reaction corresponds to photochemical changes and to those of diffusion and osmosis taking place at the periphery.

Hasselbalch tried some experiments to determine the effect of ultra-violet rays on the human skin. He found that the pigmentation of the skin had a strong influence on the extent of the absorption of the rays. It is a well known fact that blood pigments strongly absorb ultra-violet rays and when one is using the light therapeutically, direct access of the blood to the part receiving the rays must be avoided as much as possible.

Sidney Russ tried some interesting experiments on the absorbing power of the skin for ultra-violet rays. He used skin removed from the abdomen taken in layers 1/10 mm., ½ mm., and 1½ mm. thick and placed these different thicknesses of skin in front of the slit of the spectrograph. The Simpson arc was used as the source of the ultra-violet energy, and was placed about 20 cm. from the slit of the spectrograph. An exposure of a few seconds was given for a wave-length up to 3000 Ångströms. It was found that the skin was very absorbent for rays of wave-length between 3000 and 2100 Ångströms, as apparently not more than one part in a thousand of this radiation penetrates to a depth of half a millimeter. Even with the rays of longer wave-length, 3000–3800 Ångstroms, it is a question whether as much as 1 per cent of the radiation penetrates as deep as 1 mm.

Ultra-violet light has an effect on the circulation of man. The output per minute of the heart at rest in a sitting posture is a function of the respiratory metabolism. Independent of variations in metabolism, the minimum volume and the output per beat are both influenced by an arc-light bath. The primary effect during the next two or three days is, in almost all cases, an increase in blood flow. The final effect in each case will depend on the regulating power of the organism, and cannot be foretold.

When ultra-violet light acts on certain gases, nuclei are produced, though apparently only when minute traces of oxygen and carbon dioxide are present in the gases. Oxygen which contains ozone has nuclei for condensation having similar properties to those formed by ultra-violet light. The nuclei are destroyed by heating. It seems probable that the ultra-violet nuclei cause condensation of water and other liquids simply by acting as centers of condensation, like dust particles.

Ultra-violet light has a very stimulating effect on the velocity of chemical reactions and accelerates the change from unstable to stable equilibrium. Plastic sulphur, glassy antimony and barley sugar become crystalline more or less rapidly when exposed to the light from a quartz lamp. Ultra-violet light accelerates the oxidation of potassium manganate to potassium permanganate, the inversion of acid sugar solutions, and the saponification of acetic ester by sodium hydrate.

Results show that under the action of ultra-violet rays, the velocity of reaction is proportional to the intensity of the light, but is independent of the concentration of the reacting substances. According to Andreev, the rays have a catalytic action. The photolysis of oxalic acid takes place by causing a primary decomposition into carbon dioxide and formic acid, followed by a secondary decomposition of nascent formic acid into carbon monoxide and water, by rays of longer wave-length, and into carbon dioxide and hydrogen, by rays of shorter wave-length. Berthelot contends that radiant energy represents a lower form of energy than thermal energy, and that frequency of vibration plays the same role in radiant energy that temperature does with thermal.

Under the action of ultra-violet radiation, carbon monoxide is very reactive and shows exceptional photochemical properties tending to form addition products with other gases. This phenomenon is more pronounced with the first terms of the periodic series. That is, carbon monoxide combines with chlorine, but not with bromine and iodine; with oxygen, but not with sulphur; with water, but not with hydrogen sulphide; with ammonia, but not with phosphine or arsine.

Kailan tried an interesting experiment with radium rays and ultra-violet rays on toluene and found that less than 0.25 per cent of toluene was changed in two years by radium rays and that the products obtained were benzoic acid and hydrocarbons. The same change was produced in 22 hours by ultra-violet light, giving benzoic acid and formic acid. Ultra-violet light acts on glycerol, breaking it up into formaldehyde, with traces of other aldehydes. Decomposition takes place more readily in the presence of water. Glucose decomposes, yielding an acid and in time a mixture of gases containing carbon dioxide, carbon monoxide and hydrogen. Lactic acid in water is split into alcohol and carbon dioxide and is independent of the concentration of the solution. Baudisch has tried the action of rays of short wave-length on lactic acid and gets acetaldehyde, but no evidence of alcohol or methane.

Chemically, the action of ultra-violet light is of a catalytic nature. On enzymes and hormones, it has an inhibiting influence, and on living organisms it has an effect similar to heat, that is, it coagulates the albumin of the proteins in the protoplasm. Schumann was the pioneer where delicate and exact work performed in spectroscopy was involved, and for years his work in the extreme ultra-violet region remained as a model of accurate and careful measurement. Recently, Lyman and Millikan have extended this work with even greater precision and nicety, until now there is apparently no gap between the known spectral lines for certain of the metals in the extreme ultra-violet region and the lines from soft X-rays. The lines from hard X-rays overlap those of the soft gamma rays so that we have a spectrum of accurately determined wave-lengths from the long waves of the wireless region to the extremely short waves of the gamma rays from radium. All these phenomena, though so different in their manifestations, whether as wireless waves, visible light, or X-rays are considered now as fundamentally of the same origin and are the result of the motion of the units of negative electricity, the electrons. As our knowledge of the extreme ultra-violet region of the spectrum increases, its importance in helping us toward a more complete understanding of the structure of the atom and the nature of radiation becomes evident.

Industrially, the value of the rays for purifying water supplies has been clearly demonstrated in practice and a number of municipal installations are in successful operation. In the province of pathology, the field of usefulness of ultra-violet rays is being constantly enlarged.

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ERRATA

In the February number of the GENERAL ELECTRIC REVIEW in an article entitled, "What the Superpower Survey Means to the United States," by H. Goodwin, Jr., the statement was made, that Mr. R. Beeuwkes (Electrical Engineer of the Chicago, Milwaukee & St. Paul Railway Company) said, at the Pasadena Convention of the National Electric Light Association, "that he considered it would be better for the central station to own and maintain the transmission line" (along the railroad). This statement is in error. Mr. Beeuwkes states that he was not at the Pasadena Convention, nor does the statement attributed to him correctly represent his views regarding this matter. He feels that the question as to whether the central station or the transmission line should be owned by the Power Company or the Railway Company, respectively, is one dependent entirely on the circumstances of the individual case.

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.

Ball Bearings

Mounting Ball Bearings. Delaval-Crow, T. C.
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(Theory of construction of charts for the solution of various types of formulae.)

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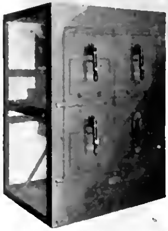

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MILAN R. BUMP

President, National Electric Light Association

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GENERAL ELECTRIC
REVIEW

IS DEMOCRACY TO FAIL?

We have gotten quite fond of talking about the human element in industrial organizations, it might almost be said to be a fashion. It is a useful fashion and a right fashion. But, as often happens, we have not laid enough stress on something even bigger. The bigger thing that appears to have been neglected in this instance is the human element in modern civilized society. It is quite right and perfectly proper to study the human element in the relationship between capital and labor—between employer and employee, but it is more imperatively important to study the human element in every home, high or low, rich or poor, because here is the cradle of our civilization.

Sometimes people hate to tell the truth, because the truth is unpleasant—but modern democratic ideas tend to level downward rather than upward. This must be changed, it must be made only a passing phase in our development upward.

Any system of education that does not provide efficient workers in all walks of life is defective. But in a democratic state are we to keep a certain set of people ignorant in order that they will be willing to dig our ditches and wash our plates and dishes?

If there is one slogan which really typifies democracy it is "equal opportunities for all." Equal opportunities for all are impossible without education for all and almost impossible without free education for all, but free education for all almost necessitates standardized curriculums for the different grades in both school and college. How can any standardized system of education provide for that higher education which is so essential if we are to develop our best brains to be the leaders in all walks of life? But does a democracy want leaders? It needs them.

Modern education tends to turn a man that would make a good laborer into a poor mechanic—to turn a man who would make a good mechanic into a poor draftsman—to turn a man who would make a good draftsman into a poor engineer. But what does it do for the man who would make a good leader? Superficial education makes poor followers and no leaders—and makes almost all men discontented. It is easier, however, to point to the faults of modern society than to demonstrate the remedy. It is easier to say that the object of education should be to draw out the inherent qualities of the individual rather than to cram in facts, a process which is so efficient in destroying the originality—than it is to suggest a system that can meet our modern needs. At present good men succeed in spite of our system of education.

Is democracy to fail for these reasons? Look at the successful democracies of history. Greece was a successful democracy in the golden age of Athens. Rome was a successful democracy in the height of her power as a republic, and in these democracies men and women both had leisure for learning and for recreation. In our democracy what leisure have we? What leisure have our wives, our sons and our daughters for learning and for recreation and for the study of those all-important things which make life really worth living and worthwhile? None, absolutely none in the case of the average home of the professional man. Domestic service and small service has become so prohibitive that the old-fashioned home life is almost a thing of the past.

Why is it that in the older democracies they could have what we cannot have? It is a strange fact that there is just one point about the old successful democracies that is always forgotten. They had slaves to cultivate their fields, dig their ditches, wash their plates and dishes and to do all those things that no one wants to do. These slaves had no part in the democratic life of the state. They were the captives of their many successful campaigns, and it should be noted that it was not until they had these slaves that they could devote their time to that literature and art which has made them famous throughout the ages.

Yes—it is absolutely true that we are in a bad way in our modern democracies because we have no slaves—and we want slaves if we are to have the leisure for learning and for the cultivation of the really worthwhile types of literature, art and music and those hundred and one other things that make people really civilized. But the thought of slaves is repugnant to our modern democratic ideas—human beings whom we can force to work for long hours and no wages and as little food as will enable them to do their daily tasks—all work and no privileges. We want them. Can we have them and give ourselves, our wives, our sons and our daughters more leisure?

The strange part of the whole thing is that the answer is just the opposite from what most people would think. It is yes—not no. We can have just such slaves if we are only sufficiently intelligent and realize it.

Have you ever thought that the electric washing machine can do more work than a strong washerwoman and twice as much as a woman with an aching back? Do you realize how much an electric flatiron can do to relieve the household burden? Are vacuum cleaners toys to play with? Do you want to make a household drudge of a human being or would you rather have a machine wash the plates and dishes? Would you rather have some human being carry coal up the cellar steps and then carry the ashes down and do all the cleaning up—or use an electric cooking stove? We do not ask a human being to turn our grindstone in our workshop. Why should we not turn our knife cleaner by an electric motor? How many burdens are there in the drudgery of everyday housework that an electric motor could relieve? How much mess and fuss and trouble can be saved in every household by using electric toasters, percolators, chafing dishes, water heaters, etc., etc?

Do you like nasty oil lamps or tallow dips—and the cleaning of the messy things—or do you prefer the incandescent lamp?

For over a quarter of a century we have been finding out how to make these things. We have found out how to make them and use them. There is no longer any question of—can it be done? It can be done, it has been done. The only question is how cheaply can it be done.

It pays sometimes to stop patting ourselves on the back—metaphorically speaking—and talking about our accomplishments and the wonderful things we have done. The advances we have made are wonderful—but let us tell the truth. The application of our advanced knowledge to everyday life is disgracefully slow. The scientist and the engineer have done their work and done it well, but when we look the facts squarely in the face why do we not use what they have done?

Today even in the most advanced countries there are more houses unwired than wired and in our cities there are still a regrettably large number of streets lighted by older forms of illumination. And when we consider the world as a whole we are forced to realize that, although electrical developments have far outgrown the infant stage, the applications of electricity in the home, office and factory are still in the infant class so far as the wide world is concerned.

It was during the reconstruction period after the Napoleonic wars that the application of the steam engine to industry in general, and to railroads in particular, not only re-established the economic status of nations but carried them to a higher plane than they had ever reached before. During this reconstruction period there is no reason why far greater results should not be accomplished by putting all our efforts into forcing the general adoption of the electric apparatus and appliances we have already developed. This is, in fact, a sacred duty to the country and to every home.

The really worthwhile civilization started, and the best form of Christianity began when men started taking the load from the backs of men and putting it on the machine—and did away with the thought of human beings as slaves. Our modern democracies will not stand for slaves of the old type—the human slave—but they cannot last and flourish without slaves of the new type—the machines. Our civilization—our democracy (that is our equal opportunity for all) our learning—our comfort—our wealth in the future are going to be a direct measure of how much work we do in the direction of taking the burden from the backs of men and putting it on machines.

Life is full of paradoxes—if you ask the man most familiar with the electrical industry why electrical apparatus and appliances are not more extensively used—why it is not in common use in every household, high or low, rich or poor, for every purpose where it could relieve the human burden—what will he say? Heaven only knows what his answer will be. Some will say that you can do this and you can't do that with electricity at the present price. The general impression seems to prevail that the cost of electricity is preventing its more general use. As a matter of fact, exactly the opposite is true. It is the limited use that we are making of electric energy that is keeping the price up.

If every household were to install the electrical apparatus it ought to use to ease the human burden the load factor would be so much better, and the power companies could do such a much greater business for the same service that they are now rendering for the smaller load, that they could and would then reduce the charges per unit used.

We hear a great deal about vicious cycles, but here is a virtuous cycle. The more you use—the cheaper it becomes—the cheaper it becomes the more uses it pays to put it to. When you pay your monthly light bill, which ought to be a bill for power and light instead of for light only, you are paying for more service than energy. The electricity has to be generated, transmitted and distributed; this all costs a lot of money. It is delivered to you in such a way that you can use it for power, heat and light. It is at your service for every minute of the 24 hours and you can use as much or as little as you please and at any time you wish. This class of service costs a lot to render.

A good simile to make you realize how much service you are really paying for in the case of electric energy is that no one would object to paying one dollar for the service of a taxi and chauffeur for an hour, but no reasonable person would expect to obtain the service of a taxi and a chauffeur for one dollar if he kept both taxi (with engine running all the time) and chauffeur waiting 24 hours outside his front door and only used them one hour in the 24. Yet this is exactly what you do in the case of electric energy.

If electricity were of such a nature that you could go to the power station and carry it home in bucketfuls you could get it cheaper, or you could pay some one else for bringing it to your house, in exactly the same way as you do with coal.

Remember our equal opportunities for all—our democracy—depends upon transferring the load from the human being to the machine—also remember—the men who have invented—made—and put into use the many contrivances that do the hard work that men used to have to do are the men who have done most for civilizing and Christianizing the world. There is no greater—no nobler—no more elevating task than contriving means to do by machines what man has formerly had to do by the sweat of his brow. Our manufacturers, our public utilities, and our railways are the Christianizing forces of our modern civilization.

Ignorance, unfortunately, has often talked very loud against these factors of our modern life. These large organizations which carry on this good work are composed of human beings—of men of flesh and blood—and they have made mistakes—but the only people who never make mistakes are the people who never do anything.

The world today does not realize in the slightest the debt we owe to the inventors and makers of our modern slaves and here is another of life's paradoxes—the people who have benefited the most have fought against them the hardest. Inventors, scientists, and manufacturers have benefited the working man more than any other section of the community. Compare the lot of the working man 100 years ago with his lot today—think of the house he lives in—the shop he works in—the clothes he wears—the food he eats—the education he receives and in general the life he leads. All of them absolutely beyond the reach of all but the very rich only 100 years ago—and yet who has fought our progress at every stage. When the first thrashing machine was invented the laborer smashed it, and burned the ricks of the owner into the bargain, because it was going to do him out of a job. When the first iron ship was built it was sunk because it was going to do the men who only knew how to build wooden ships out of a job. The first steam railways were going to put the stage coaches out of business. Machine tools were going to do mechanics out of a job. But what is the real truth when we look backward? The lot of the working man has improved, not only with, but because of every new invention. There is no one set of people in the community that have benefited more from the use of machines than the working man. Ask a modern workman to do the work that the galley slave did. See what he will say! Ask him to go into your barn and thrash your corn with a flail. See what he will say! Ask him to move your household goods on his back or in a wheelbarrow! Ask him to work all day long on a foot power lathe!

Why are these things done differently today from yesterday? Because of inventors and the children of their brains—machines. If they have so changed the state of man in one century—what can they do in the future?

Dream, sometimes dream, and in your visions see,
In years ahead, the wonders that shall be;
Each year that dawns, new marvels shall unfold.
Man may not grow; our story's never told;
Machines no limits know.
In future years, the might of the machine,
Shall far outstrip, all that the world has seen
Of Strength and Might; what limits to our use,
If you will learn, such marvels to produce,
As lies within your power?

There are no limits set to what machines can and will do for man in the future excepting the limits set by man himself.

There is no greater crime against the state and against each individual workman himself than limiting the output of machines on the foolish, criminal and wicked theory that a high rate of production puts workmen out of a job. A high rate of production per man and per machine is absolutely essential if machines are to do in the future what they have done in the past for the working man. Nothing but ignorance could start, entertain and preach such rank nonsense. How many workmen can have a car today because Henry Ford found out how to produce a cheap car? What would the workman be paying for a loaf of bread today if some one had not developed agricultural machinery—milling machinery—and railroads?

Here is a strange fact. The lot of the working man (and most of us are working men only some work harder and more intelligently than others), the lot of every one in fact, can be improved during the next quarter of a century more than our lot has been improved in the last 100 years. Our home life can be made happier, more worthwhile and brighter by a co-operation in the cheaper production of electric apparatus and appliances. Compare the price of a motor car today with the price when the first car came out. Who could afford to buy them then—who can afford to buy them today?

How many householders are there who would like an electric washing machine, an electric ironer, electric flatirons, electric cooking stoves, electric vacuum sweepers, toasters, electric water heaters, percolators, electric lights, electric fans, electric this and electric that, in short, everything that can and ought to be in every home, high or low, rich or poor, to take the household drudgery from the shoulders of human beings with souls, that yearn to do those things that no machine can do, and place these wearisome burdens on the machine? The reason why every one cannot have them today is just because of one of those vicious cycles that our pioneers, engineers, scientists and manufacturers are always up against. But it is just these people who, in co-operation with the working men, must break this vicious cycle down. Because they are costly to make and market—not 10 per cent of the people in this country are using them, and not one half of 1 per cent of the people in the world are using them—and because so few are using them the energy for working them is costly.

The solution is absolutely obvious—make them less costly. How can this be done? Design them—then redesign them—and then redesign them again until every part, as far as human limits go, can be made cheaply by machines. Then extend the human limits—get maximum results from each man—get maximum results from each machine.

Wanted—a genius who can design a washing machine—an ironer—a vacuum cleaner, etc., etc., that can be made for one quarter or less of what they cost today.

Here is another paradox. We have plenty of such men. What was Thomas A. Edison's receipt for a genius? Two per cent inspiration and 98 per cent perspiration. We have plenty of men with more than 2 per cent genius and plenty of men with 100 per cent perseverance.

Wanted—men in authority who will be more willing to listen to the man who says it can be done than to the man who says it cannot be done.

Look at what research has done for industry—imagine what it can and will do in the future in helping our civilization. The very record of industrial research inspires faith in the future. Extend it.

Wanted—large industrial research laboratories for purely mechanical design where men can devote all their time to designing, redesigning and then redesigning again electrical apparatus and appliances so that they can be produced cheaply in large quantities. Don't load these men down with other responsibilities—keep them out of touch with the type of mind that says that they cannot do it—put men in charge who say it can be done—who believe it can be done—who know it can be done.

If this is done the story of the future will be more electrical apparatus used by more people—more energy used in more homes—cheaper energy—more electric energy and less human drudgery—more leisure—more learning—better lives—brighter lives and brighter wives—not tired wives—a better—brighter—fuller—higher type of civilization.

It can be done.
It must be done.
And the engineer must do it.

Wanted—a better understanding between capital and labor—a fuller vision by all men that will prevent strikes and lockouts—prevent curtailment of production and will stimulate mutual confidence, making the workman realize that his work, by benefiting the world, benefits himself. Let the workman understand that he himself is a capitalist if he puts his savings into the industry he is working for.

Wanted—a muzzle for all those who only criticize the work and efforts of constructive brains—and for all those who only talk and won't work.

Wanted—a realization of the fact that America is a big country and that modern business is big business and that—

It is not a crime to do business at a profit,
It is not a crime to be American,
It is not a crime to be modern,
It is not a crime to be big.

We have extended our editorial this month to an unusual length because we are asked to say something that would be useful at the convention of the National Electric Light Association to be held at Atlantic City on May 15-19th.

We feel that the gentlemen attending this convention and the enterprises they represent have a very real mission to perform, which embraces something much broader and higher than the economic stability of the electrical industry. The sound economic status of the industry is essential to the success of this mission, but this mission to be faithfully fulfilled demands an understanding of the civilizing and Christianizing influence that our industry must play in the world if we are to conscientiously perform our duty. The duty of the engineer, scientist and manufacturer is not limited to the making of money but must embrace to an intensified degree the conversion of more and more of Nature's resources to the service of man. There was never a period in history when it was more important that the true aims of our industry should be realized and when we all should work and have a firm faith in the good that can be done humanity by taking the burden from human shoulders and placing it on the machine.

John R. Hewett.

Electrify

By Milan R. Bump

President National Electric Association

Mr. Bump, as President of the National Electric Light Association, was asked to write a message to the electrical industry for this issue of the Review. His message is brief and to the point. It should help to stimulate effort in all branches of the industry.—Editor.

The coming convention of the National Electric Light Association to be held in Atlantic City, May 15 to 19, will not only bring together all the leaders of the electric utilities but many, if not most, of the leaders of all branches of the electrical industry.

The keynote of the convention will be co-operation and the mutual recognition of the inter-dependence of the various interests whose success depends upon the general progress of the industry. One of the principal features of the sessions will be a discussion of the united movement which the Association is sponsoring for the development of co-operative effort all over the country and at this time it seems wise that we review the existing situation and list some of its possibilities.

Less than half of the homes in America are wired and certainly less than half of these are adequately wired. No more than half of the industrial wheels are electrically turned Railroad electrification has scarcely been begun. The fields for electric heating and electric pumping for irrigation are only beginning to be recognized. Combining these factors, it is a perfectly safe statement to say we have not as yet realized 10 per cent of the total actual possibilities, in spite of the fact that there is no question that our country is far in advance of other countries in electrical development. Taking the world as a whole, it is doubtful whether more than 2 per cent of the actual possibilities have been covered.

The present financial outlook is highly satisfactory. The turn in business conditions has given renewed hope in all industries, but no other industry can face the future with the certain knowledge that there is no possibility of over-building for many years to come. We have heard much recently of industrial revival which has brought up the percentage of operative capacity in other industries from the low point of 20 and 30 per cent to 60 and 70 per cent. As far as the central station industry is concerned, there is no such thing as over-capacity today and in fact an acute shortage of capacity exists at many points.

Plans under way, which are rapidly becoming realities, will speedily load up our manufacturing capacity of all classes and will tax the industry to find and develop sufficient man power for construction and installation purposes. Under such conditions an enthusiastic united industry is bound to move forward to success greater than ever before dreamed of and is bound to make for prosperity in every branch of the industry. The opportunity before every individual in the industry is unlimited. A realization of this opportunity must be placed before every employee and with this realization will come a period of development such as we have never known. The future can be just as big as we in the industry make it.

Business Development

By H. A. Lane

Director, Joint Committee for Business Development of the National Electric Light Association

In this article the author outlines the nationwide program of the Joint Committee for Business Development. He tells of its aims, its scope and of its organization.—Editor.

"The electrical industry has never faced a more favorable opportunity for the development of its business." This statement was made by Mr. Milan R. Bump, President of the National Electric Light Association, in calling a meeting of the representatives of the electrical industry to discuss a proposed program for business development.

This meeting was held on January 9, 1922, and on this occasion the Joint Committee for Business Development was created and representative members of the electrical organizations were appointed thereon. To simplify the work the Committee formed four departments: Appliances, Industrial Power, Lighting and Wiring—and also an Information Committee composed of the chairman of each of these departments and the chairman of the Joint Committee.

A number of meetings of the Joint Committee, as well as of the departments, have been held to outline the work. Each of these committees has prepared a very complete prospectus containing suggestions for local activities and outlining the objective of the movement.

The real objective of this movement must be to sell to the people a confident belief that good times are not only coming, but are here, and organize this confidence into a willingness to buy and to build.

For the electrical industry to make a campaign under such a slogan as "More Business—Better Business" would fail to win a popular response. But a broader vision, which would make the purpose crystallize into a "Good Times" movement, or a national program locally organized that will reflect this spirit, will react favorably upon general business now already eager for the resumption of business activity. This movement, therefore, should have a vision broad enough and a purpose big enough to make it possible to rally business interests around its banner.

The success of this movement must be expressed in actual business, if its objective is to be realized. People must be convinced that it now is the time to buy the things they need. Therefore, every industry that can contribute to the strengthening of this impulse should co-operate with the local organizations of all those interests that can assist in stimulating building and general buying.

The function of the electrical industry in this movement will be not only to lead the movement, organizing it nationally and locally, but to bring into the working team as many other industries as possible. It is only through a general acceptance by the public of the spirit of this movement that a resulting quickening of business with the electrical men will be evidenced.

The plan is to enlist all branches of the electrical industry, each branch undertaking certain functions of both the national and local program. This work will be featured nationally through the Joint Committee for Business Development, and locally through organizations existent, or to be developed.

The Joint Committee for Business Development embraces representatives of the various electrical organizations and this committee is developing a program which will be administered by a headquarters organization, located at 29 West 39th Street, New York City. This headquarters organization includes a Director operating under the supervision of the Joint Committee, and an adequate staff which will carry out the program as adopted. It is expected not only to call upon individuals in the electrical industry, but to call into consultation the different associations, each of which will have a definite part in the program of this movement.

The first step in carrying out this plan has been the development of a balanced program in which the different branches of the industry will undertake special functions which each can best perform, to the end that all engaged in the electrical industry may be united in a common effort to increase the sale of electric service, appliances, apparatus, accessories, the wiring of all classes of buildings, and the development of the market in every possible direction.

To carry out this program, aside from the outlined assignments which may be from time to time assigned to the various branches of the industry on the Joint Committee for Business Development, there are certain phases of the work which must be appreciated in advance by the various interests concerned.

The electric light and power companies, for example, as a result of war conditions and the handicaps arising therefrom, in many cases abandoned or suspended a large part of their sales and development activities. They directed their forces toward other work in order to hold their organizations together, and have not as yet reorganized their commercial activities upon a pre-war basis.

It is urged that every electric light and power company take advantage of this movement, and have a wideawake commercial department for the creating of new business. These commercial departments should be so organized that they may take a leading part in co-operation with contractors, jobbers or manufacturers in their localities. The facilities of a well organized commercial department should be such that it can offer its services to the public to plan new installations and improve existing installations. This should stimulate a desire on the part of the architect, engineer and electrical contractor-dealer to further improve lighting standards. In many instances, the central station merchandises electrical appliances and in many communities they do not do so, or are not properly organized, but in no community should the central station overlook the building of a firm foundation for better business by strengthening the community electrical merchandising influence, so that the entire local trade will be co-ordinated with the right policies. The commercial department should also organize and direct the work of readjusting power conditions in the community in step with this industrial business development movement. There will be new opportunities to sell and install electric motors, industrial heating, etc., and also situations where existing power equipment will need re-adaptation to meet changed conditions. In all matters of power development or readjustment, the closest co-operation with all business houses interested should be maintained. Each electric light and power company operating in a community where electric vehicles can be used advantageously should not overlook the possibilities of this business, to promote aggressively the sale and use of electric vehicles in co-operation with the distributors, manufacturers and prospective purchasers.

The method by which the manufacturing branch of the industry will co-operate is by throwing the weight of its selling staff in the support and the promotion of the movement. The manufacturers of washing machines can concentrate on bringing before the public the idea of washing their clothes electrically. The manufacturers of vacuum cleaners can focus on the idea of cleaning electrically. The manufacturers of electric ranges can sell the idea of cooking electrically. The manufacturers of wiring materials, lamps, fixtures, etc., can concentrate their efforts on selling the idea of a more complete electrical home. In this way the entire manufacturing industry can be marshalled behind the movement with definite work for each kind of manufacturer to do.

The jobbers can apply their intimate regional contact with the local contractors and dealers for selling the idea of business revival and facilitating the supply of materials in support of intensive local campaigns, and creating a desire on the part of the buying public for the convenience of an electrical home or a better operated factory.

The electrical contractor, during the war period, while building construction was dormant, was compelled to allow the wiring end of his business to dwindle. With the resumption of building, which is now widely advocated by all interests, there is a tremendous job to be done in wiring construction. All new buildings should be wired adequately as a basis for complete electrical equipment. Unwired houses along existing lines should be wired up under the stimulation of increasing building activity. Already wired houses should be sold additional convenience outlets to raise the standard of these installations. And then there is the idea of selling more light. This may require additional wiring or a complete rewiring of the house. There is also the idea of additional light to prevent accidents. All of this applies not only to dwellings, but to commercial and industrial buildings as well. The sale of electrical appliances should be increased and intensified as a feature of each wiring installation.

By a determined drive to present users of electric service, whose homes, stores or factories are not completely equipped with its advantages and conveniences, the electrical industry will be performing a real service and will materially help in the development of business generally.

The success of this movement will, in a very large measure, depend upon the local organization of the work that must be done in each community. In each town the local interests should organize a local activity committee, either as a volunteer organization, or under the direction of some existing agency, as an electrical club or league, etc. The national headquarters will provide any such local committee or club a suggested program with details. Records of other activities, both national and local, will be forwarded from which a wealth of worthwhile things to do can be gleaned. Where necessary, assistance will be gladly given in the organization of a local committee or club.

The efforts in a community should not be confined to only one activity, but a series of activities should be planned over a long period of time. The movement should not be a flash but a continuous drive. The Joint Committee for Business Development was not organized for the purpose of putting over a quick and furious selling campaign. It was created to apply the momentum to a continuous development of the commercial activities of the electrical industry.

In conducting lighting activities in a community, a series of efforts should be undertaken, such as home lighting, store lighting, sign lighting, factory lighting and street lighting.

In the case of industrial power activities, these can well include such things as industrial heating, city pumping, refrigeration, electric vehicles and isolated plants.

If each of these several fields were well covered it would require a year or two to carry out the program. And by the time the program had been finished it would be time to start all over again.

With the united effort of every branch of the electrical industry in the promotion of such a series of activities, a movement of this nature can command 100 per cent attention of any community. With hundreds or thousands of communities doing this, the efforts will be felt all over America.

With these thoughts in mind, the Joint Committee for Business Development has undertaken the preparation of a series of very complete and attractive Guide Books, with chapters, containing suggestions for local activities in the lighting, industrial power, appliance and wiring fields, together with a brief description of the experiences of those communities which have already successfully completed work of this nature. Methods and types of organizations are also described.

The Joint Committee will have an interesting and instructive exhibit at the Atlantic City convention of the National Electric Light Association, May 15 to 19. A full half day session upon the general program has been allotted to the explanation of the work to be accomplished, nationally and locally. In each of the afternoon sessions of the Commercial Section, one topic of the general program will be discussed.

The National Electric Light Association will offer a loving cup as an award of merit to that city whose report of activity, read on the convention floor of the N. E. L. A., is considered the best. This award will be competed for annually. The award will carry with it a well displayed announcement, describing the prize-winner's city and the reasons for it being awarded the prize.

The personnel of the Joint Committee for Business Development, its four departments and the sub-committee are:

Chairman, R. H. Tillman, Consolidated Gas, Electric Light & Power Co., Baltimore, Md.; R. H. Ballard, Southern California Edison Co., Los Angeles, Cal.; A. K. Baylor, General Electric Co., 120 Broadway, New York City; A. A. Brown, Westinghouse Electric & Mfg. Co., 165 Broadway, New York City; E.L.Callahan, Westinghouse Lamp Co., 165 Broadway, New York City; LeRoy Clark, Safety Insulated Wire & Cable Co., 114 Liberty St., New York City; Rex Cole, Duplexalite Works of General Electric Co., 6 West 48th St., New York City; S. E. Doane, National Lamp Works of General Electric Co., NELA Park, Cleveland, Ohio; F. R. Farmer, Beardsley Chandelier & Mfg. Co., Chicago, Ill.; R. E. Fisher, Pacific Gas & Electric Co., San Francisco, Cal.; C. E. Greenwood, Edison Electric Illuminating Co. of Boston, Boston, Mass.; C. E. Hillis, Electrical Appliance Co., San Francisco, Cal.; A. J. Hixon, National Association of Electrical Contractors & Dealers, 308 Dover St., Boston, Mass.; F. A. Ketcham, Western Electric Co., 195 Broadway, New York City; E. W. Lloyd, Commonwealth Edison Co., Chicago, Ill.; C. K. Nichols, New York Edison Co., 130 East 15th St., New York City; W. R. Putnam, Idaho Power Co., Boise, Idaho; W. E. Robertson, Electrical Supply Jobbers Association, Robertson-Cataract Electric Co., Buffalo, N. Y.; Frank W. Smith, Vice-president, & G. M., United Electric Light & Power Co., 130 East 15th St., New York City; L. R. Wallis, Edison Electric Illuminating Co. of Boston, 39 Boylston St., Boston, Mass.; Milan R. Bump, President, NELA; Henry L. Doherty & Co., New York City; C. L. Collins, 2nd, Reliance Electric & Engineering Co., Cleveland, Ohio; M. T. Gleason, Gleason-Tiebout Glass Co., Brooklyn, N. Y.; George Osborn, Edison Lamp Works, General Electric Co., New York City; P. B. Zimmerman, National Lamp Works, General Electric Co., Cleveland, Ohio.

Lighting Department

P. B. Zimmerman, Chairman, National Lamp Works, General Electric Co., Cleveland, Ohio; Rex J. Cole, Duplexalite Works, General Electric Co., New York City; L. R. Wallis, Edison Electric Illuminating Co. of Boston, Boston, Mass.; S. E. Doane, National Lamp Works, General Electric Co., Cleveland, Ohio; F. B. Farmer, Beardsley Chandelier Mfg. Co., Chicago, Ill.; E. L. Callahan, Westinghouse Lamp Co., New York City; F. W. Smith, United Electric Light & Power Co., New York City; George Osborn, Edison Lamp Works, General Electric Co., Harrison, N. J.; M. T. Gleason, Gleason-Tiebout Glass Co., Brooklyn, N. Y.

Appliance Department

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National Electrical Development and Its Effect Upon Utility Regulation

By M. H. Aylesworth

Executive Manager, National Electric Light Association

Mr. Aylesworth was to have prepared a special article for this issue, but has had to postpone his contribution until a later date. The substance of his present article was given as an address before the Ohio State University.—Editor.

When Edison, on October 21, 1879, produced in his laboratory at Menlo Park, New Jersey, an incandescent lamp with a filament of carbonized cotton sewing thread, he little dreamed of the great electric light and power industry that would spring into birth as a result of his discovery.

At that time the series arc lamp had established itself for street lighting, but there was no multiple system of low voltage for interior illumination whereby one lamp could be lighted or extinguished independently of all the others in the circuit.

What Edison in his epoch-making invention succeeded in doing was to make electric light divisible, thus producing something smaller, safer, better and more practical for general electric service.

The commercial promotion of the dynamo and motor came quickly on the heels of this development of the incandescent lamp and was followed by the perfecting of the alternating-current system of electric generation, transformation and distribution.

Pioneer Electric Light and Power Stations

The modern system of electric supply from a central source was inaugurated at a time within the memory of men still living and active. On an ordinary brick structure on Pearl Street, New York, is a bronze tablet with this inscription: "In a building on this site an electric plant supplying the first Edison underground central station system in this country and forming the origin of New York's present electrical system, began operation on September 4, 1882, according to plans conceived and executed by Thomas Alva Edison."

About the same time another Edison generating station was started in Appleton, Wisconsin, and while the dynamos in New York were driven by steam engines, waterwheels were used to drive the electric generators at Appleton. Strange as it may seem, the first central electric light and power station blazed the way for the best steam central station practice of today, just as the general arrangement and salient features of the first electric incandescent lamp still persist;—a marvelous tribute to the skill and genius of Edison.

Introduction of Alternating Current

At first the Edison companies were to be found only in a few cities and engaged exclusively in the lighting business. The lamp hour was the unit of measurement at that time and one cent a lamp hour was considered a very fair charge. The kilowatt-hour as a unit of measurement was not heard of until 1893-1894. With the production of commercial electric motors, the application of Edison electric service was considerably broadened although, because of the low voltage, there were distinct limitations on the distance to which direct current could be carried from the central station.

A revolution in the art of electric generation and distribution took place in 1885, with the introduction of the alternating-current system. The invention of polyphase apparatus by Nikola Tesla extended the use of alternating current still farther and gave incalculable value to water power development. As a direct result of the introduction of alternating current there sprang up the immense network of high-tension lines which now traverse all parts of the country.

Marvelous Growth of the Electrical Industry

Beginning with 1890, expansion in electrical art and science became very marked. Electric power stations grew larger and larger and more truly performed their functions as a central source of all electrical supply. Engineering practices were standardized and developed, and invention had hard work to keep pace with the ever-increasing needs of the industry. Small reciprocating engines were replaced by steam turbines which grew in size from 5000 h.p. to 60,000 h.p. in less than a decade. Transmission voltages increased with like rapidity from 33,000 to 220,000 volts and the maximum distance of transmission from a few miles to many hundred miles.

In 1906 the carbon filament lamp was displaced by the tungsten filament lamp and more recently by the nitrogen filled lamp which gives more than five times the illumination per watt than the old carbon lamp. The number of electric central stations increased to over 5000, ranging in rating from a few hundred horse power to 300,000 h.p., and the variety of uses to which electricity has since been put has eclipsed the wildest dreams of its pioneers. Due to the cumulative effect of more and more light and greater and more diversified uses of motors and electric heating apparatus, the output of electric central stations increased by leaps and bounds. In 1902 it was 2,500,000,000 kw-hr. but it kept on doubling every five years, and the United States Census, taken in 1917, gave the kilowatt-hour output of the electric central stations in the country as 25,440,000,000. In 1921 the estimated output was over 43 billion kw-hr. Thus an industry unknown less than two score years ago now ranks among the most important in the world.

Consolidation of Power Companies

Turning now from this brief summary of the stages of progress in the electric light and power field, let us trace the evolution of independent companies or systems into interconnected or correlated groups and note the trend of developments. To begin with, the impelling and underlying motive for constant improvement in the electric light and power field is service. Service is the shibboleth of that industry. All its traditions cluster around it and all its energies are bent to make it, within human limitations, perfect.

Electric power plants supply a service—not a commodity, and since no economic method has yet been devised for storing electrical energy in large quantities, electric power generation must be coincident with the demand for electricity and vary according to that demand. Every power plant must therefore not only have installation sufficient to meet the maximum demands, but must also have a certain percentage of excess installation for the purpose of anticipating increases in markets and to insure continuity of service in case of accident.

The relation between the actual equipment used and the maximum equipment installed determines the load factor. This load factor, or ratio of utilization of installation, is of the greatest importance in the electric power business. Certain charges upon the power plant, such as interest, insurance, taxes, and to a considerable extent, depreciation, are constant, regardless of the amount of electricity produced. Even operating charges become less per unit of output as the quantity of electricity produced increases and every means which may be employed to increase the percentage of the utilization necessarily decreases the cost of the business. Different classes of users have different kinds of maximum demand and the larger the market supplied, the greater this diversity. To secure the advantages attendant upon diversity of demand is one of the chief reasons for the existence of the electric central station and constitutes the chief motive for joining many plants and many markets into one combined system.

Formation of Holding Companies

The realization that small local plants operating independently could not fully serve their communities came fifteen years ago. There was no escaping the fact that small companies could not risk investment for the fluctuating supply of electricity to large users, nor could they at times command sufficient funds for the adequate extension of their systems. If the industry was to expand and grow and come up to the expectation of its leaders, something had to be done. Consolidation was realized by the clear-sighted to be an ultimate and inevitable necessity. In the very nature of things this gave rise to what is known as the holding company, a corporation which owns the securities or properties of local operating central stations. The latter are sometimes contiguous and are joined by transmission lines. Sometimes they are located largely in one state or scattered through many states, but whatever their number or location, one central management provides the necessary finances for growth, standardizes engineering practices and construction, and consolidates purchases, all of which trends for lower costs. The economies which result from such an arrangement are many.

It is evident that while a single generating station may take advantage of the diversity factor of the various industries located in the community, a larger station serving many communities or a system of interconnected stations has the added advantage of the diversity factors of the industries and activities of many communities. Under a former and to some extent still existing condition of power generation, particularly in industrial and populous districts, there is a serious waste of resources and a heavy expense for labor and materials for power production that can be and should be eliminated by centralization of power generation, by unifying the operation of the systems and by discontinuing power production in inefficient plants. Moreover, where there are water power resources, these should be developed and interconnected with existing systems for the best interchange of facilities to secure the highest economy and reliability of service. Thus, wider and wider interconnection of stations and systems is the order of the day, and it is only through the operations of the holding company that such consolidations and interconnections can be effected. Indeed, it is the holding company that has made twenty-four hour service possible in many small towns and it is to the holding companies that other rural communities and the farmer must eventually look for service. Were it not for the existence of such central organizations electric service would be greatly restricted and the rates therefor would be much higher than they are now.

Customer Ownership of Utilities

There is another phase in the modern development of the public utility industry in which holding companies play a very important part.

There is gradually being worked out the real public ownership of utilities through investment in their securities by the general public, particularly the customers served.

It is becoming generally recognized by company officials and the general public as well, that it is a most helpful thing for the millions of utility customers to become their own partners in public service enterprises through investment.

The holding companies, through their larger organizations and more highly developed sales and advertising organizations, have taken a conspicuous lead in customer ownership campaigns. And on account of this superior permanent organization they are generally able to secure contact with a larger proportion of the investing public than would a single company working independently and without a central, well established force banded together for the purpose of constantly stimulating interest in the customer ownership idea.

This home ownership of public service properties by reason of a wide distribution of utility securities in almost all localities served by holding companies, has also tended to bring about and cement a more sympathetic understanding between the public served and the utility rendering such service.

The number of stockholders in electric light and power companies is constantly growing, the last estimate being that there are now 1,500,000 holders of the securities of such companies in the United States. This great growth in furtherance of the public ownership idea hardly would have been possible without the superior facilities of the holding companies.

Formation of Super Power Systems Through Interconnection

The advantages of interconnection of large power systems, which are in themselves self-sustaining, and whose generating plants are already interconnected by tie and distribution lines, for independent economical operation, are many. Interconnection not only increases the reliability of operation, it reduces the total reserve capacity required for an interconnected system over the aggregate amount required in separately operated systems and utilizes that reserve capacity to better advantage. Moreover in cases of hydro-electric plants, it enables the company to take advantage of the diversity of the natural stream flow between drainage areas, and to reduce the amount of reserve steam power necessary to guarantee continuous service. By means of interconnection the most efficient plants may be operated at a maximum to supply any great amount of steam power required in the combined system from the viewpoint of economy and coal transportation. Newly constructed plants may also be loaded in a shorter time and may be located at more economic sites, such as coal producing centers and points accessible to condensing water. Not the least of the many advantages of interconnection is the fact that water powers otherwise unavailable are made serviceable for the use of man.

Already great strides have been made in interconnection, and striking examples of super power districts are to be found in the Middle West, on the Pacific Coast, in the New England States, and in the Southern and Southeastern districts. In California, physical interconnection has made possible the interchange of electricity by companies operating between Vancouver, British Columbia, to a point several miles below the Mexican border.

In the history of zone physical interconnection, two outstanding facts appear. First, the service has been improved or maintained at the highest point of efficiency without the necessity for proportionately increased rates; and second, ability to furnish service which otherwise would not be possible has resulted in increased demands with increased benefits to those securing the service. As these zone networks come into being, they bring electric light and power closer and closer to the farm. They make it possible for companies operating in one or more communities, and physically interconnected with properties operated in other communities, to extend a distribution system into suburbs and even into rural centers where the demand for service is sufficiently great to justify it and the construction cost is within reason.

Electric Service No Longer Local but Statewide

From these facts it may readily be seen that the electric light and power industry is no longer local, in that it furnishes only the people residing within the boundaries of any one community, but, on the contrary, is an actual or potential state-wide industry, serving a multiplicity of communities and extending sooner or later to every farm and every ranch. When this comes to pass it will not only benefit the farmer and his family and hired help, but also benefit the communities upon which the farm and farmers are dependent for their markets and which in turn are dependent upon the farm and farmers for the necessities of life.

Evolution of Regulation

With the gradual recognition on the part of the public that electric service to be efficient and economical must be monopolistic, came the necessity for some control which, while protecting the monopoly, would guarantee service at rates that were reasonable and just to all parties concerned. This gave rise to administrative bodies, charged with the enforcement of specific laws and endowed with regulatory and sometimes quasi-judicial powers, or in other words, public service commissions.

Although the formation of these commissions might seem at first sight a step away from popular government, the closeness of their relation with the interests put in their charge enables the public feeling and the public wish to be expressed clearly and forcibly to those who have authority to act. Upon the whole, their creation has been very happy since it enables improvements to be effected with a minimum of friction and with a promptness almost impossible of attainment by any other means. The granting of such powers by the legislature does not imply any hostility on the part of the government to public utility organizations. On the contrary, it is the express duty of the commissions in administering their office to conserve the interests of both the stockholder and the public.

Formation of Public Service Commissions

Public utility regulation of a state-wide character in the United States dates from the establishment of the Massachusetts Gas and Electric Light Commission in 1885. Unfortunately that Commission had relatively little power at the outset, although its authority was materially strengthened with the passing years. The first public utility commissions of wide scope and power date from the establishments of the Public Service Commission of New York State, in 1907, and with the enlargement of powers and duties of the Wisconsin Railroad Commission the same year. The example set by these two states and the success attained by their commissions led other states to create commissions or enlarge the powers of old ones. At the present time, there is only one state in the Union which does not possess a public regulatory body of some sort.

As a rule these commissions exercise supervision over the quality of the service and the rates to be charged therefor. In order to safeguard the investing public and to prevent unduly high charges to consumers for service, on the ground that the companies have to earn a fair return on their investment, the Commission in many states also has control over the issuance of securities. Full power of review of state utility commission rulings and orders is vested in the courts, and, to the credit of commissions be it said, that nearly all of their decisions when attacked have been sustained by the courts, the exceptions centering around constitutional provisions against taking property without compensation and without due process of law.

Of course, reverence for utility commissions and confidence in their effectiveness, protection and security, depend on the manner in which the commissions comport themselves and on the degree to which they are responsive to the public will. It was inevitable that a revolutionary move such as was involved in bestowing regulatory powers on a commission should meet with opposition at first. Experience shows that people do not take kindly to changes from forms to which they are accustomed. Every movement of this kind has a genesis, history and development quite its own and few reforms in government have ever been successful or permanently established otherwise than step by step and by slow degrees. The history of public utility regulation offers no exception. Normally our institutions are regarded as essentially practical, formed to meet actual human experiences and human needs under existing conditions and they ought, therefore, to be free from doubtful political innovation or speculative experimentation.

Bugaboo of Home Rule

Although in some quarters regulation is still looked upon as an experiment, fifteen years of it and the regularity with which commission decisions have been sustained in the courts indicate that public service commissions have established themselves as permanent American institutions. It is true that in many cities there has arisen from time to time strong objections to state regulation of public utilities on the ground that it violates the principle of municipal home rule. But so long as the state remains sovereign over municipalities it is bound to exercise a greater or less degree of control over that which is commonly known as "local service," regardless of whether such service is rendered by private corporations or the municipalities themselves, and the courts have invariably sustained this position.

The legal interpretation of the popular expression "home rule" is the right of the municipality to regulate and control local and municipal affairs under grant by legislative or constitutional provision. The courts have held almost unanimously that a grant of authority by the state to the municipality (a political subdivision of the state) to control its local and municipal affairs does not include the regulation of public utilities, operating wholly or partially within the municipality, unless the grant goes beyond general expression and expressly names public utilities and the rates and service thereof. The highest courts of the land have held repeatedly that police power of the state should be jealously guarded and have always held that anything less than specific or expressed delegation of authority to the municipality shall be decided in favor of the state. Time after time the learned judges have commended the legislative body for its wisdom in providing for a regulated monopoly in public utility service; and have reasoned, it would seem with great wisdom, that the public welfare demanded the greatest expansion of electrical service at reasonable rates, linking together the city and country, ultimately bringing to the home, whether mansion, cottage, tenement or farmhouse, and to industry, regardless of size or location—whether store, factory, farm or mill, the great benefits of electrical service at the lowest cost consistent with the greatest expansion of service and the proper protection of the million and a half security holders, owning the electric light and power companies of the country.

Another and strong argument for utility control through the state rather than the municipality, is that very few cities can command the necessary legal, administrative and engineering staff for effective control, whereas this can readily be done by state commissions which at the same time accumulate such valuable data and a broad and varied experience, both of which are essential to efficient regulation. Thus regulation, to be fair to the public and to the electric light and power companies, must be more than local. It must be state-wide. Local regulation and control necessarily stifles suburban and rural development because the authority of the regulating power does not extend beyond the city limits. State regulation takes into consideration all elements and all factors, whether urban, suburban, or rural, and fixes rules and practices, service, standards and rates which should be fair and beneficial to all. It encourages the growth of the utility and the extension of its service to all points where that service is demanded, whenever and wherever such growth and extension is financially and physically possible and economically sound.

Regulation Should be Progressive as Well as Corrective

There is no doubt but what the future success of utilities clearly depends on greater economy and efficiency and upon a large reduction in the ratio of expense to income. Much has already been done toward reducing expense by consolidations and interconnections of systems. During the war there were those who favored compulsory interconnection of properties, but they received little comfort in the shape of popular support because the public is desirous that the capital required to provide the facilities for the electrical demands of the future should come from private investors, and it is generally clear to anyone that only as economic conditions are favorable to consolidations will they take place, and then they will come about naturally as an evolution in the industry.

During the next few years the electric utilities will be given an opportunity to consolidate still further by voluntary action, and it will depend entirely on their financial condition whether the process be fast or slow. Under normal conditions the country may look to its electric public utilities to reach agreements and conclusions among themselves respecting the co-ordination of facilities and service or the introduction of economies essential to guaranteeing the most efficient administration and methods of distributing electricity nationally under private management. Such an achievement is easily possible under a rational system of commission regulation.

For over a decade now the American people have experienced the effects of regulation of public utilities. While particular questions to be solved change with variations in economic conditions, and with the evolution of political ideals and institutions, the basic question of how best to guarantee adequate and efficient service at just and reasonable rates may be said to be fairly understood.

If public utilities are to function efficiently in private hands, they must be placed on a stable and paying basis. They must have adequate equipment, funds for expansion to meet the growing needs of the communities they serve, and their securities must become attractive to the small investor as well as to the large banker. Any policy intended to stabilize the credit of utilities must involve a broader policy of rate regulation. The commissions if they are to determine the revenues of the utilities and sit in judgment upon the security issues, must establish rates that will enable the utilities to render efficient service and provide the country with a system of electrical supply capable of progressing with the development of the country. Any policy of rate control that stops short of this degree of responsibility on the part of the state would be inimical to the best interests of the utilities and of the communities they serve.

It is a truism that no community can develop faster than its utilities. Henceforth regulation must be progressive and efficient rather than merely corrective and negative in character.

Electric Lighting's Part in the Electrical Industry

By G. S. Merrill

Engineering Department, National Lamp Works of General Electric Company

The author after emphasizing the importance of the electrical industry to mankind proceeds to point out how great the field is for still further applications of the things already developed. He emphasizes the importance of more and better lighting and calls attention to the extensive campaign now being carried out to stimulate business in the electrical industry.—Editor.

The electrical industry of this country, in all its ramifications, represents today an aggregate of invested capital of many billions of dollars. Not only is it a very important industry in size, but it stands high in the rank of industries that are essential to our present day civilization. The electrical industry attained this enviable position within a relatively short time solely because it has rendered great service to humanity. The industry has grown and prospered because it has made itself useful to the average man; because it enables him to light his home, his shop and his factories in a way far superior to any that previous generations could conceive as being possible; because it supplies him with cheap and convenient power to turn the wheels of his mills, and heat to melt his metals; because it enables him to talk to his fellow men at a distance; and because it helps to transport him and his goods. The innumerable services that electricity renders mankind have become so familiar a part of the daily life of most of us that we no longer even think of them, yet, it is because of them that the great electrical industry exists.

It is not surprising that the average individual thinks first of the developments in generating and distributing mechanism when he thinks of the wonderful growth of the electrical industry in the past thirty or forty years. These have been fascinating and spectacular; and they have truly served to make electricity more generally available. But we must remember that electricity, like money, is valuable not in itself but in what it can do. The public favors electricity because it makes available better service than can be obtained in any other way. If, unlikely as it may now seem to us, some very economical and convenient means of producing light, or power, or heat without the aid of electricity were discovered, the average man would quite readily adopt the new and discard the old. He has no particular interest in electricity or regard for the electrical industry except as it is of use to him. And all of its physical equipment is important only as long as, and to the extent that, it can render service to him.

The further existence of the electrical industry rests on its ability to continue to render useful service to humanity; and its future growth and prosperity depend upon its power to serve more and more people in more and more ways. Fortunately for the industry, there are vast possibilities of extending the services that it can render to the real benefit of the public in general.

Confining our attention to the production of light electrically—which is the point of contact with the greater portion of the public as far as the supply of electric service is concerned, and the most important individual revenue producer in that field—it seems evident that several times as much light could be employed by present users as is actually the case, to their own very good advantage, and that many more people should use electric light than now do use it.

During the past ten years the art and science of illumination has made particularly great progress. Various improvements have been made in the physical means of producing and utilizing light. These have been accepted as a matter of course by the general public to whom the old type of carbon filament lamp that was in use for so many years is beginning to look a bit odd and strange.

Not only has the improvement in physical lighting equipment made better lighting possible but those who have specialized in the study of illumination now have a very definite knowledge of the lighting effects which should be produced in various cases where lighting is used. This knowledge has been obtained by analyzing and studying the purposes for which the light is used and by determining in the various cases the essential requirements of illumination with respect to its intensity, distribution, diffusion and color. Incidentally, the knowledge thus obtained has reacted directly to bring about still further improvements in the lighting equipment itself. In arriving at these requirements it was necessary to know not only in what way, but also to what extent, the intensity, distribution, diffusion, and color affected the particular end to be attained, that is, it was necessary to discover the possible benefits that would follow the use of good light, to evaluate them, and weigh them against the cost.

Although modern lighting equipment is not unfamiliar to the general public, the general public is unfamiliar with the essential requirements of good lighting systems; it does not, as yet, know how to use this equipment to obtain for itself the very material benefits that it could derive from good lighting.

If a hunter who was unfamiliar with any weapon but sticks or clubs could be given a modern rifle, he might swing it by the barrel with telling effect. To him it would be merely a different kind of a club, one, perhaps, a little better than some he had been using. He would be wholly unconscious of the fact that this particular "club" possessed properties that might make it of far greater service to him than any of his old ones. He could not even imagine that he could bring down game with it that would otherwise be far beyond his reach. We might, if we had his best interests in mind, show him how to use this new weapon as it should be used, not as a club, but as a rifle. An actual demonstration would undoubtedly be required to fully impress him with the vast difference in results attainable.

This is perhaps an extreme instance of the possible misuse (or rather lack of best use) of one of the products of our modern civilization. We would not wish to suggest that modern light sources are used quite as unknowingly, but it is true that the great majority of people make but crude use of the means of producing light that are at their disposal. They do not know what good lighting is and consequently they can have no idea of the benefits they might derive from its use.

While much has been done to make proper means for lighting available, and to discover how light can be used to the best advantage, there is much that remains to be done in showing the public what good lighting is (as judged by advanced standards), how it may be of maximum advantage to the user, and how it may be obtained. It is in the task of awakening an appreciation of good lighting and its benefits that every part of the electrical industry engaged in or connected with the production of light should join. Lamps, reflectors, sockets, wire, meters, transformers, switchboards, generators, and boilers, and the electrical energy itself are all but links in the chain of lighting service. Once create the demand for more and better light and the business represented by every link of this chain will grow and strengthen.

The central stations, the contractors, and the dealers are the three sections of the electrical industry with which the greatest part of the light using public comes into contact and it naturally follows that they should be especially concerned with the task of carrying to the public the message of good lighting and its benefits. The promulgation of the knowledge of good lighting has been particularly difficult because of the intangible nature of the product dealt with. Since the development of the foot-candle meter, however, by which the intensity of light can be read from a scale almost as easily as the temperature can be read by a thermometer, it is becoming generally possible to talk to the ordinary man about light as though it were a material commodity.

In other lines of business, manufacturers of competitive products are co-operating in advertising the general merits of their goods. The importance of directing efforts to creating business, so that there will be more for all, is recognized in many lines of business, as may be verified by a glance at the advertising sections of various popular and business magazines. The electrical industry has already directed some efforts along this line, but its future prosperity would seem to lie in greatly extending and amplifying its co-operative activities.

Enough work of this kind has been done in different localities to prove that concerted efforts to show the public how to use electric light and to demonstrate the convenience of a well wired home, in which the many electrical labor saving devices can be used, yield handsome returns to the central station, the contractor, the dealer, and the manufacturer. The organized effort that is now being made through several of the leading national electrical associations and societies to instill a proper appreciation of electric lighting, heating, and power application in the mind of the consuming public, deserves the hearty support of every individual directly or indirectly concerned in the electrical industry. This appreciation when it has been awakened in the public mind will create business for every branch and part of the industry, from the appliances themselves back to the very boilers and generators.

Voltage Limitations and Flashing of Synchronous Converters

By J. L. Burnham

Direct-current Engineering Department, General Electric Company

The elimination of serious flashovers on synchronous converters is an important engineering problem. The author discusses the technical details of the causes and shows the remedy. He describes and illustrates the flashover barriers which have been put into service and which have proved most successful. The very severe tests which were carried out on these barriers are also described and illustrated.—Editor.

The higher the frequency and voltage the more sensitive to changes in load does a converter become. The reason, briefly stated, is that the voltage per inch of commutator periphery is proportional to the frequency and voltage with constant peripheral speed and the tendency to flash increases as the voltage across a unit length of commutator periphery becomes greater. The tendency to flash may not be a directly proportional relation to voltage per unit length but is near enough for general practice. The relations of voltage, frequency and commutator speed may be seen by the following expression:

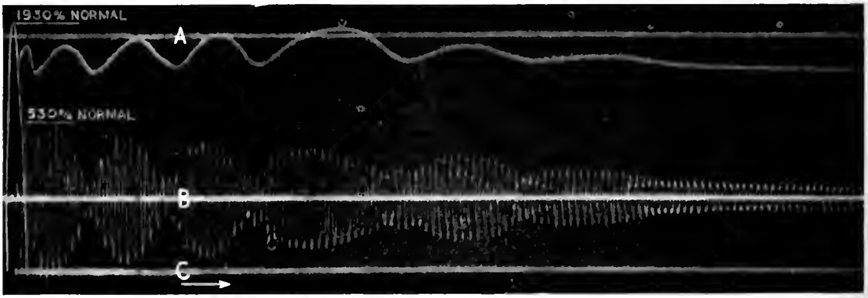

Fig. 1. Record Showing Abnormal Relations of Alternating Current and Direct Current During a Short Circuit Disturbance

A: Zero Line of Direct-current Voltage
B: Zero Line of Alternating Current (530 per cent normal)
C: Zero Line of Direct Current (1930 per cent normal)

(1) Average volts per inch around commutator = machine voltage × 2 × frequency ÷ peripheral speed of commutator (inches per second).

From these relations it will be seen that the higher the voltage the higher must be the surface speed of the commutator with the same factor of safety against flashing, that is, with the same voltage per inch of periphery. If we limit the speed the voltage is also limited.

Experience shows that an arc may be maintained with about 20 volts. It is, therefore, desirable to keep below this value for voltage between segments. Experience also shows that on the average 75 volts per inch is about the maximum that will give good commercial operation. With five segments per inch this is 15 volts between segments.

Present practice indicates 6000 ft. per min. (1200 in. per sec.) as about the maximum conservative speed of commutator to give reasonable maintenance and required precision of finish. Substituting these values in expression (1) we have

$$75 = \frac{\text{machine voltage} \times 2 \times \text{frequency}}{1200}$$

or (2) frequency × machine voltage = 45,000

For 60 cycles this gives a maximum safe voltage of 750 and for 25 cycles, 1800 volts.*

These proportions give successful performance for ordinary changes in load conditions. But for the unusual changes other conditions will be considered in their effect on the constants assumed by changing the voltage distribution on the commutator and the phenomena of commutation by which sparking is produced and the arc propagated around the commutator.

In a synchronous converter the effect of changing loads, particularly when sudden,

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* General Electric Review, June, 1916, p. 457.

causes varying voltage distribution on the commutator. The alternating- (motor) current armature reaction tends to shift the main field backward; the direct-current (generator) armature reaction tends to shift it forward with respect to rotation. With steady loads these effects are balanced, but with varying loads the currents do not have their normal relations so that one or the other predominates. As the voltage distribution on the commutator is proportional to the field distribution it is evident that excess direct current would cause lower voltage per inch on that portion of the commutator just leaving the brush, and an increase of voltage per inch on the portion approaching the brush. Excess alternating- (motor) current would give higher voltage per inch on the leaving side and lower on the approaching side of the brush.

Flashing is caused by excessive sparking on the leaving side of the brush which forms an arc between segments having sufficient voltage across them to maintain the arc. It will, therefore, be seen that excess motor current (usually a-c.) produces a voltage distribution on the commutator favorable to the formation of a flash. The varying relations between the alternating and direct current are shown on oscillogram, Fig. 1, which records the effects of a direct-current short circuit. It will be seen that the ratio of alternating to direct current changes through a wide range. At the first instant the direct current is high and later, when the direct current has been completely interrupted, the alternating current is high with later oscillations in the alternating current, changing from motor to generator, giving first favorable conditions to flash and then unfavorable.

It is evident that a generator has the advantage in regard to flashing in that the effect of its armature reaction would always make conditions less favorable to propagation of an arc around the commutator, starting at the leaving sides of the brushes.

A converter is further handicapped in unbalanced effects of alternating and direct currents on the commutating poles, as described in the GENERAL ELECTRIC REVIEW of May, 1920, page 392. This tends to cause sparking at the time conditions are most favorable to spreading of the arc. The high reluctance pole was developed to mitigate this effect.

Recognizing the desirability of still greater factors of safety than are obtained by modifying the inherent characteristics of the converter, external means of protection against flashing have been developed. The flash barrier was devised to prevent the spreading of the arc and the high-speed breaker to avoid formation of the arc by limiting the magnitude and duration of short circuit. A form of protection less effective than the flash barrier is the radial type of brush rigging which has no overhanging conducting parts on those sides of the brush where the arc forms, and is protected by insulating material to discourage arc growth. An insulating enclosure around the brush is not sufficient, however, to give complete protection. A machine provided with such an enclosure only may arc over. To interrupt the flashing the arc must be removed from the commutator.

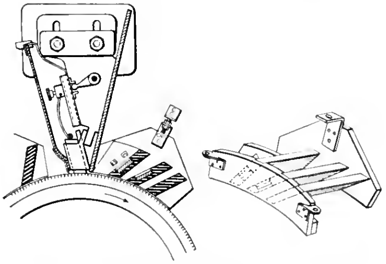


Fig. 2. Perspective of Flash Barrier and Section with Radial Brush Rigging

A later form of flash barrier which accomplishes this is shown in Fig. 2. The action of this barrier is as follows: When a short circuit occurs the arc is formed between the brushes and leaving commutator segments, being drawn out in the direction of rotation as shown by the arrow, and expanding outward. The arc is mechanically scooped from the commutator by the pointed barrier, which has metal inserted in its face. This metal and the barrier as a whole has a cooling effect, reducing the arc in volume and directing it where it can do no harm by completing any further short circuit paths. A second and a third scoop shaped barrier are also provided as additional factors of safety in case of poor adjustment or defect of the first barrier. It is seldom that the second barrier is ever required to remove any of the arc from the commutator. The member at right angles, and in front of the first barrier, shown more clearly in the perspective view, splits the arc, and confines that portion developed in the front of the two sections, in their respective sections, so they do not pile up at one corner, thus avoiding the escape of conducting gases under the side members. This form of barrier allows the free expansion of the gases, by proportioning the expansion chambers with increasing area at increasing distances from the commutator. Furthermore, it being low, releases the gases quickly after changing their course and allows free dissipation in the open air.

Fig. 3 End View of Flashing Caused by Short Circuit Recorded in Fig. 1. Machine equipped with radial brush-holders and barriers

Fig. 4. Side View of the Machine Shown in Fig. 3 Under the Same Conditions

Fig. 3 shows a short circuit on two 750-volt, 60-cycle converters in series for 1500 volts, protected by flash barriers and circuit breaker of ordinary speed. The current was approximately 20 times full load. The exposure of the negative was throughout

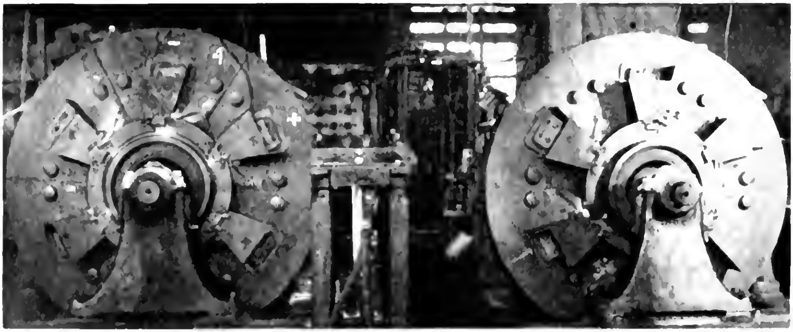


Fig Maximum Short Circuit of Two 750 volt, 60 cycle Converters Connected in Series for 1500 Volts. Machine equipped with radial brush rigging and high reluctance commutating poles and protected by flash barriers and high speed breaker the short circuit period. It will be seen that the arc is scooped from the commutator by the first barrier and thrown out almost radially where it can do no harm. Sixty-six of these short circuits were applied in succession and no appreciable burning or damage was done that would prevent the machine from carrying its usual loads. The photograph is the 46th short circuit and is representative of all. This is probably the most severe short circuit test ever applied to a commutating machine, the current in each of the 66 tests being about 20 times full load.

Fig. 4 is a side view looking down into the barrier, showing how the arc is confined to the first expansion chamber following the brushes. It is evident how the arc splitter holds the arc from moving sidewise.

As alternating-current disturbances may also cause flashing, barriers are equally useful in such emergencies.

The variation of alternating and direct-current ratio during load changes and subsequent oscillations of alternating current are influenced greatly by the reactance in the alternating-current supply circuit and the duration of the load. The reactance voltage produced by the load current shifts the applied voltage backward. If the heavy load is on for a sufficient time to allow the converter to drop backward in phase a corresponding amount, the maximum oscillation of alternating current will be produced when the load is removed By removing the load very quickly before the converter has gone appreciably out of phase, the unbalanced effects of alternating current and direct current are less and following oscillations are reduced. The high-speed breaker reduces the tendency to flash by both reducing the amount and duration of sparking and preventing an excessive increase in the voltage across the commutator bars leaving the brushes.

Fig. 5 is a short circuit of the same machine as shown in Figs. 3 and 4 but protected with a barrier and a high-speed breaker, two machines being operated in series at 1500 volts. It will be seen that the high-speed breaker has so greatly reduced the sparking that it is only slightly visible.

Fig. 6. Barrier Removed for Inspection After 50 Maximum Short Circuits as Shown in Fig. 5

Fig. 6 shows the 750-volt, 60-cycle converter with flash guard removed after it had been subjected to 50 high-speed short circuits. The commutator, brushes, and barriers were unburned. The only mark indicating that short circuits had occurred were slight soot deposits.

It will be noticed that the barriers have 3-point supports and may be quickly removed by unscrewing three nuts.

Light Weight Interurban Cars

By C. T. Dehore

Railway and Lighting Department, General Electric Company, Cincinnati, Ohio

The results accomplished by the use of light weight cars—as set forth by the author—should prove of great value to many electric roads throughout the country. These results are as astonishing as they are gratifying. The rehabilitation of our electric roads is one of our big economic problems—this article should bring encouragement to those engaged in this arduous task.—Editor.

The past five years have been such trying ones to interurban railways that every possible means had to be considered to keep the properties intact and to weather the storm. As we all know many roads went under, were abandoned and sold for scrap. We had several instances of this kind in the Central States. Some of the roads saw the inevitable in time, and took steps to prevent receivership and abandonment, by improving their power conditions and purchasing light weight cars.

The mere mention of the words "light weight" at first caused opposition on the part of some of the railway operators. They had been so accustomed to the heavy, high speed cars that the "light weight" proposition immediately seemed all wrong. Objections were raised that the cars would not stand up over a period of years; that they would not ride well; that the public would be opposed to them; that they would not hold the rail; and that accident liability would be increased. This opposition was natural and was to be expected. It is hard for anyone to turn from what he has been doing, and in general doing very well, to the exact opposite over night. However, the performance of the light weight cars over the past few years has entirely eliminated all doubt from the minds of operating men who have had a chance to investigate the situation first hand.

To analyze the objections mentioned above:

Did the Cars Stand Up Well?

After carefully watching the performance of these cars for four years in interurban service, the writer can truthfully say that they have stood up as well as any car he has ever seen; and, ordinary wear and tear excepted, are as good as the day they left the shop.

Did the Cars Ride Well?

The riding qualities were very much better than with the old heavy, high wheel cars—in fact, these light cars with 26-in. wheels are the most comfortable interurban cars ever ridden in.

The principal reason for this is that the low center of gravity, with correctly designed spring construction, eliminates practically all of the side sway, so noticeable in the older designs.

Did the Cars Make the Schedule?

All of the cars so far put into operation (with which the writer is familiar) have been required to make schedules from 18 m.p.h. up to 24 m.p.h. with actual stops ranging from $2\frac{1}{2}$ per mile to about 1 per mile. The light car, with four 25-h.p. motors, in every instance has been able to perform the service with much more leeway than the old car, although geared for 5 to 10 m.p.h. less free running speed at 600 volts.

The voltage at the motors has been so much improved by the reduced power consumption of the light car that the speed actually attained is practically the same.

Did the Public Oppose Them?

On the contrary, the public have been very much pleased with the change. The new cars are more comfortable, ride better, have no bulkhead obstructions and in every case the operating men have been commended for their move, and public relations have been improved. I should like to add here that the light weight car is not an apology for a real car—in my opinion, it is the real car in which to transport passengers.

Accident Liability—How Did it Compare?

Step accidents were entirely eliminated. Collisions were decreased, and when they did happen, were not so serious as with the old cars. Derailments have decreased—in fact, are now rarely heard of.

A brief history of the reasons for making the changes, the costs, and results obtained, may be interesting:

Cincinnati, Lawrenceburg & Aurora

This road had been in the hands of a receiver since the flood of 1913. It had been carefully managed, well maintained, and

ROADS USING 12- TO 15-TON DOUBLE-TRUCK CARS

Interurban Roads

	Length of Road in Miles	Years in Service	No. of Cars
Cincinnati, Lawrenceburg & Aurora	32.5	4	7
Union Traction Co., Nashville, Tenn.	28	2½	6
Cincinnati, Milford & Blanchester Traction Co	28.8	1½	3
Pittsburg County Ry. Co., McAlester, Okla	25	1	3
Kentucky Traction & Terminal, Lexington, Ky	70	3 mos.	10
Toledo & Western R. R.	75	1 mo.	3
Youngstown, Ohio, Suburban R. R. Co.	39	On order	2
Western Ohio Railway Co	120	On order	10
Fostoria & Fremont Railway Co	22	On order	2

City and Interurban Roads

Portsmouth, Ohio, St. R. R. & Light Co.	40	On order	4 inter. 6 city
Dayton, Ohio, Springfield & Xenia Southern Ry. Co.	20	On order	4 inter. 2 city
Bangor Ry. & Elec. Co., Bangor, Me.	66	6 mos	6 inter.

Suburban Roads

Charleston, W. Va., Interurban R. R.	75	4	7
Princeton Bluefield Traction Co	12	5	3
Interstate Public Service Co.	200	On order	5

City Roads

South Covington & Cincinnati St. Ry. Co	70	5	25
City Railway Co., Dayton, Ohio	36	On order	15
Milwaukee Electric Railway, Light & Power Co	404	1 year	100

everything possible done to make it pay its way. When the rising costs of 1917 struck it, the net began to drop, and it was apparent that drastic action would have to be taken to keep the road from abandonment. This action was taken—$175,000 was put into the property in change of alignment; shutting down the old power plant and installing two automatic substations, and the purchase of light weight cars.

There was no precedent to govern the operators of this road. They could not go anywhere else to see how it was done; they had to be the pioneers. However, they believed they were on the right track and had the courage to go ahead and find out. That was four years ago. Since that time the cars have made over 2,250,000 miles, or an average of 320,000 miles each.

The operating statistics are:

	Old Cars	New Cars Average Four Years
Weight	52,000	26,600
Motors	4-50 h.p.	4-25 h.p.
Maintenance cost per car mile	2.75c.	1.2c.
Kilowatt-hours per car mile—a-c.	4.9 kw-hr.	1.9 kw-hr.
Tie spacing—average centers	2 ft., 0 in.	3 ft., 0 in.
Schedule speed	18.5	20

The a-c. power consumption includes: a-c. and d-c. losses; conversion losses; shop motors and lights; electric heat on all cars.

The railway company estimate that the increased tie spacing is saving them about $4500 per year.

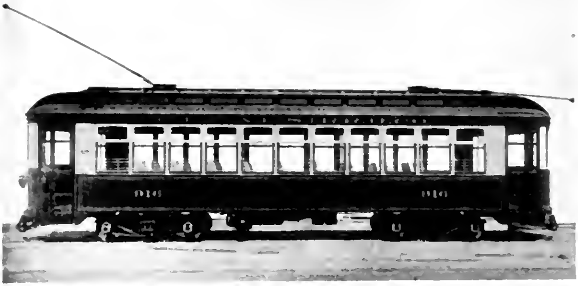


Fig. 1. Double End 13-ton, 44-passenger Car in Operation on Cincinnati, Lawrenceburg and Aurora Since June, 1918

The shop department consists of two men in the shop, one car cleaner and one night watchman. Outside work is taken in and nets the company about $900 per year. These two men maintain the seven new cars, one freight motor car, three old passenger motor cars used on holidays, etc., and do the outside work. These cars are equipped with four GE-258 ball-bearing motors on 26-in. wheels, and have double-end K35 control and G-E air brakes with CP25 compressors. Not a motor failure has been experienced in the past three years; wheels have been replaced only once and are giving a better average life than the 36-in. rolled steel wheels on the heavier cars.

The two substations each contain a G-E 200-kw. rotary converter with G-E automatic control. A daily inspection and weekly cleaning has been all of the attention normally required.

Financial results:

The cost of the new cars and substations totaled approximately . . .	$95,000.00
The old rolling stock, power house equipment and feeder wire salvaged for approximately	35,000.00
Leaving a net investment of	60,000.00
The saving per year has been approximately	34,500.00

Union Traction Company, Nashville, Tenn.

This road was built in 1912; went through a receivership and was re-organized; and in 1919 found it necessary to add a passenger car to its equipment in order to give proper service. The equipment at that time consisted of four 40-ton, 52-passenger interurban cars, equipped with four 100-h.p., 600/1200-volt motors, the line potential being 1200 volts. There were also two freight motor cars with similar equipment.

An investigation developed that a new passenger car of similar type would cost about $25,000, and as the prospects for net earnings were not bright enough to justify this expenditure other methods of procedure were considered.

The road is 27.7 miles long, of which 4.5 is over the tracks of the Nashville City lines. The balance, 22.2 miles, was fed from one 1200-volt substation 11 miles from the end of the line, two 600/1200-volt rotaries being run in series.

It was decided to "clean the slate." The company purchased five light weight passenger cars and one light weight freight car; changed the trolley voltage to 600; reconnected the rotaries for parallel operation; and bought five miles of 300,000-cir. mil feed wire. The car equipment consists of four GE264 motors and K35 control with CP27 compressors.

Fig 2. Single End 14 ton, 48-passenger Car with Baggage Compartment in Operation on Union Traction Company, Nashville, Since January, 1920

The installation has been wonderfully successful. Not a motor failure has been experienced in over two years of operation;

there has not been one hot journal. It has not been necessary to take a truck out from under a car in those two years. During that time the cars have made approximately 600,000 car miles.

The operating statistics are:

	Old Cars	New Cars
Weight (passenger)	80,000 lb.	28,000 lb.
Weight (freight)	75,000 lb.	32,000 lb.
Motors (passenger)	4–100 h.p.	4–25 h.p.
Motors (freight)	4–100 h.p.	4–40 h.p.
Average schedule speed	21 m.p.h.	21 m.p.h.
Maintenance cost per car mile	4.4c.	2.4c.
Kilowatt hours—a-c	5.54 kw-hr.	2.1 kw-hr.
Tie spacing—average centers	2 ft., 0 in.	3 ft., 0 in. & 3 ft., 6 in.

The a-c. power consumption includes: a-c. and d-c. line losses; conversion losses; shop motors and lights; electric heat on all cars.

The old cars were all disposed of at a very fair price, and as a result of the change the company is able to: (1) give better service; (2) maintain schedules better; (3) decrease their expenses about $15,725 per year.

The total cost of making the change was	$66,300
The approximate salvage value of old equipment was	36,100
Making the net cost	30,200
The approximate net return per year is	15,725

Cincinnati, Milford & Blanchester Traction Co.

The story on this road reads like a dream. It is 28.8 miles long, running from Madisonville (Cincinnati) to Blanchester, Ohio. The principal point on the line is Milford, 8.5 miles east of Madisonville. After leaving Milford the territory is very sparsely settled and the business available is extremely limited. The road was built in 1903 at a cost of approximately $1,250,000. It had a very rough voyage; went through a receivership and was bought in by the present owners in 1914. It still failed to pay interest, and in 1918 was turned over to the present management.

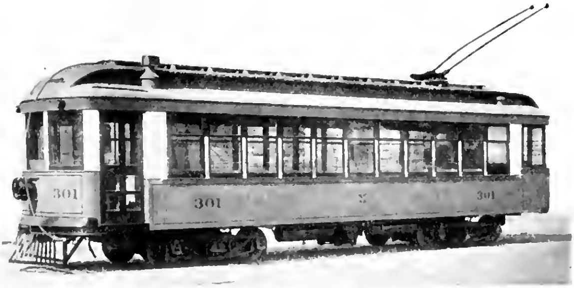


Fig. 3. Single End 15-ton, 1-man, 49-passenger Car in Operation on Cincinnati, Milford & Blanchester Traction Company Since November, 1920

About that time, the Cincinnati, Lawrenceburg & Aurora Ry. was beginning to show signs of having a new lease on life, due to light weight equipment and purchased power, and the president of the C., M. & B. decided to follow their example. After several months of negotiations, sufficient capital was discovered to purchase three new light weight cars and two substations. Deliveries at that time were long and uncertain, and in the meantime the price of coal kept continually climbing, until in the summer of 1920 the company was paying an average of $10 per ton, and for three months during that year the cost of fuel alone was 60 per cent of the gross receipts of the entire system. If

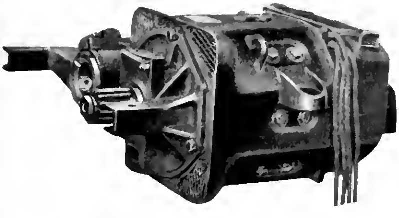


Fig. 4. GE264-A Motor (Suspension Side)

they had been required to run their old station two months longer than they did, it would have been necessary to have again gone into a receivership. Fortunately, about this time, the substation material arrived and was installed, and power purchased from the central station at Cincinnati. The light cars also were delivered at the same time. The power cost immediately dropped from an average of about $7000 per month to less than $1500.

The operating statistics are:

been entirely successful. The cars make the schedule better than the old ones; they ride better, and they are popular with the operators and with the public.

The company borrowed about $70,000 to make the change—18 months ago. Since that time this has been paid off; their bond interest for a year was also paid and a dividend of 1 per cent—the first in the history of the road. The company is now in a good financial condition, and has an operating ratio of approximately 50 per cent.

	Old Cars	New Cars
Weight	64,000 lb.	30,000 lb.
Motors	4–70 h.p.	4–25 h.p.
Schedule speed	21.5 m.p.h.	21.5 m.p.h
Maintenance cost per car mile	2.83c.	1.5c.
Kilowatt-hours—a-c	6.0 kw-hr.	2.2 kw-hr.
Tie spacing—average centers	2 ft., 0 in.	3 ft., 6 in.
Number of platform men	2	1
Cost per hour	$1.00	$0.58

These cars use GE264 motors, K35 controllers and CP27 compressors and have full safety features for one-man operation. They have now been operating for 18 months, and have averaged over 150,000 miles each. During that time not a motor failure, not a hot journal, or any trouble of any nature has been experienced. The wheels show very little signs of wear and will not need turning for probably 150,000 more miles. For the first 15 months the three cars were in regular service every day—two cars for 18 hours each, one car for five hours—and during those 15 months they did not miss a single day. The one-man operation with 22 fare zones has

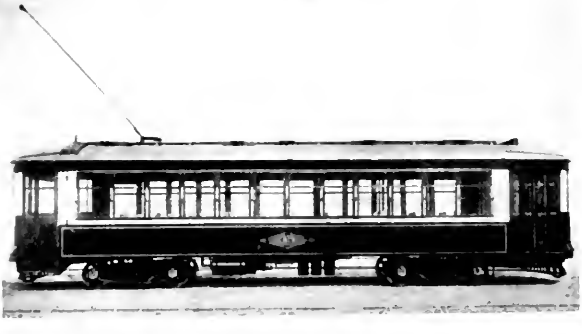


Fig. 5. Double End 15-ton, 53-passenger Car in Operation on Pittsburg County Railway, McAlester, Okla., Since January, 1921

Pittsburg County Railway, McAlester, Okla.

This company installed two of the light weight cars about one year ago. An order for a duplicate car has since been received, shipped and placed in operation. The writer has no detailed information as to the operating costs of these cars except that:

(1) The running time per trip has been cut from two and one half to two hours.

(2) The power consumption has been cut squarely in half.

(3) The operation of the cars has been entirely satisfactory.

Bangor Railway & Electric Company

This company had secured such good results from light weight Birney one-man cars on their city lines, that they decided to extend the principle to their suburban system, and purchased six cars which seat 52 people and weigh 28,600 lb., which have replaced cars which weighed 45,400 lb. and seated only 40. The new cars are equipped with full safety features, and use four GE258 motors and K35 control. They are operated by one man over a medium speed interurban line having two fare zones, and are maintaining the old schedule better than did the heavier two-man cars.

The riding qualities are reported as the best of any cars on the system; one-man operation has been highly successful, and the management reports that heir performance through several snow storms was entirely satisfactory, no equipment troubles developing, and no delays.

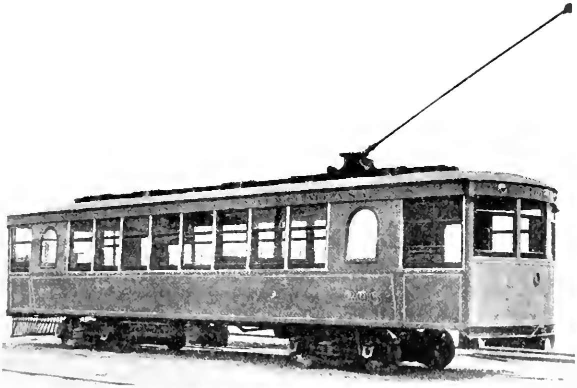


Fig. 6. Single End, 1-man, 12.5-ton, 45-passenger, 3-compartment Car in Operation on Kentucky Traction & Terminal Company, Lexington, Ky., Since February, 1922

Kentucky Traction and Terminal Company, Lexington, Ky.

This is the latest and largest installation to be actually put in operation. The company has four lines radiating out of Lexington, with a total distance of 70 miles. The line from Paris to Lexington to Frankfort is 46 miles long, and from Georgetown to Lexington to Nicholasville 24 miles. These lines have always been fairly prosperous, are well maintained, and the equipment, while heavy, was reasonably modern and was kept up in good shape.

Fig. 7. Interior of Lexington Car, Showing Fare Register Mounted under Table on which Change is Handled

The interurban lines out of Lexington parallel the public highways, which are all well paved and kept in first class condition. As a result, in the early fall of 1921, bus competition developed on every one of the four lines. With no obligations and no road tax, the busses were able to live and seriously cut into the receipts of the railway company—so much so that something had to be done at once. Here was a company with an investment of several million dollars in four interurban roads, facing absolute bankruptcy from the operation of ten or twelve independent parties with motor busses. It does not seem possible that a community would stand for such a state of affairs, but it is a fact.

The company was already seriously considering the light weight car, so they at once purchased ten cars. These cars are of the very best type that could be secured; they have wide comfortable roomy seats, with arm and foot rests; the upholstering is in plush, with spring edge cushions The seats are spaced 33 in. apart, giving plenty of room. Battleship linoleum covers the floor and rubber mats the platforms. They are equipped with

Fig. 8. Single End, 2-man, 52-passenger, 3-compartment, 36-ton Car of Kentucky Traction & Terminal Company, Replaced by 12.5-ton, 1-man Car, Shown in Fig. 6

four GE264 motors, K35 control, CP27 compressors, are completely equipped with safety features, and are operated entirely by one man. A fare register collection system is used on these cars. This system is simple, quick and has proven entirely satisfactory.

No difficulty has been experienced in making the schedules with the new cars. They get in and out of Lexington, where traffic is congested, in considerably less time than the old cars. Where formerly it was often necessary to put out cars to take the place of cars late in arriving at Lexington, this has practically ceased with the new cars.

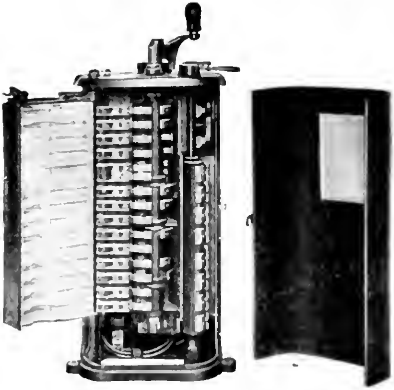


Fig. 9. K35 Controller

The headway between cars has been cut from one and one half to one hour, and with the new cars on the more frequent headway, the receipts have picked up, and the busses have begun to quit, most of them being offered for sale.

The statistics are as follows:

The company estimate that they will save per year, in track maintenance, $8000 to $10,000.

It will be noted that the demand on the power station will be reduced 360 kw. As the company does a light and power business, and can dispose of this capacity in that department, this, of course, is equivalent to increasing the capacity of the station by that amount, at a cost of approximately $45,000.

While the new cars are in operation only three months, they have already demonstrated their popularity with both the public and the operators. The men are all very enthusiastic about them; the public and press have commended the company generally on their purchase, and the receipts of the company have materially increased. It is too early to state definitely just what the financial returns will be, but the indications are that they will exceed even the company's greatest expectations.

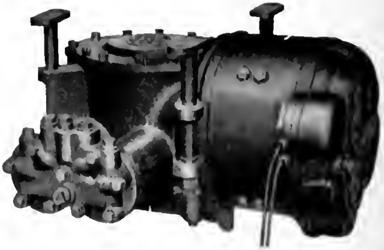


Fig. 10. CP Air Compressor

As these cars are a radical departure from the type so generally used, particularly as to the seats, etc., the following details are listed:

Length overall	40 ft., 3 in.
Extreme width	8 ft., 6$\frac{3}{8}$ in.
Post centers	33 in.
Width of seats	38 in.
Width of aisle	24 in.
Total weight	25,100 lb.
Seating capacity	44

	Old Cars	New Cars
Weight	50,000 to 76,000 lb.	25,100 lb.
Motors	4–50's to 4–75 h.p.	4–25 h.p.
Free running speed, 600 volts	40 to 45 m.p.h.	36 m.p.h.
Maintenance cost (estimated)	4c.	2c.
Kilowatt-hours per car mile—a-c	4.0 to 6.0 kw-hr.	1.9 kw-hr.
Tie spacing—average centers	2 ft., 0 in.	3 ft., 6 in.
Number of platform men	2	1
Cost per hour—platform wages	83c.	45c.
Headway between cars	1½ hours	1 hour
Demand on power station	600 kw.	240 kw.
Schedule speed	21 m.p.h.	21 m.p.h.

Toledo & Western R. R.

This road is about 75 miles long, running west out of Toledo to Sylvania and Pioneer, Ohio, with a branch to Adrian, Mich. The section between Toledo and Sylvania, eight miles, had built up to such an extent that local service was necessary, and the old cars, weighing from 30 to 36 tons, equipped with four 75-h.p. motors, geared for high speed, slow acceleration, with high platforms and steps, were entirely inadequate for the service.

It was decided, therefore, to purchase three 25,000-lb. cars with safety features, suitable for either one-man or two-man operation which can be used in either the local or through service, and equipped with quadruple GE258 motors and K35 control. These cars are just going into regular service, and it is estimated that the return on the investment will pay for the cars in two to two and a half years.

Youngstown—Suburban Ry. Co.

This company operate a line out of Youngstown to Leetonia, a distance of about 20 miles. Due to the density of population on the Youngstown end it is necessary to run three classes of service—city, suburban and interurban—on that end of the line, all of which is single track.

After investigating the situation carefully, the railway company purchased two 40-passenger, 26,000-lb. cars, which will be completely equipped with safety features, and will be suitable for operation in any of the three classes of service. Later on it is proposed to add to this number and eventually have but one class of equipment. These cars are equipped with four GE264 motors and K35 control.

Shipment of these cars will be made sometime in May. It is expected that the return on the investment will pay for these cars in about two years.

Western Ohio Railway Co., and Fostoria and Freemont Railway Co.

The Western Ohio company operates a line from Piqua, Ohio, to Findlay, with branches to St. Mary's, Celina and Minster, Ohio. The total distance is 120 miles.

The Fostoria and Freemont Railway runs between Fostoria and Freemont, a distance of 22 miles, connecting at Freemont with the Lake Shore Electric for Cleveland and Toledo, and at Fostoria with the Toledo, Fostoria and Findlay for Findlay.

Through cars are now run from Wapakoneta and Lima over the W. O. to Findlay, the T. F. & F. to Fostoria, the F. & F. to Freemont and the Lake Shore to Cleveland.

The Western Ohio Railway and the Fostoria and Freemont have placed orders for sufficient light weight cars to operate their local service, and also to give an improved limited service from Freemont to Piqua, a distance of about 117 miles. The cars will be identical in every respect, and will be interchanged between the two roads—all of the repair work being done in the Western Ohio shop at Wapakoneta.

The cars have been designed to give the maximum comfort to the passengers. They are 45 feet long, 8 feet, 10 inches wide, with baggage, smoker and main compartments. The aisle width will be 24 inches. The seats will be of the spring type, 40 inches wide, and 33 inches spacing; arm rests and foot rests will be provided; cushions will be of the spring edge type with automobile springs. These cars will be geared for a free running speed of about 45 m.p.h., on 600 volts and will make the same schedule that is now being made by 35-ton cars, geared for 60 m.p.h., at a corresponding line voltage. The motors will be four GE265, 35 h.p., with single end K control, and CP27 compressors. The cars will weigh completely equipped about 30,000 lb., and will seat about 50 passengers. They will be called upon to make about 24.5 m.p.h., schedule speed in local and about 31 m.p.h., in limited service.

CITY AND INTERURBAN LINES

Portsmouth (Ohio) Street R. R. & Light Co.

This company operates the city lines in Portsmouth and also an interurban line from Portsmouth to Ironton.

They have recently placed an order for six of the 25,000-lb. 48-passenger cars for city service, and four of the same type for the interurban line. The cars will be identical in length, weight and type of equipment, except that the city cars will have 30-in. post centers, and the interurban cars 33-in.; the seats will be equipped with arm rests, spring edge cushions and imitation leather upholstering; the electrical equipment will be identical except the gear ratio, four GE264 motors with platform control being specified for all.

These cars are scheduled for delivery about May 1st, and it is the company's purpose to later purchase additional cars of this nature, and eventually get down to one type of equipment, as compared to five types of motor as at present used.

Dayton (Ohio) Springfield & Xenia Southern Traction Co.

This company operates a city line in Dayton and an interurban line from Dayton to Xenia, Ohio, a distance of 18 miles. The company has standardized a 26,500-lb., 50-passenger car for both city and interurban service, and the only difference in the equipment will be the gear ratio. This will be quite an improvement over the present arrangement, which includes four different types of motors, control, trucks, etc. The equipment of the new cars will be four GE264 motors and K35 control.

The cars are scheduled for delivery early in June, and it is the intention of the company to gradually increase their number until there will be but one type of car on the system.

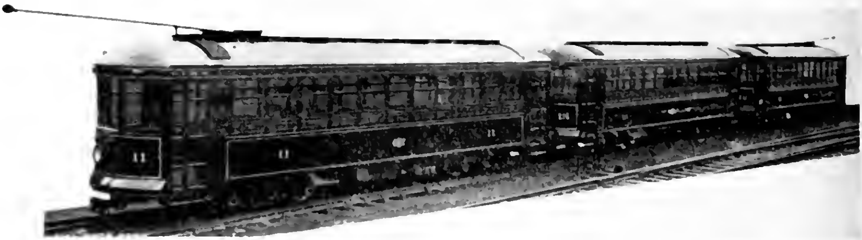


Fig. 11. 3-car Train Operated on Charleston Interurban Railroad, West Virginia, Since January, 1917. This train of 2-motor cars and trailer weighs 71,300 pounds and seats 132 people

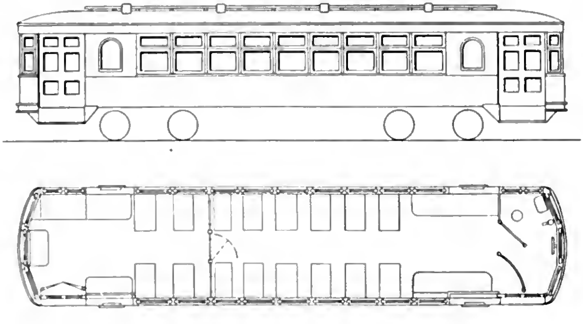


Fig 12 Dimensions and Seating Arrangement of 1-man Car of the Interstate Public Service Company, Showing Entrance Gate at Rear Door

SUBURBAN ROADS

Charleston Interurban Railroad

This road has been operating the light weight car in suburban service for about four years; they also have several cars of a similar nature in city service. The suburban unit is a three-car train, permanently coupled together, with a motor car on each end; the train can be controlled from either end and is used principally for service between Charleston and some of the manufacturing plants when large crowds have to be handled.

This train weighs complete 71,300 lb., seats 132 people, and carries a total load of over 400

Princeton-Bluefield Traction Co.

This company has been operating the light weight car between Princeton and Bluefield for about five years. The cars only weigh 19,500 lb. and seat 36 people. They have been very successful and the company is now standardizing this type of car for their city work.

Interstate Public Service Co.

This company have on order, for operation between New Albany and Jeffersonville, five 24,000-lb., 49-passenger single-end cars, which will be equipped with safety features and operated by one man.

Four GE258 motors are specified with K35 control.

These cars will replace some heavy interurban cars, giving half-hour headway between the two cities, and also some single truck city cars which operated part of the way out from each terminal, giving 15 minute headway for the city passengers. Under the new arrangement, the new light weight cars will operate every 15 minutes between the two cities and also do the city work. These cars will be operated by one man. A fare box will be used for fare collection, and the rear door will be equipped with a protective gate, so that the passengers can board the car at the terminal through the rear door, but cannot get out that way. Delivery of these cars will be made in June, and it is expected that the return on the investment will pay for the cars in three years.

CITY LINES

South Covington & Cincinnati Street Ry. Co.

This company have had in operation for five years 25 cars weighing 29,000 lb. each, and with a seating capacity of 54, handling city and suburban service in Covington, Newport and surrounding towns. The rush-hour service is particularly severe, loads of 150 to 160 per car being common practice. In addition, the Fort Thomas and Fort Mitchell lines are up grade, averaging approximately $1\frac{1}{2}$ per cent for several miles.

Even under these conditions, the light weight car has stood up wonderfully well; the lines of the car are as straight as the day they started operation; the truck maintenance has been negligible; excellent life is being secured from 24-in. cast steel wheels; the cars ride well; they are popular with the public; and the company expects future purchases to be duplicates, which, after all, is about the best recommendation for any equipment.

City Railway Company, Dayton, Ohio

This company operates 36 miles of city and suburban lines in Dayton, and have recently placed an order for 15 cars, with a seating capacity of 50, and weighing 26,000 lb., equipped with four GE264 motors and full safety devices for one-man operation.

These cars will be arranged for single-end operation, with a smoker on the rear end. Passengers will be taken on at the rear through a turnstile or gate, and let off at the front. It is expected that the cars will be ready for delivery in June, and their operation will be watched with interest throughout the Middle West.

GENERAL SITUATION

From the data given it is patent to all that the light weight car will work wonders with interurban operating costs—particularly on roads that are in a position to completely equip all of their regular runs with such cars.

When it is considered that $25,000 to $50,000 increase in net per year will either "make" or "break" the average interurban line of small or medium size, it would not seem with the light equipment to be a very hard job to swing the balance in favor of the "make" side. Incidentally, the securities of the roads using these cars have taken on an entirely different aspect since the cars went into operation.

Advantage of Electrical Operation in Mountain Districts

By Frank Rusch

Superintendent of Motive Power, Chicago, Milwaukee & St. Paul Railway Company, Tacoma, Wash.

We are very pleased at being permitted to reprint from *The Milwaukee Employees Magazine* for March, 1922, the following article. It is a practical contribution by a practical man—telling the actual accomplishments rather than the possibilities. The results recorded reflect credit on all concerned and are a more eloquent tribute of electric traction than volumes of mere talk.—Editor.

We are, as you all know, operating electrically on the main line over five mountain ranges, formerly the most difficult parts of the system, being the Cascade and Saddle Mountains in Washington, and the Bitter Root, Rocky and Belt Ranges in Montana, a total of about 660 route miles. We have two maximum gradients of 2 per cent to 2.2 per cent for about twenty miles; two grades of 1.6 per cent to 1.7 per cent and several of 1 per cent.

In freight service on grades of less than ½ per cent we can handle as much tonnage as the operating conditions will permit with one electric locomotive at speeds which may vary up to 30 m.p.h. On 1 per cent grade ascending one electric locomotive will handle 3,500 tons; on 2 per cent grade, 1,250 tons; on 2.2 per cent grade, 1,100 tons; all at a speed of about 15 miles per hour. We ordinarily use a helper locomotive in freight service on mountain grades so that our average freight trains will run about as follows:

Per Cent Grade	Tons
1	3,500
1.6	3,200
1.7	2,800
2.0	2,500
2.2	2,200

These ratings are based on the continuous capacity of the locomotives which occurs at 15 miles per hour at full trolley pressure of 3,000 volts.

In making comparison with the steam locomotives that were used prior to the electrification, the tonnage rating and what was actually hauled over the Rocky Mountains is as follows and applies to freight trains only:

	Tons
2 Mallets, Butte Yard to Donald	2,250
2 L2 Engines, Butte Yard to Donald	1,600
2 Electric, Butte Yard to Donald	3,200
2 Mallets, Piedmont to Donald	1,800
2 L2 Engines, Piedmont to Donald	1,400
2 Electric, Piedmont to Donald	2,500

From this you will see that the tonnage hauled over this mountain is greatly in favor of the electric motors. I might add that the mountain grade from Butte Yard to Donald is 1.6 per cent and from Piedmont to Donald on the east slope is 2 per cent.

On the 2 per cent grade over the Saddle Mountains in Washington two electric motors are hauling 2,200 tons at a speed of fifteen miles an hour, whereas two Mallet engines haul 1,600 tons at a speed of about eight or ten miles per hour.

In passenger service we are not using any helper power. These locomotives are built strong enough to handle 960 tons of passenger equipment over any portion of our track. They make good speed in ascending grades and their speed on level track is only limited by operating conditions.

In switching service we have electric locomotives at Butte, Deer Lodge and Othello. In special service we have used electric locomotives to push snow plows, on work trains and for wrecking outfits and obtained efficient results.

One thing which seems of considerable importance to the steam man in first operating an electric locomotive, and which is soon likely to be forgotten with other commonplace things, is that no stops are necessary for fuel or water. When you consider the delays, train troubles and extra work of watering engines, encountered in mountain traffic, you can see that the complete elimination of such is no small item in bettering train operation. When you consider that a large part of our mountain district is through comparatively dry territory the elimination of pumping plants to supply this water represents economy. We use water certainly, to generate power in electric operation, but we do not have to pump it nor clean out the scale it may form in boiler tubes, nor transport fuel for long distances in order to heat it for use. We merely let it drop through turbine machines, extract the power and let it go on for further usage by others in its original form. Not only does this save work in getting fuel out of the ground, but it conserves the fuel itself for use in other lines and other parts of the system where such use cannot be avoided.

Another feature which applies to all kinds of service and of which we have good report is that although the electric locomotives weigh more on drivers than any steam power, they are easier on curved track, at least, than the steam engines. On tangent track the difference is not so apparent but it may be stated that there has been no radical changes made in track construction since we electrified nor has there been any apparent reason for making changes. Considering that mountain trackage has a high percentage of curvature, this advantage of electrical operation is appreciable.

But in order to deal specifically in bringing out advantages of electric motive power in the mountains, it will be better to go more into detail and to separate the subjects into more parts. I can perhaps do this best by considering different kinds of service separately and by giving examples of actual operation.

First in importance there is the freight service in which we have reduced the number of engines required and the work of keeping them in service. We have practically reduced our running time between points by 40 per cent and have increased our tonnage in the worst districts by about the same amount. In spite of increased tonnage the drawbar reports show a decreased number of accidents of this nature after the men have become accustomed to electric operation. The fuel consumption or kilowatt-hours at the locomotive shows marked economy and there is no doubt but that with a sufficient number of trains operating, marked economy for the whole system is possible over steam operation.

Freight trains can be handled over mountain grades without stopping and due to the regenerative feature may be handled without applying an air brake on the whole train, unless for some reason it is necessary to come to a dead stop. The regenerative braking not only saves the use of brake rigging but also returns energy to the trolley which may be utilized in helping move other trains. Whatever may be the return on this regenerated energy the saving made in ease of train handling with less number of break-in-twos with consequent damage and delays, is an important advantage.

In connection with the regenerative braking feature, the various tests on brake shoes in making a run from Avery to Harlowton about one-fourth of the brake shoe was worn away in controlling the speed of the trains on mountain grade, while in the westward movement between these two points it showed approximately one-fifth of the brake shoe worn away. A conservative figure on the value of the metal dissipated through brake shoe wear during a thirty-day month period would be $6,000; this is not including the saving in the way of cracked wheels through overheating. Both of these items of expense have been practically eliminated through electric operation.

We expect at some future date to combine regenerative braking which sends the current back into the wire and which we have at present, with rheostatic braking which consumes the braking energy in the starting resistors, so that we can use electric braking at speeds down to practically a standstill. This will be a matter for experimentation but the possibilities of electrical operation are quite easily handled and are unlimited in variations which may be put to practical usage for improved operation.

Starting freight trains on ascending mountain grades is comparatively easy and not at all likely to result in drawbar damage. The helpers are placed in the middle of the train and the head locomotive can when starting let the slack back as far as the helper. The helper man then can advance his controller to give maximum tractive effort and is ready to follow with the slack when the head locomotive starts. With electric operation we have almost entirely quit "getting" drawbars in the mountains, the most of them which "cut out" now do so when making stops on early grades.

We do not need engine watchmen with electric motive power and at any point where one of these machines is tied up it is only necessary for the enginemen to drop the pantographs and shut the doors and windows. This is particularly advantageous at helper tie-up points. At Butte and Piedmont when we first electrified we had as high as six to ten steam engines, mainly required for helper service. These were replaced with two electric locomotives, which have successfully done the freight helper work since. The passenger trains not requiring helpers have to some extent made this possible of course, but this itself is also another advantage of electrical operation.

Regenerative braking makes it a decided advantage to use a helper descending a grade as well as in going up on the other side. We have only one heavy grade on the Cascade Mountains where this is not applicable.

Otherwise our helpers ordinarily go clear over the summits where used. It is common for a helper to go in a train upgrade to Boylston and down to Beverly then back to Kittitas light with zero net consumption of kilowatt-hours, or regeneration in this case, making it possible to operate helpers in eastward traffic from this point at no fuel expense whatever.

The increased safety in having two locomotives in trains of this sort on heavy grades can be appreciated.

In passenger service the delays and rough handling necessary to the operation with helpers is entirely eliminated. The same locomotive which may haul the train at 50 miles per hour can also handle it with ease and certainty on a 2.2 grade.

Here again the regenerative braking feature is important. One who has tried to sleep in a passenger train through mountain districts and has been kept awake by application of brakes at frequent intervals can readily appreciate the comfort of an electrically operated mountain trip in which it is impossible to tell from the way the train is handled as to whether a grade is being ascended or descended.

The smooth ease of handling of passenger trains is a point of merit and occasions many favorable comments from passengers about our service.

The entire absence of cinders and a certain amount of grime from coal burning locomotives is appreciated by the passengers. Complaints of delays caused by poor fuel, engine not steaming and sundry things have become things of the past. We do have our troubles with electrical failures, it is true, but these are nearly all in a class not to be called serious and fortunately are of uncommon occurrence. The small detentions here and there of large variety and frequent appearance in the past are not now evident.

In electric switching service we find that the energy or fuel expense at the locomotive has been more than cut in two over steam operation. The locomotives are quick in acceleration, easy to handle and because the engineer has little to look out for other than the operation of starting and stopping, he can lend his whole attention to the business at hand and thus get as much work done as the yardman can attend to.

The maintenance of these machines is very slight and because of taking but little energy the extra demand for power that they require is not very noticeable at the substations which furnish it

As to special service, wherever the trolley wire goes the electric locomotive has given particularly good results. In rerailing cars or engines or pushing snow plows the uniform rate of speed for a given load and the ease with which the locomotives can be controlled make their use decidedly advantageous.

The rated tractive effort of an electric locomotive is usually given as that within the continuous or 24-hour capacity of the traction motors. This is 72,000 lb. for our freight locomotives but does not mean very much as compared to the maximum tractive effort which the locomotive can exert. This is only limited on these machines by the slipping point of the wheels. With sand used on the rail they have been known to exert a tractive force of 160,000 lb., and this could be maintained for a period of time until the tractive motors are in danger of overheating due to the large flow of current through them. Such strong tractive effort makes these machines efficient in handling certain work under adverse conditions as mentioned above.

Because the tractive effort is nearly proportional to the current flowing through the motors regardless of the speed, it is very easy to judge train weights, proper ratings and other things may be ordinarily left to a dynamometer car. In fact, every electric locomotive is equipped with its own instruments so that it is a very good dynamometer itself, and in cases where the engineer runs into conditions of overloading, he can readily judge the amount and reduce as necessary. There is no argument as to whether one man can get more out of an engine of this kind than another—they are all placed on an even basis. Moreover, the normal running times are so well made uniform that the dispatchers do not have to figure much on the personal element of the enginemen in supervising train operations.

In conclusion, I may state that the results obtained from this kind of motive power in its operating features have been found desirable. There are possibly other benefits to be derived from electrification, but I have endeavored to stay within the limitations applying to the locomotives alone. There are disadvantages too, of course, and many ways of improvements and developmental changes as is true of all electrical equipment. However, the field for experiment and such changes is large, and with the successful electric motive power we now have, we have made the start, and further improved features can be inaugurated if necessary.

The Quality of Hydro-electric Service, Yesterday and To-day

By Alex. E. Bauhan

Superintendent of Stations, Pennsylvania Water and Power Company

To the purchaser of electricity, service is service. Whether the power be generated by a local central station and distributed to him underground or be generated hydro-electrically in some remote mountainous district and transmitted over miles and miles of high-voltage tower line, he wants it when he wants it. The following article relates to the quality of service that is to be expected from a properly equipped and ably operated hydro-electric plant and shows how, by indefatigable effort, such service "now compares very favorably with, and in many cases is better than, that rendered by the metropolitan steam plant."—Editor.

Twelve years ago at a meeting of the A. I. E. E., at which a paper by Henry L. Doherty on the development and operation of water powers was being discussed, the reliability of the service rendered by a hydro-electric plant with extended transmission system was the subject of much adverse criticism. Today such criticism, while occasionally heard, is based on special unfavorable cases and not on the accomplishments in the field as a whole, and is in general not justified. Such important strides have been made in the improvement of apparatus, transmission lines, and operating methods that the service from hydro-electric plants now compares very favorably with, and in many cases is better than, that rendered by the metropolitan steam plants. A survey of the various past and present causes of interruptions on hydro-electric systems and the remedial measures which have been adopted is herewith presented to show how most of the causes of trouble have been eliminated and service improved.

The principal causes of interruption to service from hydro-electric plants are those in connection with transmission lines, relays, ice, station equipment, operating mistakes, and out-of-step conditions.

TRANSMISSION LINE TROUBLES

Line troubles can be subdivided into several classes, but in general transmission service depends principally on the number of circuits available between the generating station and the load. A single circuit cannot deliver continuous service. Short circuits will develop on it due to various causes which can be cleared only by at least a momentary interruption of the service. Maintenance work will necessitate taking the circuit out from time to time, although such outages are being prevented on some systems by the development of live line maintenance methods. The use of two transmission circuits, either one of which is sufficient to carry the load, with proper relay protection will largely eliminate interruptions of service due to transmission line troubles. It is true that lightning may affect both circuits simultaneously, but if the two circuits have different routings simultaneous lighting trouble on both circuits is made unlikely. While it is possible to deliver service of very high order with two circuits, still more dependable service may be had with three or more circuits, especially if they have different routings. While some of the various causes of line trouble enumerated in the following cannot be completely eliminated, their effect on service can be made inappreciable if two or more circuits are available and if a proper system of protective devices is used.

Lightning

Lightning has been by far the most frequent cause of transmission line troubles. In the early days of long distance transmission with improper and little understood relay protection, with inadequate line insulation and lightning arresters, every lightning storm played havoc with the service and frequently did permanent damage to equipment. Today lightning is becoming one of the least important causes of trouble. The principal reasons for this are improved design of station equipment, lightning arresters, line insulators, the use of two or more circuits, arc extinguishing equipment, and better relay protection. Line insulators, which formerly punctured on account of improper design or deterioration, now flash over because of improved design and because deteriorated units are currently eliminated. The more general use of the higher voltages with longer insulator strings and with improvement in the distribution of potential stresses tends to make flashovers less frequent. Improvements in the insulator unit and the string which prevent the arc from too badly damaging the insulators have made it very unusual that the up-to-date line cannot be immediately restored to service after a flashover. The dissipation of lightning charges by the natural corona characteristics of a high voltage circuit plays an important part in the elimination of lightning troubles. On those systems in which the favorable circumstances mentioned above do not exist, improved operating methods have resulted in the elimination of service interruptions due to lightning. Such procedures as the isolation of that part of the system on which the lightning storm occurs with separate generators, calling in steam auxiliaries, running extra generators, and rearranging connections to get higher short-circuit currents to make relay operation more certain and quicker, play their part in relieving consumers of inconvenience during lightning.

Fig. 1. A Punctured Insulator String, Quite Common Some Years Ago, is Today a Rarity Due to Superior Insulator Design and Maintenance Methods

Insulator Failures

Insulator failures were the cause of much concern some years ago. The defects in insulator design, which were the cause of these troubles, have been largely eliminated. Insulator deterioration has been reduced and periodic tests by megger, buz stick or similar device has made possible the replacement of defective units before breakdown occurred; and this practice has been recognized as a solution of the difficulty as far as effect on service is concerned. Mechanical troubles in the insulator hardware, which had been the cause of some difficulties in the past, are now rarely heard of. Such few insulator failures as may occur are effectively handled by relay protection.

Interference

Interference with transmission lines, by mischievous boys throwing hay wire up to the wires, shooting at insulators, blasting, hay stacking machines and locomotive cranes coming into contact with conductors, etc., at one time quite common and while as yet not entirely eliminated, are certainly less frequent due largely to the education of the public in such matters.

New lines may be troubled during wind storms by spans blowing together and trees blowing into the line, but the effect of errors in sags or tower locations and oversights in right of way clearing are eliminated during the first periods of operation and are not a continued cause of trouble. On one system traversing a mountainous country subject to severe choppy winds, the conductors which were rather light were picked up and blown together with consequent detriment to service. This case was remedied by putting weights on the end of the insulator strings, tying the conductors down to a lower cross-arm, and by the introduction of more strain towers. The experience gained resulted in these defects being eliminated on later extensions. This is typical of the manner in which special problems on all systems are being or have been permanently disposed of. Interference troubles, such as an instance of straw being picked up from a field and blown into a transmission line tower in such a manner that a succeeding rainstorm caused

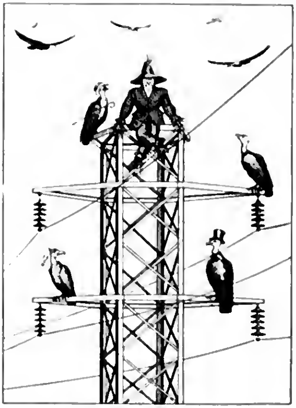


Fig. 2. The Result of an Experiment to Eliminate Buzzard Troubles as Illustrated by One of the Line Patrolmen

a flashover, while very rare, cannot be entirely foreseen or prevented. In such cases service is protected by having two or more circuits and proper relays.

Birds on Line

Interference by birds such as buzzards, herons, cranes, etc., although prevented from affecting service by duplicate circuits and relays, has been frequent enough to warrant special mention. Sometime ago a line patrolman in a section where buzzards, averaging 24 inches in height and 5 feet in wing spread, were in the habit of congregating to the number of 30 or 40 in the upper part of a tower, conceived the idea of putting boards with nails sticking through them on the crossarms so as to make uncomfortable roosts. However the buzzards seemingly found that by carefully arranging their toes between the nails the wooden strips made a more comfortable roost than the cold steel of the tower and welcomed the innovation.

The patrolman undismayed tried another tack. This time he placed a scarecrow on top of the tower. It was reported that the buzzards instead of being frightened away came in increasing numbers to visit the tower with the scarecrow, evidently thinking it was something dead on which they might feed.

This may seem to be giving the buzzards credit for an undue amount of intelligence. But on this particular line some six years ago buzzard interference suddenly stopped although in the previous years there had been many killings and it is seriously advanced by some that the buzzards have become educated to the hazards involved in coming too close to a line conductor. This educational phenomenon has been reported with respect to herons on a line in Texas and with respect to other birds elsewhere. However the general remedy which has taken care of this trouble is increased spacing between the conductor and the crossarm, which of course is inherent in the higher voltage lines.

I have heard that transmission lines in the Transvaal are subject to interference by elephants scratching their backs against the towers. While this difficulty has not as yet been reported in America, I am quite sure that someone will find a solution for it when it confronts us.

Sleet

Sleet (meaning "glaze" in the terminology of the meteorologist) has been a serious transmission line trouble for the reason that it is not confined to a definite point on but one circuit. It may affect all circuits for many miles and do material damage at several places.

Sleet affects the line in two ways. First, if the ice drops off the various spans unequally it will cause the conductors to whip together and burn off; a thin coating of ice is sufficient to cause this. Second, if the ice coating becomes heavy enough it will break the conductors by dead weight.

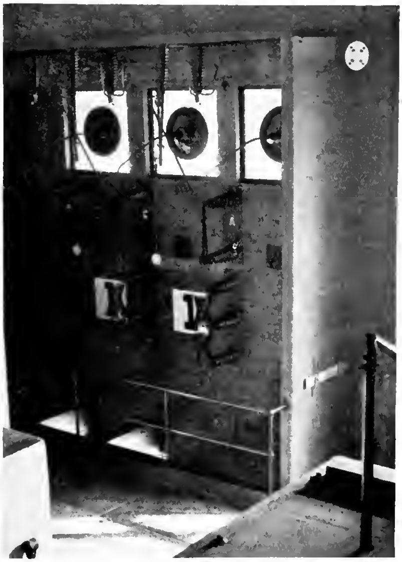


Fig. 3. Sleet Prevention Facilities at Receiving Station. The upper disconnectors serve to short circuit the transmission line when heating current is to be circulated. The disc in the upper right-hand corner carries eight 8-volt lamps in parallel connected to a series transformer in the short circuiting connections and indicates when the heating current is on

Damage by unequal loading has been largely overcome on new lines by offsetting the conductors in different vertical planes. This in many cases has been sufficient but it does not prevent the conductors from being pulled down by dead weight. To protect circuits whose conductors are in the same vertical plane and those unable to withstand the dead loading, a method of keeping the lines free of sleet by heating currents has been successfully applied on some systems

The method developed by the Pennsylvania Water & Power Company for its 70,000-volt lines between Holtwood, Pa., and Baltimore, which has given complete protection for several years, is that of taking each circuit out in rotation, short circuiting it at the receiving end, and applying to it at the generating end a potential sufficient to give the desired heating current. The potential in this case happens to be that of the generators, 11,000 volts, and the circuit is put directly on the main low-tension bus. Each of the four circuits is on heat run one hour out of four. As the telephone lines are likely to be interrupted during an ice storm, it is the practice to go through the above procedure in accordance with a prearranged time schedule and a system of signalling by power circuit switching without the use of telephones.

On the line from Holtwood to Lancaster, Pa., consisting of two circuits, similar arrangements have been made, service being maintained on one circuit while the other is on heating current. In this case special transformer equipment has been installed to give the proper voltage for the desired heating current.

This method of preventing sleet from interfering with service is being more generally considered, and it is undoubtedly a solution for sleet troubles in many of those cases which have not been remedied by other means. Ice storms need not therefore be looked at as a menace to a modern, well operated, high-voltage transmission system.

RELAYS

The foregoing has dealt with the troubles of the transmission line and in almost every case of trouble it has been pointed out that complete elimination is dependent on proper relays.

It may seem strange that the very device so necessary to improved service is here set down as one of the major causes of service interruption. Relay systems, however, have been a grave offender against service, although the fact is not generally recognized. Many cases of serious system trouble have been blamed on the original cause of a minor short circuit, which would have been cleared without affecting service had it not been for the improper functioning of a relay system. In such cases it is unfair to charge the original trouble with the responsibility. The relays should have received the blame.

Relay systems have been laid out in many cases without a proper knowledge of operating conditions by the designing engineers, and in other cases installed and used without a proper knowledge of relay characteristics and short-circuit conditions by the operating engineers. Operating conditions have been changed on some systems without being followed by the proper changes in the relay system. Over-enthusiasm in the use of relays, defectiveness in scheme, design and construction, the use of untried relays and complicated relays without proper maintenance, have been the cause of many interruptions. The fault has been not so much in the relays themselves as in their improper application; and while the design and construction of the relay itself has progressed, the principal advance has been in a greater understanding of their characteristics and of short-circuit conditions by the users of the relays.

Fig. 4 Cake Ice Does Not Ordinarily Affect Hydro Plant Operation. This illustration shows how an arched wall prevents the ice from getting into the forebay

It is because of this greater understanding of the problem that power companies have been able to eliminate the menace of relay trouble and to take full advantage of the large benefits offered by relay protection.

ICE

In those plants located in the colder climates, ice conditions have been one of the outstanding troubles. Such plants have to deal with three different kinds of ice:

1. Cake ice or sheet ice, which consists of the broken up cakes of ice which have formed on the surface of the water.
2. Slush or frazil ice, which consists of needle-like crystals of

ice which have formed on rapids or in the water agitated by wind and wave action.

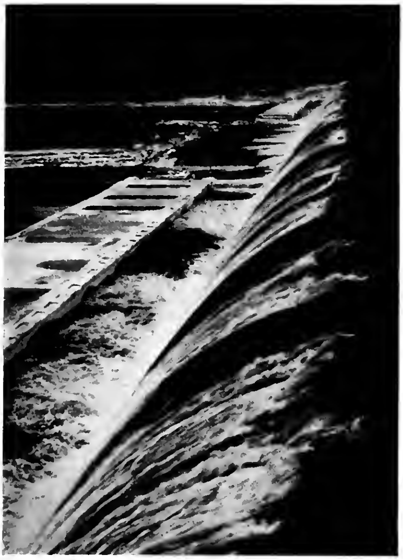


Fig. 5. Anchor Ice Adhering to the Crest of a Dam

3. Anchor ice, which forms on the bed of the river on calm, cold nights when the sky is clear, and rises in the morning bringing with it river bottom debris.

Most plants are so laid out that cake ice does not inconvenience service. It is supposed by people not informed in such matters that it is cake ice that causes the hydro-electric man all of his trouble. Anyone who has seen one of the northern rivers passing its thousands of tons of crushing, grinding cake ice in a late winter freshet readily imagines that this must do terrific damage to a hydro-electric plant. Such, however, is not ordinarily the case and I know of but few cases where cake ice has actually interfered with service.

Slush ice and anchor ice on the other hand have been the cause of some very serious interruptions, shutting down stations for hours and even days at a time. Such ice adheres to the screens, prevents the passage of water, and possibly causes the crushing of the screens. The remedy which has been adopted by most hydro-electric plants is simply to remove the screens during the winter season and allow the ice to pass through the machines. This is effective only where the turbine casings or head covers are exposed to room temperature. In those plants whose turbines are completely submerged in a wheel pit the ice will adhere to the turbines and completely obstruct them if allowed to progress that far. Such is the case at the Holtwood plant. In this plant it is necessary to take each unit out periodically during an ice run and to heat it by forcing steam from a 30-h.p. boiler into the pit. The steam plant operating in parallel is called upon to pick up that part of the load which must be dropped to permit steaming of the units. The ice is not actually melted but after 20 minutes of steaming the ice loses its cohesiveness and when the unit is again started the ice is easily washed out. This must be done to each unit every couple of hours and has become a regular routine operation at the plant. The exciter turbines are kept free in the same way.

Other plants, when the temperature is low enough, have been able to avoid interference with service to customers by transferring the load to some other plant and shutting down long enough to permit the forebay and intake canals to freeze over. As soon as an ice coating has been formed, service can be restored without danger of slush ice. It has been found that if the gates of the turbines are set

Fig. 6. Ten Years Ago This Plant Was Shut Down by Frazil Ice Obstructing the Screens and the Turbines. Today improved operating methods prevent any interference with consumers' service

at that position where the flow of water is tangential to the vane surfaces the ice will not form so rapidly as when the water impinges on the surfaces. Modern designs of single-runner units with carefully designed angles and flow lines are for this reason not affected by slush ice to the same extent as the older designs in which there were more eddies and impinging action on the turbine parts. Thus, in one manner or another ice trouble has been taken care of so that it does not affect consumers.

STATION EQUIPMENT

Under the heading of "Station Equipment" as a cause of trouble are included many different kinds of apparatus—turbines, generators, exciters, auxiliaries, switchboards, bus structures, transformers, lightning arresters, oil switches, etc. Not only may these be considered by themselves but their relation to each other, i.e., the general station layout, has a bearing on the character of service to be rendered. Such defects or troubles as may occur in the mechanical end of the hydro plant do not ordinarily affect service. There is less trouble with the hydraulic turbine than with other forms of prime movers and the modern single-runner turbine is less troublesome than the older multi-runner turbine.

With regard to electrical apparatus generally, much improvement has been made in the last ten or fifteen years. Generators, while they have never been the cause of many troubles, are today so well built that they very rarely interfere with service by burnouts or otherwise. Particularly noticeable is the advance made in transformers. The transformer with its high-voltage terminals has changed from a notoriously troublesome piece of equipment to one of the most rugged and reliable. This has been recognized in the tendency to use the transformer and generator, or the transformer and transmission line, as a unit without intervening switches—certainly a fine tribute to the reliability of the modern transformer and generator. Lightning arresters have in many cases originated fires with consequent effect on service. The present general practice of placing them out of doors is the answer to this hazard. The introduction of oxide film arresters in recent years bids fair to still further remove the hazards which exist in the oil-filled electrolytic arresters.

There is however one particular class of apparatus in which the development has not been able to keep up with the requirements. I refer to the oil circuit breaker. Various limitations have made oil switches one of the most serious problems in the way of rendering good service. Oil switch breakdowns have frequently prevented prompt restoration of service. Oil switches which when installed adequately met their requirements became totally inadequate with the rapid growth of the system and with the tying in of one system with another. In some cases oil switch limitation actually stood in the way of desirable interconnections.

Fortunately extensive high-voltage transmission systems, because of high circuit impedances, were not confronted with switch limitations at all points on the system. But at important switching stations and load centers where there was considerable capacity concentration the switch limitations were exceeded. At these points replacements with higher capacity switches, installation of current-limiting reactors, and special operating connections have served to eliminate the trouble. Each system which has been confronted with these difficulties, while they may still be the cause of inconvenience, has undoubtedly found some way of preventing them from interfering with service and today no system which requires high-class service need be without it on account of oil switches. Within the last year or two important advances in oil switch design have been made and the near future will undoubtedly see switches handling rupturing duties far in excess of those of present day switches.

With regard to hydro-electric station equipment generally, superior design, construction, and layout, with more skillful operation, have made equipment troubles a minor and in some cases even a negligible factor in service disturbance.

OPERATING MISTAKES

But perfect as the apparatus may be electrical systems must be manipulated, regulated, and controlled by human beings and the operation and service is therefore subject to the failings of the human element. Operating mistakes have been charged with a large proportion of service interruptions particularly on the large and extensive hydroelectric systems. It is a most difficult problem, particularly in those stations which have not been favorably designed and in those which have not been equipped with the facilities essential to mistake prevention. It is partly a problem of design and partly a problem of supervision.

Simple, easily operated and properly safeguarded apparatus, laid out with an appreciation of the problems of the operating man and of the shortcomings of the personal element, are necessary to prevent operating mistakes. Progress is being made on this score. Complicated layouts are being replaced by simple ones, adequate grounding and testing facilities are being installed, improved construction of disconnecting switches to prevent their improper operation, and interlocking devices of various kinds are coming into use. Those stations which have made intelligent use of these improved practices can undoubtedly claim less frequent mistakes as a result.

The responsibility of supervision is of course quite evident. While length of service and experience has much to do with the ability of the operating attendants, they are not sufficient. The secret of preventing mistakes as far as it may be possible by supervision lies in the establishment of proper and safe practices and methods of operation, expressed in the form of rules and instructions, in the instruction and training of the men in the performance of their duties, and most of all in establishing rigid operating discipline. Good operators like to work under such conditions—conditions which are necessary for their own safety as well as for continuous service—and respond with the desired results.

Almost every new station built shows evidence of thought being given to the equipment factor in mistake prevention; and particularly in hydro-electric transmission systems has there been improvement in operating methods.

OUT-OF-STEP CONDITIONS

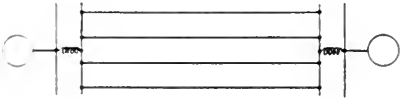
The introduction here of out-of-step conditions as a serious cause of service troubles may be surprising to some. I refer to those troubles which are caused by generators, stations, or systems falling out of synchronism with each other with consequent disruption of service. An instance of this trouble which occurred in Chicago in 1918 is discussed in papers by Schuchardt and Steinmetz in the A. I. E. E. Transactions and indicates the serious effect on service which may result therefrom. Out-of-step conditions have been occurring for years on some systems, in many cases unappreciated and unrecognized. The falling out of step is not ordinarily an original cause of trouble. It is started by something else and this something else has been getting the blame for all the trouble which resulted. For instance a feeder is short circuited, and perhaps cleared, but the two generating stations feeding the system fall out of step. Voltages are pulled down, load lost, and the system is generally disrupted. Possibly relays operate on switches at different parts of the system and considerable time is lost by the operators in finding out what has happened and in locating the defective feeder. In the meantime the stations may have been separated completely, either manually or automatically, and quite likely the load on one station comes back far in excess of the capacity then available. This results in swamping of the station which in turn possibly (and improperly) interferes with auxiliaries and confusion reigns in general. After some minutes, possibly even half an hour or more, conditions are restored to normal and the explanation is that there was a short circuit on No. 13 feeder.

The real cause of the trouble however was the stations falling out of step, and an understanding of the factors which influence synchronizing power and the likelihood of falling out of step are necessary for remedial action. Falling out of step is fundamentally caused by low synchronizing power. Low synchronizing power may be caused by low voltage and by unfavorable tie line characteristics. Linked with the fundamental causes are the generator and excitation characteristics, magnitude of, voltage drop due to, and the time required to clear the short-circuit current. One thing not ordinarily appreciated is that when a short circuit occurs on the only tie connection between two stations inevitably they must fall out of step with each other.

This whole subject is rather complicated and technical and one to which operating men in general have not given much study. Corrective measures have in some cases been adopted for other troubles such as the introduction of reactors or changes in connections, which unknowingly have had an adverse effect on synchronizing power of the system. For instance Fig. 7 shows the effect which a reactor application may have on synchronizing power. The system with individual reactors on each tie connection has greater synchronizing power than the one with group reactors (of like reactance) for the reason that it has less impedance between stations. If the short circuit is on a radial feeder from one of the stations the system with individual reactors has still more synchronizing power than if the short circuit is on one of the tie connections.

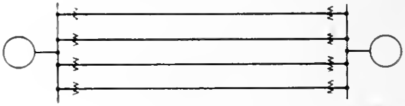
Fig. 8, showing two stations or systems tied together by four circuits with four transformers at each end, indicates the influence that system connections may have on the stability of the systems during short circuit. In case of a short circuit on one circuit the system with the circuits split on the high-tension side has greater synchronizing power than the same system with circuits tied together on the high-tension side for the reason that its station voltages are maintained at a higher value. It is apparent that the latter system would have no synchronizing power—with the short circuit on one of the circuits—if the circuit had no impedance.

Individual Reactors



Group Reactors

Fig. 7. Of the Two Schemes for Tie-Line Short-Circuit Protection Shown Above, the Upper One Gives Greater Synchronising Power than the Lower One



High Tension Sides Split

High Tension Side Tied Together

Fig. 8. Influence of System Connections on Synchronizing Power. In Case of a Short Circuit on One of the Circuits the Upper Connection Gives Greater Stability Than the Lower

The subject of synchronizing power and stability of stations is one in which there is much room for progress and one which requires greater consideration to the design of tie connections with the idea of getting the lowest impedance possible consistent with permissible short-circuit currents and getting ample voltage on station buses during short circuits.

Illumination Fundamentals for the User of Light

By J. R. COLVILLE

ENGINEERING DEPARTMENT, NATIONAL LAMP WORKS OF GENERAL ELECTRIC COMPANY

The importance of good lighting is not generally recognized; its industrial importance is only beginning to be understood. The author describes in some detail the fundamentals which must be considered in producing "good lighting"—these fundamentals are: (1) amount of light, (2) diffusion, (3) color quality, (4) shadow, (5) uniformity, (6) maintenance. He concludes his contribution with an analysis of good and bad lighting. In analyzing bad lighting he gives the cause, the effect and the remedy.—EDITOR.

Much has been written on the fundamentals of illumination for the designer of lighting systems. Comprehensive information and data are readily available which not only map out step by step the method of procedure in lighting design but which also provide charts and tables which reduce the mechanics of the work to a minimum and guard against errors in calculation. The steadily widening use of such authoritative information is being reflected in the improvement in lighting installations now being made in all parts of the country. The advance in American practice is, in fact, attracting much attention, and much favorable comment, from Europe.

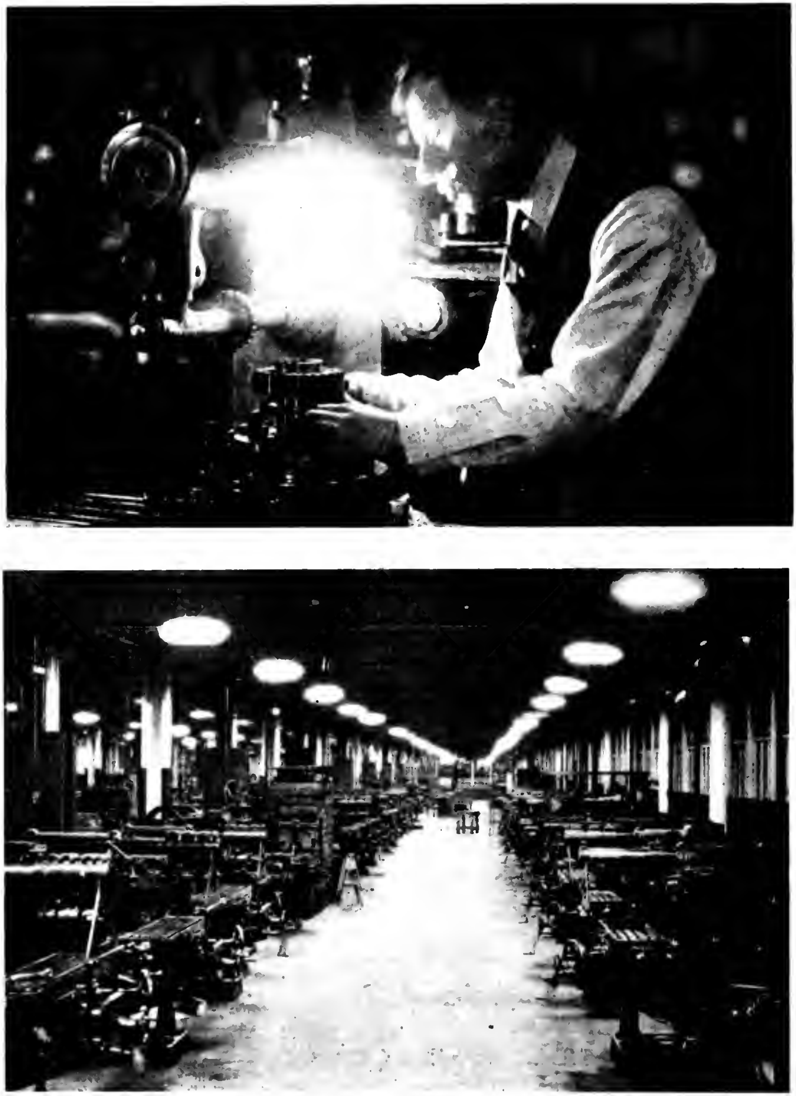
The user of light is not, however, primarily interested in data which deal minutely with the details of illumination design. The fundamentals so necessary for the lighting specialist are not the fundamentals that he, the user, needs to know and comprehend. The one is quantitative, the other qualitative.

In this article such fundamental factors as amount of light, diffusion, color quality, shadow, uniformity, and maintenance are discussed from the standpoint of their effect upon the usefulness of the lighting system.

Amount of Light

In the last year of the war and in the year immediately following, more progress was made in the application of artificial lighting than in any ten-year period preceding. This followed experiments conducted under actual working conditions, which showed that startling increases in production were possible when industrial plants, working under average artificial lighting conditions, were provided with systems which furnished artificial lighting comparable with the daylight lighting of well designed, modern factories. In perspective it appears that what had retarded the application of artificial lighting was not so much a question of its value as a wrong conception of what constituted good lighting. It seems self-evident that the expenditure in lighting of an additional three or four cents per employee per day would have been made unhesitatingly had it been realized that the existing lighting system was enabling the employee to produce at only 80 per cent or 90 per cent of his capacity. Most executives believed in good lighting, they acknowledged its importance, but what they did not know, and what the lighting specialists were uncertain of, was that the average existing lighting installation was not supplying enough light; in other words, it was not giving *good lighting*. Once the traditional illumination levels were broken through and levels three, four and five times as high tried out in service, the handicap imposed by previous standards became apparent.

We do not know today how much light is right for the many applications. We do know that 3 or 4 foot-candles will enable one to see more detail than will 1 foot-candle; that 10 foot-candles will reveal more than three or four; that 50 foot-candles will increase perception over 10; that 100, or even more, will sometimes produce still further improvement when the eyes are taxed to the utmost. We know that vision is *quickened* when the illumination is increased from 2 or 3 foot-candles to 10, 50, or to 100 or more. We know also that persons with defective vision, and this means a surprisingly large proportion of the people, are even more greatly handicapped by poor lighting than are those with good vision, and that they respond more markedly to improvement in the lighting. Again we know that bright and cheerful surroundings are stimulating, that they inspire cleanliness, that they make for order and neatness. In these simple fundamental facts we find the reasons why, in industry, higher levels of illumination increase production without imposing strain upon the employees, why they automatically reduce accident hazard, decrease spoilage, and improve morale; why, in the office, they enable more work to be performed with fewer headaches, less mistakes, and better tempers; and why, in the store, they attract customers, facilitate the examination of material, and make for quicker sales.



Figs. 1 and 2 The glaring local light shown in the top picture is a menace to safety and vision and is one of the evils which lighting codes are aiming to destroy. Contrast the lighting of this milling machine with the lighting of those shown in the bottom picture

To these facts we must also look in deciding how much light is needed in a specific case. The engineer has his tables which show what constitutes good present practice for practically every lighting application; these facilitate but should not entirely govern the decision.

Diffusion of Light

With the 10 to 1 increase in efficiency of the incandescent lamp, since its invention scarcely two-score years ago, has come the generation of large volumes of light in a small space. This means, of course, light sources of great brilliancy. A bright source does not in itself insure adequate lighting; in fact, unless skillfully handled, it presents a positive menace to vision. Objects are seen by the light which comes from them to the eye; light which comes directly from the light source to the eye or is reflected from the source to the eye by some polished surface is not only useless in illuminating the object viewed but if of high intensity or of large volume, it produces a blinding effect which seriously interferes with seeing and may result in permanent injury to the eyes. "Glare" is the term applied to light which obstructs vision in this way.

Glare blinds the driver of an automobile when approaching another with improperly adjusted headlights at night; it handicaps the workman who is trying to see fine detail with a brilliant light source near his line of vision; it produces acute discomfort in the conference room where men sit facing inadequately shaded windows for a long period of time; it is annoying in the home where wall brackets containing unshielded lamps are seen against dark backgrounds; it blinds the ball player, who tries to follow the ball against the sun. In hundreds of ways it is constantly interfering with vision and handicapping us in work and play.

Specular reflection, that is, the reflections of light sources in polished surfaces, while sometimes an aid to vision is often, because of its insidious nature, more harmful than direct glare. Under proper control, it facilitates the reading of the micrometer scale or the inspection of a polished surface; in excess, it becomes reflected glare, dulls perception, and paves the way for accident. As moderate specular reflection, it brings out the texture of materials and assists the housewife in her sewing; as reflected glare, it blurs the printed page and causes eyestrain in reading. In small amounts, coming from the pavement to the eye it discloses the inequalities of the road to the motorist at night or reveals the pedestrian in silhouette; in large amounts, as from snow in sunlight, it produces painful and serious injury to the eyes.

Fortunately, once the danger in direct glare and the advantages and disadvantages in specular reflection are understood, the means for eliminating the bad and retaining the good is readily available. The answer lies in proper diffusion of the light. The reflecting equipments now regularly manufactured provide any degree of diffusion considered desirable. The totally indirect type which directs all of the light to the ceiling, whence it is diffused throughout the room, represents the utmost in diffusion; the semi-indirect type, which directs a large proportion of the light to the ceiling, but transmits some through the bowl, provides a degree of diffusion which is preferred by many; so-called light-directing semi-enclosing, or totally enclosing, units are available in designs which provide good control of the light and satisfactory diffusion; enclosing globes of the proper size and density provide diffusion of the light but afford little control of its distribution. Open reflectors of proper design eliminate direct glare from the lamp filament but afford no protection against reflected glare in polished surfaces. Such reflectors, however, when designed for, and used with, the bowl-enameled lamp constitute an equipment which is almost ideal for the large majority of industrial applications. They are inexpensive, easy to maintain, allow considerable control of the light distribution, provide good diffusion, and eliminate objectionable specular reflection while at the same time producing sufficient glint for the reading of a scale or the examination of textiles.

The charts and tables which have been published by the manufacturers of lamps and reflecting equipment and by illuminating engineering organizations simplify the selection of the equipment best suited to individual requirements.

Color Quality of Illumination

Since an object is seen by the light which comes to it from the source and thence by reflection to the eye, it follows that color in the object is seen only when the light contains rays of that color. For example, a red object will appear black under light in which red rays are lacking or a blue object will appear black when blue rays are absent in the source. Daylight is composed of all the colors in the proportions seen in the rainbow. The light from Mazda lamps contains all the colors composing daylight but if the spectra, or rainbows, of the two were to be compared it would be seen that the Mazda lamp was richer than daylight in the orange-red region and weaker in the blue. For ordinary purposes, the light from clear Mazda lamps is sufficiently like daylight to answer all requirements, but where color discrimination is a factor, as in sorting or grading processes for example, and in the laundry where scorch

Direct Glare

Reflected Glare

Figs. 3 and 4. A brilliant source of light is not necessarily "good lighting." Either direct glare or indirect glare are particularly harmful. Such glare produces a blinding effect. The term glare is applied to light which obstructs the vision in this way

Fig. 5. Deep black shadows are troublesome and a source of constant danger because of what they may conceal

Fig. 6. Equipment should be thoroughly cleaned at regular intervals, the frequency depending upon the location

marks must be readily distinguishable, or where the artificial light is used to supplement daylight, as in an office, daylight lamps, which screen out the majority of the excess orange-red rays, find wide application.

For purposes of color matching, dyeing, process printing, and the like, where extreme accuracy is necessary in the observation of colors, a still further correction of the light is necessary. For this service so-called color-matching units, which provide a light of true and unvarying north-sky quality, are available.

The high efficiency of present incandescent lamps which makes practicable the approximation, or the duplication, of daylight on a large scale also permits the modification of light to any desired extent for obtaining striking and unusual effects in display windows, in decorative lighting, and in the home.

Equipments designed especially for the control of color are readily available.

Shadow

Contrary, perhaps, to popular opinion, a certain amount of shadow is desirable in artificial lighting. Objects illuminated by perfectly diffused light appear flat and uninteresting, contours are lost, and it is difficult for the eye to form a correct judgment of the shape of an object. On the other hand, deep, black shadows are troublesome and are a source of constant danger because of what they may conceal. Shadows having a sharp edge or a series of sharp edges, which result from several small light sources near one another, are particularly annoying in office work, where they dance about the pencil point most disconcertingly. In general, in interior lighting, only soft illuminated shadows with gradually fading outlines should be tolerated.

The number of shadows cast by an object and their length depends upon the number and the position of sources directing light toward the object; the softness of the shadow depends upon the area of the surfaces from which the light comes and upon the number of directions from which light is received. Indirect and dense semi-indirect units which make the ceiling serve as the principal light source, and large units of the direct-lighting type, therefore, make for soft shadows; small units of the direct type make for sharp shadows. As a general rule, lighting units which are satisfactory for the application from the standpoints of light diffusion and low brightness will also prove satisfactory from the standpoint of shadow when a sufficient number are used to provide a satisfactory degree of uniformity in the lighting of the work.

Uniformity of Illumination

One of the most common mistakes made in artificial lighting is the spacing of units so far apart that the areas in the middle-ground between units are inadequately lighted. It is not an uncommon experience to find in industrial plants that some workmen are supplied with only one half or one third as much light for their work as are others. Many office employees are forced to work under the same handicap. There are cases on record where the suspected incompetency of an employee with respect to his co-workers has been traced to the unsuspected cause of poor lighting.

Definite relations exist between the height at which units are mounted above the work and the distance by which they may be separated to provide reasonable uniformity in lighting, and light from a sufficient number of directions so that shadows will not prove troublesome. These relations have been reduced to simple tabular form for the convenience of the designer of lighting systems. In general, the permissible distance between units should not be more than one and one half times the height of the light sources above the work; closer spacings can do no harm and are often desirable but when this spacing distance is exceeded, the illumination between units falls off very rapidly. The user of light should consider carefully before allowing his desire to install the minimum number of units necessary for satisfactory results to influence him in favor of a system in which the proper spacing distance is materially exceeded.

Maintenance

The experiences of those who have installed high levels of illumination prove conclusively that every foot-candle delivered at the work has a definite, tangible value. The man who provides a system capable of delivering 10 foot-candles at the work and then allows the system to depreciate until it delivers only three or four is losing not only 60 or 70 per cent of the light he is paying for but, what is far more important, he is losing the profit on the difference between the output of his employees at this low level of illumination and their output at the higher level. If the depreciation of a lighting system were of the order of 2 or 3 per cent or even 10 per cent, the matter would not be so serious a one, but surveys of installations in service show depreciations of 50 per cent, 60 per cent, and more. Many users are not getting more than one third of the light their systems are capable of delivering.

There are five principal causes of depreciation. These are:

1. Dirty reflectors and lamps;
2. Soiled ceiling and walls;
3. Unobserved lamp burnouts;
4. Replacements of lamps with new ones of wrong size or incorrect voltage;
5. Blackening of lamps due to use in service far beyond their rated life.

It will be noted that each of the causes may be remedied simply and easily. Dirt and dust are the principal factors in depreciation and are the ones most readily dealt with. The equipment should be thoroughly cleaned, not merely dusted off, at regular and frequent intervals; once each week is not too often in some locations while once each month may suffice in exceptionally clean ones. The work should be handled by an individual or by a department as a definite duty for which the responsibility is fixed.

Summary

The accompanying chart has been prepared to assist the user of light in analyzing lighting conditions as he finds them and to suggest the proper remedies for the faults he uncovers. In the elimination of these faults he will find a partial answer to the perplexing problem of how to increase efficiency, a question made vital by the change in business conditions.

CHART FOR ANALYZING LIGHTING CONDITIONS

Good Lighting

Good lighting requires three things:

1. Light of suitable quality.
2. Light of the proper direction.
3. Light in the correct amount.

Good lighting	Suitable quality	Absence of glare Absence of reflected glare Proper color
	Proper direction	Shadows soft and luminous Uniform distribution
	Correct amount	Lighting for safety Lighting for economical production Proper cleaning of units

Bad Lighting

Cause	Effect	Remedy
Bare lamps.	Glare, eyestrain, wasted light, harsh shadows.	The modern efficient type of equipment.
Miscellaneous local lights dangling on drop cords.	Glare, eyestrain, danger of accident, particularly about belting and moving machinery, short circuits, breakage.	General overhead system.
General system—Units too far apart or too low.	"Spotty" lighting; areas between lamps receive very little light; shadows are very black.	Proper relation between mounting height of units and spacing distance.
Clear lamps where polished surfaces are present on material or machinery.	Reflected glare, eyestrain.	Equipment to diffuse downward light from filament.
Too little illumination.	Time lost by employees; eyestrain. Accidents; no incentive to keep place cleaned up.	Larger lamps in suitable reflectors spaced closer together if necessary.
Sharp, black shadows.	Accidents; time lost; eyestrain.	Modern equipment properly spaced.
Gloomy and cheerless appearance of room.	Unpleasant contrast between light sources and background; dispirited employees.	Liberal use of white paint accompanied in some cases where location is suitable by use of glass reflectors.
Dusty, dirty, or broken equipment.	Loss of 40 per cent to 60 per cent of the light paid for.	Institute a regular cleaning schedule.

Sampling for Test Purposes

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> "Perfect knowledge alone can give certainty and in Nature perfect knowledge would be infinite knowledge, which is clearly beyond our capacities. We have, therefore, to content ourselves with partia lknowledge—knowledge mingled with ignorance producing doubt."—Jevons, "Principles of Science."

Part I

WITH SPECIAL REFERENCE TO EXTENT OF SAMPLING IN RELATION TO RELIABILITY OF TEST RESULTS

One approaches the subject of sampling with some diffidence because the variety of problems involved makes it difficult to formulate principles applicable to products in general.

Basis of Consideration

The investigation which this paper covers had for its principal object the determination of the accuracy of inspectional findings among incandescent lamps, but the principles are applicable to any product of which a large number of units is to be tested.

Purpose to be Served by Test

The purpose of the test must, of course, be considered as an important element. In general, tests are made for one of the following purposes: (1) To acquire information as a basis for future improvement in the product; (2) to determine whether or not a product averages above certain limits of acceptability; (3) to eliminate unsatisfactory units from the product, and (4) to determine by comparison which of two products is superior. In making tests for the first purpose mentioned, a high degree of accuracy is required and the samples on which tests are made must be truly representative. For the second and fourth purposes the general practice is to average the results of a number of samplings, whereas for the full accomplishment of the third purpose it is necessary to test 100 per cent of the product.

Considerations Involved in Sampling

Between no testing and tests of 100 per cent of the product there is an economic sampling which best meets a given set of conditions. It is hardly necessary to observe that in most cases the great expense involved in testing a high percentage of a product makes it necessary that we examine carefully the information desired before attempting to determine the proportion of the product to be tested and the kinds of tests to be made. Large samplings and correspondingly large tests involve a high labor cost, a large amount of equipment, space, etc., and a certain amount of delay in shipment. If a large sampling is made merely to determine quality without improving upon it by the substitution of good material for poor, it is usually uneconomical.

Experience as an Asset

Experience in testing the material involved is of great aid in establishing the proportion of the product that must be tested to yield a result within a given degree of accuracy. So also experience enables one to determine readily the kind of test that will most quickly and satisfactorily yield a result within a given degree of accuracy. No man with lamp experience would life-test five lamps chosen from one package and expect to form an opinion of the life of a factory's lamp product

Limitations in Accuracy

One of the most important elements to be decided upon before sampling a product is the accuracy to be required of the result The degree of homogeneity known to exist in a given material has an important bearing on the accuracy resulting from a given sampling. For example, alloys of metals are, by process of manufacture, so homogeneous in character that a small sampling yields a typical result. Here again, experience is valuable since the man who has performed many tests of a certain character can readily estimate the accuracy which may be obtained with a given sampling, or for a definite expenditure of money. One class of products in which this element is of great importance is that of manufactured materials where two or three elements are found in very large proportions and others in minute quantities.

Interdependence of Variables

The interdependence of certain variables in products should also be considered, especially if, as in many cases, such interdependence permits one to acquire the same information with less sampling due to a knowledge of such interdependence. For example, the purity of copper wire has a definite relation to its electrical resistance.

Everything that has been said above might be called common sense, but this particular form of common sense is gained by experience and it is experience which must govern largely in determining the kind of test and the per cent sampling.

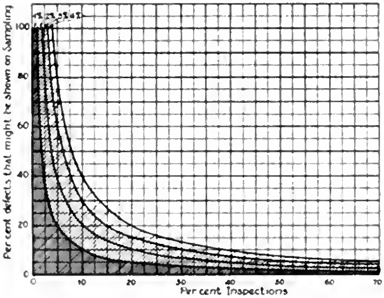

Fig. 1. Maximum and minimum values that might be shown as a result of various samplings of 100 lamps having 1, 2, 3 or 4 per cent defects

Elements to be Considered

There are certain primary considerations which must be borne in mind when making a sampling of a product, whether it be a natural one such as coal or a manufactured one such as steel. These elements include time or period, quantity at each period, relative position of elements, composition and variations in the product due to special influences. To some extent this is equivalent to saying that one must consider the time element, the magnitude of the several quantities involved, and the physical and chemical properties peculiar to a given material to be tested.

Sampling a Natural Product

To explain the preceding paragraph let us consider for a moment a natural product such as milk. As an illustration let us suppose that the quality of milk from a given herd of cows is to be determined. Here the time element would refer to the periods of the year in which the tests were made. The portion of a given quantity of milk which is chosen for sampling should be selected with regard to position, for one must remember that milk standing in a vessel varies in quality from the top to the bottom of the vessel, as the fats are to be found accumulated at the top. One would have to rely upon experience to a certain extent in determining the nature of the tests to be made to determine the composition of the milk and also the range of possible variations. The general practice in sampling a natural product is to first thoroughly mix the product, sample, put the sample aside, make additional samplings after further mixing, put the additional samples with the first and then proceed in the same manner with the vessel containing the accumulation of samples, subdividing until the desired quantity is reached. In this way the ultimate sample should be fairly typical of the total product.

Usual Method of Sampling Manufactured Products

In sampling artificial or manufactured products it is common to select at random a number of units from each portion of the total product that represents a given "run," the number of units taken from each portion being proportional to the magnitude of that portion. The samples thus accumulated are tested individually and the average result obtained is considered to be representative of the whole product. In making selections of units previous knowledge of variations in raw material and manufacture should be given consideration. It is not difficult to see how important experience may prove to be in the sampling of products whose manufacture involves a variety of materials and a variety of manufacturing operations.

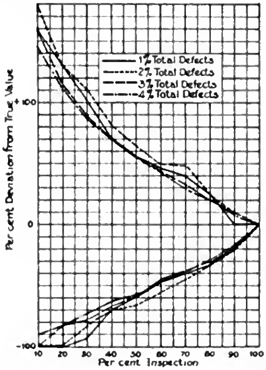

Fig. 2. Maximum and minimum deviations based on an actual inspection of 5000 lamps

The ultimate test of the sufficiency of a given sampling is the reproducibility of the results obtained with similar additional samplings.

PART II

RELATION OF THE THEORY OF PROBABILITY TO ACCURACY

Introduction

In the preceding paragraphs some of the fundamental principles governing sampling have been noted briefly. They are the broad general propositions that will be conceded by anyone who takes the time to give them thought. In the succeeding pages we shall attempt in a very elementary way to explain how the theory of probabilities affects the accuracy of sampling results, the samples being taken in various proportions.

Elementary Considerations

Let us first consider a few simple cases. If we have 100 lamps of which one is defective our chance of finding the defective lamp in a random selection of one from the lot is one in 100. If, however, we select in a group 50 of the 100 lamps, our chance of finding the defective one in the 50 we selected would be one in two. If our selection comprised ten lamps our chance of getting the defective would be one in ten, or in a five lamp selection, one in 20.

Range of Results in a Particular Case

Now let us assume that the 100 lamps include three having a given defect. What is the range of accuracy of the result with various proportions of sampling? If, for instance, a 2 per cent sampling were made, that is, if two lamps were chosen together at random, it is possible that neither of these would be defective and also possible that both of them would be defective. In the former case we would show zero per cent of defects and in the latter 100 per cent. If a 20 per cent sampling were made it is possible that no defects would be found or that a total of 3 or 15 per cent might be shown, while if 50 per cent of the lot were chosen we might find no defects, or we might find three, the latter case yielding 6 per cent. These are the limitations within which findings must lie. These and similar elementary cases are shown graphically in Fig. 1.

In order to get representative data concerning maximum and minimum values found in actual practice, the writer tabulated the results of actual inspections of four groups of 5000 lamps each and listed the maximum and minimum proportions of defects that could be found in them with various percentages of sampling.

The first group of the four was selected to yield 1 per cent defects, the second 2 per cent, the third 3 per cent and the fourth 4 per cent. The data for each group were so arranged in sequence that those subdivisions with the least defects were at the top of the column increasing until that with the greatest number of defects was at the bottom of the column. Samplings were then made of 10, 20, 30, etc., per cent, first from the end of the column where the groups contained small numbers of defects and then from the end of the column which contained the group having the greatest number of defects. In this way we show for practical cases, taken from actual data, the maximum and minimum values that resulted from samplings of various proportions of four groups of 5000 lamps. The results of the four sets of data are plotted in Fig. 2 in per cent of the proportion of defects in each case so that the curves are directly comparable. In good practice these maximum and minimum values are seldom approached as we shall see later in this paper.

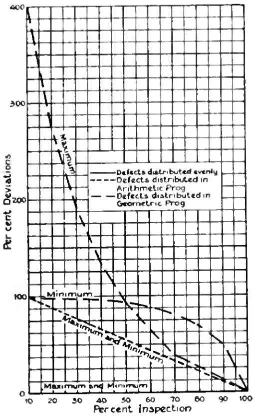

Fig. 3. Maximum and minimum deviations that may result from various samplings of 10,000 lamps in which defects are distributed in three ways

It is to be noted particularly that these are the greatest and least deviations and are not those that would obtain with a random sampling. The latter case is covered by Figs. 4, 5 and 6.

Pursuing this matter still further the writer desired to learn the effects on maximum and minimum deviations of having the defects—(1) equally well distributed throughout 10 lots of 1000 lamps each; (2) not so evenly distributed, and (3) quite well concentrated in the latter ones. The figures taken are shown in Tables I(A) and I(B). The second and third columns in Table I(B) are respectively arithmetic and geometric progressions. The resulting deviations of findings from the three values, if the sampling is in multiples of 1000 lamp groups, are shown graphically in Fig. 3. The samples were taken in the same way as for Fig. 2. The result is of course to be expected but it serves to give a mental picture of the very much wider deviations that may occur when the defects are concentrated in a few packages than is the case when the defects are fairly well distributed.

It is important to note that if the defects in a product are very unevenly distributed, or if one believes that such is the case, as in

TABLE I (A)

VARIOUS DISTRIBUTIONS OF REJECTIONS IN A PRODUCT OF 10,000 LAMPS

Number of Lamps in Each Lot	NUMBERS OF DEFECTS IN EACH LOT		
	Equal Distribution	Arithmetic Distribution	Geometric Distribution
1000	100	1	1
1000	100	24	2
1000	100	47	4
1000	100	70	8
1000	100	93	16
1000	100	116	32
1000	100	139	64
1000	100	162	128
1000	100	185	256
1000	100	208	512
Total	1000	1045	1023

TABLE I (B)

Per Cent Inspected	ARITHMETIC PROGRESSION				GEOMETRIC PROGRESSION			
	First Group in Per Cent	Last Group in Per Cent	Deviations from True Per Cent*		First Group in Per Cent	Last Group in Per Cent	Deviations from True Per Cent*	
			First	Last			First	Last
10	1	208	10.35	10.35**	1	512	10.13	40.97
	0.10%	20.8	99.0		0.10	51.2	99.09	400.4
20	25	393	9.20	9.20	3	768	10.08	28.17
	1.25%	19.65	88.0		0.15	38.4	98.6	275.3
30	72	555	8.05	8.0	7	896	10.00	19.57
	2.40%	18.50	77.0		0.23	29.8	97.8	191.3
40	142	694	6.90	6.90	15	960	9.86	13.77
	3.55%	17.35	66.0		0.37	24.0	96.1	134.6
50	235	810	5.75	5.75	31	992	9.61	9.59
	4.70%	16.20	55.0		0.62	19.82	93.7	93.7
60	351	903	4.60	4.60	63	1008	9.18	6.57
	5.85%	15.05	44.0		1.05	16.8	89.5	64.2
70	490	973	3.45	3.45	127	1016	8.41	4.07
	7.00%	13.90	33.0		1.82	14.3	82.0	39.7
80	652	1020	2.30	2.30	255	1020	7.04	2.52
	8.15%	15.75	22.0		3.19	12.75	68.6	24.6
90	837	1044	1.15	1.15	511	1022	5.06	1.17
	9.30%	11.60	11.0		5.67	11.4	49.3	11.4
100	1045	1045	0	0	1023	1023	0	0
	10.45%	10.45	0		10.23	10.23	0	0

* And per cent deviations form of true value, shown at the bottom of columns 2 and 6.

** Observe that the maximum and minimum deviations are alike.

the third and fourth columns of Table I(A), the product should be subdivided before sampling. Each subdivision should represent a part of the product whose elements are of fairly uniform quality.

In Table II are shown the probabilities of finding exactly 1, 2, 3, etc., defective units in 50, 100 or 1000 lamps, with various sampling proportions. These are expressed as decimals for the sake of simplicity. Thus, one chance in ten is expressed as 0.1. The theory, underlying the results obtained in this table, is explained in the appendix.

There are certain points of interest connected with the values of probability shown in Table II which have a distinct bearing on the accuracy of the results obtained with a given proportion of sampling.

First note that with a 10 per cent sampling of 50 lamps, or 5 examined, you have 100 chances in 1000 of finding the only defective one (fourth column). If this lamp is found it means that you record one defective lamp in 5 or 20 per cent defects (fifth column). This result is 10 times too large, but a 10 per cent sampling of 100 lamps with two defectives, or the same percentage as in the first case, yields but nine chances in a thousand of showing a result of 20 per cent or 10 times the true value.

Compare also a 10 per cent sampling of 50 lamps with two defects, or 4 per cent in the product, with the same sampling of 100 lamps with 4 per cent. The possibility of showing 20 per cent defects in the first case is 182 against 45 in the second case. Other similar cases will be observed readily by a further examination of the table. Thus we may deduce one principle in connection with sampling as follows:

The greater the number of units in a given product the less likely is the result of a given per cent sampling to show a proportion a certain number of times too large the true value.

These instances taken in connection with others to be found in samplings of 1000 lamps will be confirmed by certain data based on practical experience as outlined later in this paper.

Now examine the probability from another angle. In the cases just discussed the per cent of defects in the total product was considered to be uniform. If, however, the number of defects is the same but of varying proportions of the total product, a different result will be shown. Compare, for instance, the chances of finding two defective units in each of the three cases shown in Table III.

Each of these results (i.e., percentage defects found) is 10 times the true value and the probability is best where the two defective lamps form the smallest proportion of the total product. It is to be particularly remarked that in these three cases we are dealing with the same number of defects but different percentages, whereas in the previous cases we dealt with the probability of finding lamps which existed in the product in the same proportion, or formed the same per cent of the total product.

A further analysis of Table II tends to prove that the probability of a given accuracy is greater with a given per cent sampling of a large than a small group where equal numbers of defects are involved.

Some time ago, in connection with a proposal that certain tests be made for Mazda Service, it was found desirable to determine the character of the results that various samplings of a given product would yield. For this purpose tags numbered from 1 to 5000 were secured and upon certain ones, chosen at random, were written defect numbers to indicate that the lamps represented by those tags were defective in the way shown by the symbol employed. A sufficient number of tags was marked with each symbol so that the proportions in the total 5000 were equal to those in the first column of Table IV, which is a summary of the results of an actual inspection. All of the defects represented in this first column were placed, in the proportions noted, among the 5000 tags. Twenty per cent of these 5000 tags, or 1000, were then selected individually at random and the results tabulated under the heading "Twenty Per Cent Inspection—First Sampling." These 1000 tags were then returned to the group and a second sampling of 1000 was selected, the results being tabulated under the heading "Second Sampling." Similar selections of 10 per cent and 5 per cent were subsequently made and the results will be found in the succeeding columns. This table shows the deviations that may be expected in the results of samplings of products containing a large number of variables in small proportions. It shows, also, in general, that the smaller the proportion of a given defect in the whole product of a given number of units, the more probable are wide variations in the results of a given sampling. This confirms the results shown in Table II, thus showing proper accord between theory and experience. For instance, in the second line the whole product shows 0.02 per cent of defect No. 2 while the samplings show a result from zero to 0.20 per cent or ten times the proper amount, while of defect No. 7 the total product shows 0.02 per cent, while one of the 5 per cent samplings yields a result 20 times as large. Of defect No. 16 in which 0.44 per cent were found in the whole product, the results range from 0.20 to 1.20 or from 0.5 to 2.7 times the proper amount. Similarly of defect No. 31, another high item, the largest proportion found is somewhat less than three times the correct amount.

It would seem inadvisable to omit from the discussion of this table the point that one does not obtain from the small sampling even an approximately correct proportion of defects which, though appearing in small quantities, are of a serious nature.

From data given in Table IV concerning various samples of 5000 units and similar data on samplings of 1140 other units, the deviations from true values have been figured in terms of the proportion sampled. These deviations are shown in Tables V and VI. We have, therefore, two sets of figures representing deviations in the case of 20 per cent samples, three sets of deviations typical of 10 per cent samples and three of deviations representing the results obtained with five per cent samples. The human element has been eliminated from these results by the method in which they were obtained. The lamps were represented by tags, and symbols representing certain defects were placed on certain tags. If the clerical work involved is correct, the chance of overlooking defects, as in actual inspection, is eliminated. From the results shown in Tables V and VI we have plotted Figs. 4, 5 and 6 which show deviations to be expected in 20 per cent, 10 per cent and

TABLE

PROBABILITY OF FINDING DEFECTIVE LAMPS IN 50, 100 AND

No. of Defective Lamps in Product	Per Cent Defects	Per Cent Sampling	Probability of Finding One Defect	Per Cent Defective of Number Examined	Probability of Finding Two Defects	Per Cent Defective of Number Examined	Probability of Finding Three Defects	Per Cent Defective of Number Examined
								50 LAMPS
1	2.0	10	0.100	20				
2	4.0	10	0.182	20	0.008	40		
3	6.0	10	0.250	20	0.023	40	0.0005	60
4	8.0	10	0.313	20	0.044	40	0.002	60
								100 LAMPS
1	1.0	10	0.100	10				
		5	0.050	20				
		2	0.020	50				
2	2.0	10	0.182	10	0.009	20		
		5	0.096	20	0.002	40		
		2	0.040	50	0.0002	100		
3	3.0	10	0.250	10	0.025	20	0.0007	30
		5	0.139	20	0.006	40	0.00006	60
		2	0.059	50	0.0006	100		
4	4.0	10	0.303	10	0.045	20	0.003	30
		5	0.175	20	0.011	40	0.0002	60
		2	0.078	50	0.002	100		
5	5.0	10	0.345	10	0.050	20	0.006	30
		5	0.213	20	0.019	40	0.0006	60
								1000 LAMPS
1	0.1	10	0.100	1				
		5	0.050	2				
2	0.2	10	0.180	1	0.010	2		
		5	0.095	2	0.002	4		
3	0.3	10	0.241	1	0.029	2	0.001	3
		5	0.136	2	0.007	4	0.0001	6
4	0.4	10	0.244	1	0.048	2	0.004	3
		5	0.172	2	0.013	4	0.0004	6
								1000 LAMPS
10	1.0	10	0.385	1	0.196	2	0.056	3
		5	0.313	2	0.074	4	0.010	6
20	2.0	10	0.270	1	0.286	2	0.192	3
		5	0.385	2	0.189	4	0.059	6
30	3.0	10	0.139	1	0.228	2	0.238	3
		5	0.345	2	0.264	4	0.128	6

5 per cent samplings of 1140 and 5000 lamps at each proportion of defects from 0.02 per cent to three per cent inclusive. It should be noted particularly that with the larger group (5000 lamps) the deviations are very much smaller with small proportions of defects than is the case with the group of 1140 lamps.

In order to emphasize the differences in deviations due to certain variables, Table VII is provided. It shows certain data taken from the three sets of curves.

One should observe, for instance, that approximately the same deviations are encountered in a 20 per cent inspection of 1140 lamps as one would find in a 5 per cent inspection of 5000 lamps if there be 1 per cent defects in each. In the case of 0.5 per cent defects a 5 per cent inspection of 5000 lamps would give smaller deviations than two 20 per cent inspections of 1140 lamps.

In general it may be remarked that the differences in deviations at a given per cent defects become larger as the per cent sampling is decreased and that as the per cent defects is increased, with given sampling, the deviations decrease most rapidly in the case of the small groups of lamps.

In Figs. 4, 5 and 6 we have shown the deviations that resulted from 5, 10 and 20 per cent samplings of 1140 and 5000 lamps which were transcribed to numbered tags. From the probability figures given in Table II certain theoretical average deviations have been computed. These are shown in Table VIII.

It is interesting to observe, for instance, that a 10 per cent inspection of 50 lamps containing 2, 4, 6 and 8 per cent defects yields deviations between 180 and 130 per cent respectively, and the same proportion of

II

1000 LAMP PRODUCTS WITH VARIOUS PROPORTIONS OF SAMPLING

Probability of Finding Four Defects	Per Cent Defective of Number Examined	Probability of Finding Five Defects	Per Cent Defective of Number Examined	Probability of Finding Six Defects	Per Cent Defective of Number Examined	Probability of Finding Seven Defects	Per Cent Defective of Number Examined	Probability of Finding Eight Defects	Per Cent Defective of Number Examined
IN PRODUCT									
0.00002	80								
IN PRODUCT									
0.00005	40								
0 000001	80								
0.0003	40	0.000003	50						
0.000006	80								
IN PRODUCT									
0.0009	4								
0.000006	8								
IN PRODUCT									
0.011	4	0.0001	5						
0.0009	8	0.00005	10						
0.089	4	0.031	5	0.002	6				
0.013	8	0.002	10						
0.182	4	0.104	5	0.005	6	0 014	7	0 143	8
0.044	8	0.012	10	0.002	12				

sampling of 100 lamps in which there are from 1 to 5 per cent defects results in deviations between 180 and 117 per cent, while the deviations resulting from 10 per cent sampling of 1000 lamps are very much smaller. Compare also the findings with respect to deviations when a 5 per cent inspection is made. It is important to note in this connection, as has been emphasized earlier in this paper, that with a given per cent sampling the probability and the resulting deviation is dependent upon the number and not on the per cent of defects in the product. For instance, the same per cent deviation is found on a 10 per cent sampling of 100 lamps if there is 1 per cent or one defective lamp as is found in 1000 lamps if there is 0.1 per cent or one defective lamp.

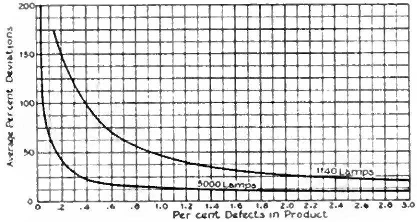

Fig. 4. Average per cent deviations resulting from 20 per cent samplings of two groups of lamps having varying proportions of individual defects

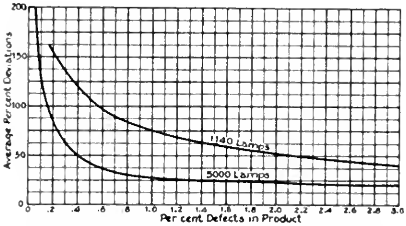

Fig. 5. Average per cent deviations resulting from 10 per cent samplings of two groups of lamps having varying proportions of individual defects

Another significant development in connection with this work is an indication that we may be able to determine the efficiency of an inspection by means of certain samplings that we may make of the results, transcribed to tags, from which we shall learn whether or not the average deviations are of the order shown in Table VIII for the per cent defects in the whole product that we investigate. For instance, if we take the results of an actual inspection of a group of 5000 lamps and make 5, 10 and 20 per cent samplings the deviations found should be of the order of those shown in Table VIII for the proportion of defects that the actual inspection recorded. If the deviations are not similar to the theoretical ones, we can determine by trial what the true per cent is in the product and thus learn how efficient the inspection was.

As an illustration of the above we took a group of 5000 lamps actually inspected and made 5, 10 and 20 per cent samplings. According to the recorded findings on this whole group of lamps, each of which was inspected, there should have been three per cent defects in the product, but by using the method outlined above we found that the true per cent of defects was probably in the neighborhood of 3.5 and that the inspection was apparently about 85 per cent efficient. In other words, 15 per cent of the defects in this group were not recorded on the inspection.

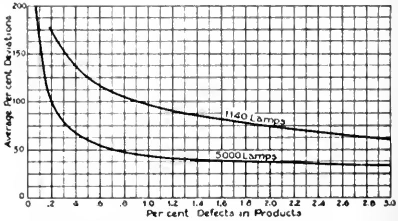

Fig. 6. Average per cent deviations resulting from 5 per cent samplings of two groups of lamps having varying proportions of individual defects

In conclusion, the writer might say that although a considerable amount of work has

TABLE III

No. of Units in Product	No. of Defects in Product	True Per Cent Defects	Per Cent Sampling	No. of Defects to be Found	Per Cent Defects	Probability
50	2	4.0	10	2	40.0	0.008
100	2	2.0	10	2	20.0	0.009
1000	2	0.2	10	2	2.0	0.010

TABLE IV

PER CENT DEFECTS FOUND IN VARIOUS SAMPLINGS OF 5000 LAMPS

	100 PER CENT INSPECTION	20 PER CENT SELECTION		10 PER CENT SELECTION			5 PER CENT SELECTION		
		First Sampling	Second Sampling	First Sampling	Second Sampling	Third Sampling	First Sampling	Second Sampling	Third Sampling
Number Examined	5000	1000	1000	500	500	500	250	250	250
Group A									
DEFECT NO.									
1	0.18	0.20	0.20	0.20	0.20	0.20	0.40		0.40
2	0.02		0.10			0.20			
3	0.02								
Sub totals	0.22	0.20	0.30	0.20	0.20	0.40	0.40	0	0.40
Group B									
4	0.28	0.40	0.30	0.20	0.20	0.20	0.40	1.20	
5	0.04	0.10				0.20	0.40		
Sub totals	0.32	0.50	0.30	0.20	0.20	0.40	0.80	1.20	0
Group C									
6	0.02		0.10				0.40		
7	0.02						0.40		
8	0.08	0.10	0.20					0.40	
9	0.04		0.10		0.20				
10	0.02		0.10		0.20	0.20	0.40		
11	0.12	0.20	0.20						0.80
12	0.24	0.20	0.10	0.40	0.60	0.80	0.40		
13	0.02		0.10			0.20			
14	0.06	0.10						0.40	
Sub totals	0.62	0.60	0.90	0.40	1.00	1.20	1.20	0.80	0.80
Group D									
15	0.26	0.20	0.30	0.20	0.50	0.40			
16	0.44	0.70	0.40	0.20	0.80	0.80	0.80	0.40	1.20
17	0.16		0.20	0.20	0.20		0.80	0.40	
18	0.16	0.10	0.30	0.20	0.40	0.40			0.80
19	0.02				0.20				
20	0.02	0.10							
21	0.02								
22	0.04		0.20						
23	0.06	0.10						0.80	
24	0.02	0.10							
Sub totals	1.20	1.30	1.40	0.80	2.20	1.60	1.60	1.60	2.00
Group E									
25	0.08								
26	0.36	0.30	0.50	0.40		0.60	0.80		0.40
27	0.02		0.10						
28	0.02								
29	0.04	0.10		0.20					
30	0.02	0.10							
Sub totals	0.54	0.50	0.60	0.60	0	0.60	0.80	0	0.40
Group F									
31	0.32	0.90		0.40		0.20		0.40	0.80
32	0.10	0.10	0.20			0.20	0.40		0.40
Sub totals	0.42	1.00	0.20	0.40	0	0.40	0.40	0.40	1.20
Grand totals	3.32	4.10	3.70	2.60	3.60	4.60	5.20	4.00	4.80

been performed in gathering together the data included here, nevertheless this is but a preliminary study of the field of sampling and resulting accuracy. It is to be hoped that this work may be continued along such lines as may prove of most benefit in interpreting future inspectional findings. The writer wishes to acknowledge the assistance of Messrs. Woolfson and Evans in making certain of the computations required.

TABLE V

WEIGHTED DEVIATIONS, 5000 LAMPS

True Proportion Appearing in Product Per Cent	Times Proportion Appears	20 PER CENT INSPECTION		10 PER CENT INSPECTION		5 PER CENT INSPECTION	
		Average Deviation Per Cent	Per Cent Deviation	Average Deviation Per Cent	Per Cent Deviation	Average Deviation Per Cent	Per Cent Deviation
0.02	13	0.02	100.0	0.04	200.0	0.04	200.0
0.04	4	0.06	150.0	0.07	175.0	0.06	150.0
0.06	2	0.05	83.4	0.06	100.0	0.22	83.3
0.08	2	0.05	62.5	0.08	100.0	0.12	75.0
0.10	1	0.05	50.0	0.10	100.0	0.23	43.5
0.12	1	0.08	66.6	0.12	100.0	0.30	250.0
0.16	2	0.10	62.5	0.12	75.0	0.33	200.0
0.18	1	0.02	11.1	0.02	11.1	0.20	111.0
0.24	1	0.09	37.5	0.36	150.0	0.21	87.5
0.26	1	0.05	19.2	0.18	69.3	0.26	100.0
0.28	1	0.07	25.0	0.08	28.5	0.44	143.0
0.32	1	0.45	14.0	0.17	53.0	0.29	90.6
0.36	1	0.05	13.8	0.22	61.2	0.28	78.0
0.44	1	0.15	37.4	0.32	72.8	0.38	86.5
0.54	1	0.05	9.3	0.22	40.0	0.31	57.4
0.62	1	0.15	24.2	0.39	64.0	0.31	50.0
0.84	1	0.20	23.8	0.45	53.0	0.39	46.4
1.20	1	0.15	12.5	0.60	50.0	0.53	44.0
1.74	1	0.16	9.2	0.42	24.0	0.49	28.2
3.32	1	0.58	17.6	0.76	23.0	1.35	41.0

TABLE VI

WEIGHTED DEVIATIONS, 1140 LAMPS

True Proportion Appearing in Product Per Cent	Times Proportion Appears	20 PER CENT INSPECTION		10 PER CENT INSPECTION		5 PER CENT INSPECTION	
		Average Deviation Per Cent	Per Cent Deviation	Average Deviation Per Cent	Per Cent Deviation	Average Deviation Per Cent	Per Cent Deviation
0.09	16	0.14	155	0.15	167	0.16	176
0.17	8	0.26	153	0.33	194	0.35	149
0.26	4	0.29	112	0.35	135	0.47	180
0.35	2	0.63	180	0.38	109	0.35	100
0.44	1	0.44	100	0.44	100	0.44	100
0.53	1	0.09	17	0.70	132	0.76	143
0.62	1	0.18	29	0.39	63	0.62	100
0.69	4	0.47	68	0.69	100	0.69	100
0.78	1	0.25	33	0.65	83	1.04	134
0.88	1	0.63	72	0.01	1	0.88	100
1.23	1	0.89	69	1.67	131	1.58	128
1.32	1	1.56	118	0.76	58	1.02	76
1.41	1	0.31	21	0.43	132	1.20	85
1.85	1	0.30	16	0.96	52	0.62	88
1.93	1	0.50	26	0.98	51	0.65	34
2.46	1	1.10	45	1.10	45	1.99	81
2.81	1	0.49	17	1.19	42	1.98	71
2.98	1	0.32	11	1.49	50	1.58	53

APPENDIX

Fig. 1 represents the total range of possible values but does not take into account the probability of showing each of the results.

To make clear the theory of probabilities as applied to sampling let us consider a simple case. If one has four lamps of which two are defective the probability of selecting defective ones only in a selection of two at random is $\frac{1}{6}$ because there are $\frac{4\times3}{1\times2}$ or six possible combinations of the lamps taken two at a time. If, however, we had six lamps the number of combinations three at a time would be $\frac{6\times5\times4}{1\times2\times3}$ or 20. If three or 50 per cent were selected as above from six of which two are defective our probability of finding two defective ones in the first three selected would be $\frac{4}{20}$ or $\frac{1}{5}$, since there are four combinations that contain two defective lamps. It is to be remarked here that the probability increases as the number of combinations, in which the desired units may figure, increases.

It must be conceded that if the probability that an event will happen is $\frac{1}{M}$ then the probability that it will not happen is $1-\frac{1}{M}$. Thus the sum of the ratios of the probabilities of the event happening and its not happening is unity.

Second, the probability that all of a set of events will occur is the product of the ratios representing the probabilities of each of the events in the set. For instance, if of six lamps two are defective, the possibility of selecting a defective one on the first trial is $\frac{1}{3}$. If this one is selected and not replaced the probability of selecting a defective one on the second trial is $\frac{1}{5}$. The probability of selecting two defective ones in successive trials is $\frac{1}{3}\times\frac{1}{5}=\frac{1}{15}$.

Third, the probability of an event happening exactly "r" times in "n" exclusive trials from the total number, is represented by the expression

$$C_r^n\, p^r q^{n-r} \tag{1}$$

TABLE VII

TYPICAL DEVIATIONS FROM TRUE VALUES WITH PRODUCTS OF TWO SIZES, VARIOUS SAMPLING PROPORTIONS AND DIFFERENT PER CENTS OF DEFECTS

PER CENT DEFECTS	0.5 PER CENT		1 PER CENT		2 PER CENT		3 PER CENT	
No. in Product	1140	5000	1140	5000	1140	5000	1140	5000
Per Cent Sampled	Per Cent Deviations From True Values							
5	±130	±60	±95	±45	±80	±37	±70	±33
10	105	40	70	30	55	25	43	20
20	80	20	45	15	30	10	20	9

TABLE VIII

APPROXIMATE THEORETICAL PER CENT AVERAGE DEVIATIONS

Total Lamps in Product	PER CENT DEFECTS												
	0.1	0.2	0.3	0.4	0.5	1	2	3	4	5	6	7	8
10 Per Cent Inspections													
50 lamps							180		162		145		130
100 lamps						180	162	145	130	117			
1000 lamps	180	162	145	130	117	71	50	42					
5 Per Cent Inspections													
100 lamps						190	180	170	162	153			
1000 lamps	190	180	170	162	153	117	71	60					

where

n = the number of trials
r = the exact number of times the event is to happen
p = the probability that the event will happen in a single trial $= \frac{1}{M}$
$q = 1 - p = 1 - \frac{1}{M}$ = the probability that the event will fail on a single trial.

To illustrate the use of this formula suppose we desire to know the probability of twice selecting the same coin from among five in two successive trials from the whole group of five.

$$p = \frac{1}{M} = \frac{1}{5} \quad n = 2 \quad r = 2 \quad q = 1 - p = \frac{4}{5}$$

$$C^2_2 (1)^2 q^0 = \frac{2 \times 1}{1 \times 2} \times \frac{1}{25} \times 1 = \frac{1}{25}$$

Fourth, the method by which selections are made affects the probability of a given result. To make this clear let us consider 100 lamps of which four are defective. If a group of five is selected the probability of finding two defective units in the group is 1 in 88 or 0.011. If, however, one lamp is selected, examined and returned to the remainder of 99, a second selection made at random and returned, etc., the probability of finding two defective lamps in a total of five such selections is 1 in 47 or 0.021. This is the kind of case to which the formula (1) applies. In order to investigate the probabilities involved in sampling in groups, as our work is performed, the writer has devised a formula as follows:

$$\frac{C^{P-D}_{n-r} C^{D}_{r}}{C^{P}_{n}} \tag{2}$$

where

P = the total number of units in the product
D = the number of defective units in the product
n = the number of samples taken
r = the number of defective units desired in the samples taken.

It is by means of this formula that the results shown in Table II have been computed. To illustrate its use, suppose we desired to learn the probability of finding one defective lamp among four in a product containing 100 lamps, with a 10 per cent sampling. Here $P = 100$ $D = 4$ $n = 10$ $r = 1$. Substituting in (2)

$$\frac{C^{96}_{9} C^{4}_{1}}{C^{100}_{10}} \frac{96 \times 95 \times 94 \times 93 \times 92 \times 91 \times 90 \times 89 \times 88}{1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9} \times \frac{4}{1} \times$$

$$\frac{1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10}{100 \times 99 \times 98 \times 97 \times 96 \times 95 \times 94 \times 93 \times 92 \times 91} = \frac{1}{3.3}$$

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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.

Brakes, Dynamic

Regeneration Characteristic Curves of Direct-current Locomotives. Atwell, C. A.
Elec. Jour., Mar., 1922; v. 19, pp. 113-116.

Cars, Electric

Gasoline Bus or Trolley Bus—Which? Jackson, Walter.
Auto. Ind., Mar. 16, 1922; v. 46, pp. 597-600.
(A short comparison of the advantages of each system. Pays special attention to operating costs.)

Condensers, Static

Condenser Discharges Through a General Gas Circuit. Steinmetz, Charles P.
A.I.E.E. Jour., Mar., 1922; v. 41, pp. 210-223.
(Mathematical study. Preceded by a non-mathematical synopsis of the subject matter.)

Converters, Synchronous

Analytical Investigation of the Causes of Flashing of Synchronous Converters. Shand, E. B.
A.I.E.E. Jour., Mar., 1922; v. 41, pp. 174-183.
(Presents results of an investigation. Includes bibliography of 13 entries.)

Cranes, Electric

Selection of Electrical Apparatus for Cranes. McLain, R. H.
A.I.E.E. Jour., Mar., 1922; v. 41, pp. 249-256.
(Mathematical paper showing methods of selecting electric drive apparatus.)

Electric Cables

Aluminum Cable with Steel Core. (In German.)
Zeit. des Ver. Deut. Ing., Feb. 18, 1922; v. 66, p. 168.
(Brief report of tests made by Felten & Guilleaume Carlswerk of Koeln-Muelheim, Germany.)

Electric Control Systems

Control of Blower Motors. Issertell, Henry G.
Am. Soc. Heat. & Vent. Engrs. Jour., Mar., 1922; v. 28, pp. 107-120.
(Illustrated article on various types of control panels for motor-driven blowers and exhaust fans.)

Electric Distribution

Cable Charts and Cable Calculations. "Anode."
Elec. Rev. (Lond.), Mar. 17, 1922; v. 90, pp. 387-388.
(Shows how alignment charts or nomograms may be used in calculating distribution lines.)

Electric Drive—Steel Mills

Application of Electric Power in the Iron and Steel Industry. Hall, W. S.
Assoc. Ir. & St. Elec. Engrs., Mar., 1922; v. 4, pp. 127-151.
(General discussion.)

Electric Motors in the Steel Plant. Fox, Gordon.
Blast Fur. & St. Pl., Mar., 1922; v. 10, pp. 171-173.
(Serial.)

Electric Drive—Ventilating Machinery

Electric Ventilating. Reace, Wm. T. and Breidert, George C.
Elec. Jour., Mar., 1922; v. 19, pp. 119-123.

Electric Motors, Synchronous

Induction-type Synchronous Motors. Carr, Laurence, H. A.
I.E.E. Jour., Feb., 1922; v. 60, pp. 165-195.
(Explains the construction and theory of operation. Includes bibliography of 21 entries.)

Electric Wire and Wiring

Information That You Need When Wiring for Motors in Ordinary and Special Service. Cornelison, H. L.
Elec. Rev. & Ind. Engr., Mar., 1922; v. 80, pp. 127-130, 151, 154.
(Tables of data for use in selecting wiring equipment for a-c. and d-c. motors.)

Electrical Machinery—Temperature

Heating of Railway Motors in Service and on Test-Floor Runs. Luke, G. E.
A.I.E.E. Jour., Mar., 1922; v. 41, pp. 165-173.
(Theoretical paper. Includes bibliography of ten entries.)

Temperature Measurements of Electrical Machines. Keinath, Georg. (In German.)
Elek. und Masch., Feb. 26, 1922; v. 40, pp. 97-105.
(Reviews various methods and apparatus and discusses their applicability. Serial.)

Electricity—History

Institution Jubilee Commemoration.
Elec'n (Lond.), Mar. 3, 1922; v. 88, pp. 254-257.
(Article composed of reminiscences of the early history of various phases of the electrical industry as brought out at the 50th anniversary meeting of the I. E. E. Serial.)

Gas Welding

Strength of Mechanically Welded Pressure Containers. Roark, R. J.
Mech. Engng., Apr., 1922; v. 44, pp. 225-230.
(Describes tests on electrically-welded, gas-welded and riveted pressure containers.)

Hydro-Electric Development

Hydro-Electric System of Province of Ontario Investigated.
Elec. Wld., Mar. 11, 1922; v. 79, pp. 471-474.
(An abstract of an investigation by W. S. Murray.)

Mechanical Storage of Water Power.
Elec. Rev. (Lond.), Mar. 10, 1922; v. 90, pp. 327-330.
(Describes the hydro-electric plant at Walkerburn, England. In idle hours water is pumped to a high-level reservoir to be utilized during peak loads.)

Walkerburn Water Power Mechanical Storage Installation.
Engng. (Lond.), Feb. 17, 1922; v. 113, pp. 189-193.
(Illustrated description of an English plant in which water is pumped to a high level during off hours to be used when the load comes on. Serial. Same in *Engr.*, Feb. 17, 1922.)

Hydro-Electric Plants—Testing

Test Code for Hydraulic Power Plants and Their Equipment.
Mech. Engng., Apr., 1922; v. 44, pp. 248-258.
(Preliminary draft formulated by the A. S. M. E. Committee on Power Test Codes.)

Insulating Oils

Care of Transformer Oil. Sampson, E. R.
Elec. Jour., Mar., 1922; v. 19, pp. 125-126.
(Short article on methods and equipment for testing.)

Insulation

Effect of Heat on the Electric Strength of Some Commercial Insulating Materials. Flight, W. S.
I.E.E. Jour., Feb., 1922; v. 60, pp. 218-235.
(Includes many tables and graphs showing results of tests on various common insulating materials.)

Lubrication and Lubricants—Testing

Thickness and Resistance of Oil Films in High Speed Bearings. Stoney, Gerald and others.
Engng. (Lond.), Mar. 3, 1922; v. 113, pp. 249-250.
(Describes apparatus and methods for making tests.)

Magnets

Manufacture and Tests of Permanent Magnets. Roussel, C. E. (In French.)
Génie Civil, Mar. 11, 1922; v. 80, pp. 223-225.
(Extract from an extensive paper. Goes into considerable detail. Serial.)

Radiotelegraphy

High-Speed Wireless Telegraphy. Cusins, A. G. T.
I.E.E. Jour., Feb., 1922; v. 60, pp. 245-262.
(Discusses theory, apparatus, circuits, etc., for various kinds of mechanical sending and receiving schemes for wireless telegraph messages.)

Railroads, Industrial

Electrification of Industrial Plant Railways. Petty, D. M.
Assoc. Ir. & St. Elec. Engrs., Mar., 1922; v. 4, pp. 153-162.
(Discusses the essential features.)

Rheostats

Some Notes on the Design of Liquid Rheostats. Wilson, W.
I.E.E. Jour., Feb., 1922; v. 60, pp. 196-217.
(On the theory of design.)

Short Circuits

Result of Short-Circuit Tests on Outdoor Type Reactance Coils. Bang, A. F.
Elec. Wld., Mar. 4, 1922; v. 79, pp. 425-428.
(Tests conducted under conditions of artificial rainfall.)

Skin Effect

Skin Effect and Proximity Effect in Tubular Conductors. Dwight, Herbert Bristol.
A.I.E.E. Jour., Mar., 1922; v. 41, pp. 203-209.
(On theory of design. Includes graphs for use in calculation of conductors.)

Steam Plants

Heat Balance and Steam Distribution in a Large Service Plant. Kutner, S. D.
Power, Mar. 28, 1922; v. 55, pp. 488-491.
("Tells how steam, hot water and power are charged to different departments in a large building supplied from an isolated power plant.")

Still Engines

Still Engine for Marine Propulsion. Rennie, Archibald.
Inst. Engrs. & Shipbuilders, Trans., Mar., 1922; v. 65, pp. 17-72.
(Extensive paper illustrating and describing the marine Still engine.)

Water Turbines

Moody Ejector Turbine. Kerr, S. Logan.
Mech. Engng., Apr., 1922; v. 44, pp. 243-247.
(Discusses the theory of this special type of water turbine.)

NEW BOOKS

Airplane Engine. Marks, Lionel S. 454 pp., 1922, N. Y., McGraw-Hill Book Company, Inc.

Atomic Theories. Loring, F. H. 218 pp., 1921, N. Y., E. P. Dutton & Co.

Construction, Cost Keeping and Management. Gillette, Halbert Powers and Dana, Richard T. 572 pp., 1922, N. Y., McGraw-Hill Book Company, Inc.

Essentials of Industrial Costing. Armstrong, George S. 297 pp., 1921, N. Y., D. Appleton & Co.

Handbuch der Drahtlosen Telegraphie und Telephonie. Nesper, Eugen. 2 vol., 1921, Berlin, Julius Springer.

Hydraulics and Its Applications. New ed., rev. and enl. Gibson, A. H. 813 pp., 1921, N. Y., D. Van Nostrand Company.

Industrial Fatigue and Efficiency. Vernon, H. M. 264 pp., 1921, N. Y., E. P. Dutton & Co.

Protective Relays. Todd, Victor H. 274 pp., 1922, N. Y., McGraw-Hill Book Company, Inc.

Short Course in the Testing of Electrical Machinery. Ed. 4, rev. and enl. Morecroft, J. H. and Hehre, F. W. 220 pp., 1921, N. Y., D. Van Nostrand Company.

Theory of the Induction Coil. Taylor-Jones, E. 217 pp., 1921, N. Y., Sir Isaac Pitman & Sons, Ltd.

GENERAL ELECTRIC REVIEW

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CHANGES IN THE DIRECTORATE OF THE GENERAL ELECTRIC COMPANY

Changes in the directorate of the General Electric Company were announced after a meeting held in New York, on May 16th.

Owing to the fact that our June issue was off the press two weeks ahead of scheduled date, so that it could be used at the National Electric Light Association's Convention we have been unable to comment on these changes until our present issue.

Mr. C. A. Coffin retires as chairman of the board of directors and Mr. O. D. Young was elected to that office. Mr. E. W. Rice, Jr. retires as president and Mr. Gerard Swope assumes the presidency.

Both Mr. Coffin and Mr. Rice asked to be relieved of their heavy responsibilities and to have younger men assume the arduous duties. Mr. Coffin will continue as a director of the Company and do all in his power to assist its officers. Mr. Rice, who has done so much for the scientific research, engineering and technical work of the Company, will devote his time to furthering the interests of the Company in these directions. The position of honorary chairman of the board of directors was created and Mr. Rice was elected to this position.

Mr. Coffin and Mr. Rice have been business associates for over forty years. In fact, the lives of both men have been so intimately connected with the electrical industry that it is impossible to say anything brief which can give any adequate idea of the part they have played in its upbuilding,—the electrical industry is one of the youngest but at the same time one of the greatest in the country and there are no two men who have done more for it than these two.

Ever since the year 1882, when Messrs. Peavear, Coffin and Silas Barton of Lynn bought a majority interest in the American Electric Company, in which company Mr. Rice was acting as Professor Thomson's assistant, Mr. Coffin and Mr. Rice have worked together in building up the organization which today is known throughout the world as the General Electric Company.

Prior to his election as president Mr. Rice was a vice-president and chief engineer of the Company. He is by nature and inclination an engineer and it was chiefly due to his foresight and initiative that so much money and energy was spent in scientific research and technical development. The very progress of the organization testifies to the value of his foresight. Every one concerned is keenly pleased that Mr. Rice will now be active again in this work.

Mr. O. D. Young, who now becomes chairman of the board of directors, was born in 1874. He is a graduate of St. Lawrence University and the Boston University Law School. He has been for several years a vice-president of the Company and he is also chairman of the board of directors of the Radio Corporation of America. In addition to these positions, he is a director of the Electric Bond and Share Corporation, of the Bankers' Trust Company and many other organizations.

Mr. Anson W. Burchard, who has been elected vice-chairman of the board of directors, has for many years been one of the Company's vice-presidents, having devoted his attention particularly to public utility interests and foreign investments. For many years Mr. Burchard was Mr. Coffin's assistant and was very active in building up the lamp business until Mr. Morrison took charge of this work. Mr. Burchard in his new capacity as vice-chairman of the board will be able to make an extended use of his wide experience in the affairs of the Company.

Mr. Gerard Swope, who now assumes the presidency, has had both an engineering and commercial training which were the qualifications that those retiring at this time were anxious to combine in a new president. He was born in 1872 and graduated from the Massachusetts Institute of Technology in 1895 as electrical engineer. In 1893 he worked in the shops of the General Electric Company and after graduation entered the employ of the Western Electric Company, starting from the bottom in their Chicago shops. He was appointed designing engineer of the power apparatus engineering department and was afterwards made manager of the Company's organization at St. Louis. Four years later he was called back to Chicago and made manager of the power apparatus department, having charge of engineering, manufacture, and sales. In 1908, Mr. Swope was transferred to New York as general sales manager and in 1913 he was elected vice-president and director of the Company. This connection was severed to enter the army, and on January 1, 1919, he became president of the International General Electric Company.

Mr. J. R. Lovejoy and Mr. G. F. Morrison, who have both been vice-presidents of the Company for a number of years and who have grown up in the service of the Company, were elected members of the board of directors

J. R. H.

Electric Power Afloat

GENERATION AND DISTRIBUTION ON THE WATER FOR TRANSPORTATION AND OTHER PURPOSES

By William T. Donnelly

Consulting Engineer, 17 Battery Place, New York

Many an engineer will read this story with keen interest. It is written by an optimist—and what good is an engineer unless he is optimistic? You must think before you can act—there is an untold future before "Electric Power Afloat" and we wish the pioneer all success.—Editor.

Way back in the year 1882 on Pearl Street, near its intersection with Fulton, in Old New York, was built the first central station for the distribution of electricity; and the possibility of its sale at that time depended entirely upon its value for lighting purposes alone and remarkable as it may seem, Fulton Street, New York, between Fulton Ferry and Broadway, offered the greatest possibilities for this use. The station referred to was equipped with four 150-h.p. Porter-Allen high speed engines directly connected to four Jumbo generators. From this small beginning, all the great industry of the generation, sale and distribution of electricity to the municipalities of America had its origin.

At this time the writer, then sixteen years old, was carrying the key, lighting the fires and sweeping out a pattern shop nearby, and did not miss in his spare time one move from the breaking of ground to the completion and first operation of the plant, and the electricity then absorbed has never ceased to circulate actively in his system. This early contact and inoculation is his only apology for what follows.

In the summer of 1915, the yacht *Dawn*, a boat 50 feet long and 12 feet beam, was completed and launched; she was equipped with a 60-h.p. Lamb gas engine driving a 40-kw. generator, and directly connected to the propeller was a 20-h.p. electric motor operating at 450 revolutions per minute. This boat and entire equipment was described and illustrated in a paper read before the Brooklyn Engineers' Club on "Application of Electricity to Marine Transportation," January, 1915.

The *Dawn* operated by this power plant was used as a yacht, cruising in and about New York and eastern waters, until the outbreak of the late war, when under the command of my son, Norman E. Donnelly, she was turned over to the United States Government and served as a scout patrol boat, serving for more than a year, off Newport, and in the winter of 1917 encountered some of the most severe weather, both as to temperature and gales, ever experienced there. The *Dawn* was returned to her owner in the summer of 1918 with her power plant in good working condition, and in that fall upon the completion of the electric propelled yacht *New Era*, equipped only with a 20-h.p. motor, the original power plant, as installed in 1915, furnished the power for both boats on a cruise up the Hudson and through the Barge Canal to Schenectady, New York, and return. This cruise was made in November and some of the weather conditions may be described as at least trying.

In the summer of 1920 the original power plant was replaced by one comprising a 50-kw. General Electric generator driven by an 86-h.p. Van Blerck engine, operating at approximately 1000 revolutions per minute. These two boats, together with the power plant, were described and fully illustrated in an engineering paper read before the Brooklyn Engineers' Club, "A New Development in the Application of Electricity to Marine Transportation," January, 1920.

On October 10, 1920, the *Dawn* and *New Era* left the Bayside Yacht Club for a winter cruise in southern waters. The party comprised myself and wife, my son, Norman E. Donnelly, and my daughter, Helen V. Donnelly, on the *New Era*, and on the *Dawn* was my crew, Captain J. Sluker and mate M. Harasti.

In many ways I consider this the most remarkable journey ever made on any inland or other waters.

Consider yourself for a few moments in my place with twenty years of close, hard application to business behind you and in your possession two boats of your own design and construction, as new to the world as Noah's ark, and before you all the possibilities of realizing a "dream of years." Way off somewhere to the south, the sunny land that knows nothing of the ice and snow and biting frost of our northern winters, where the skies are always blue and the warm sun shines the winter through.

And then, how much better the prospect than Noah with an ark full of animals to feed and take care of and rainy weather for forty days, whereas my fleet comprises a floating power plant to furnish the most desirable requisite that mortal man has so far discovered, an adequate supply of electricity, this power plant to be a home for my crew of retainers.

A second ship fitted up with all those cunning and clever devices that man has gotten together to make home a comfortable place to live in, and then take the best month in the year, October, to start your journey. Pull up your anchor and head southward, ever southward, hunting snug harbors when the wind blows, and sailing on when the warm sun shines, visiting one after the other, everyone of our coastwise cities, staying just so long as your inclination or desire dictates, and then moving on, and having with you every comfort of a home, whether you tarry in the wilderness or in the heart of some great city.

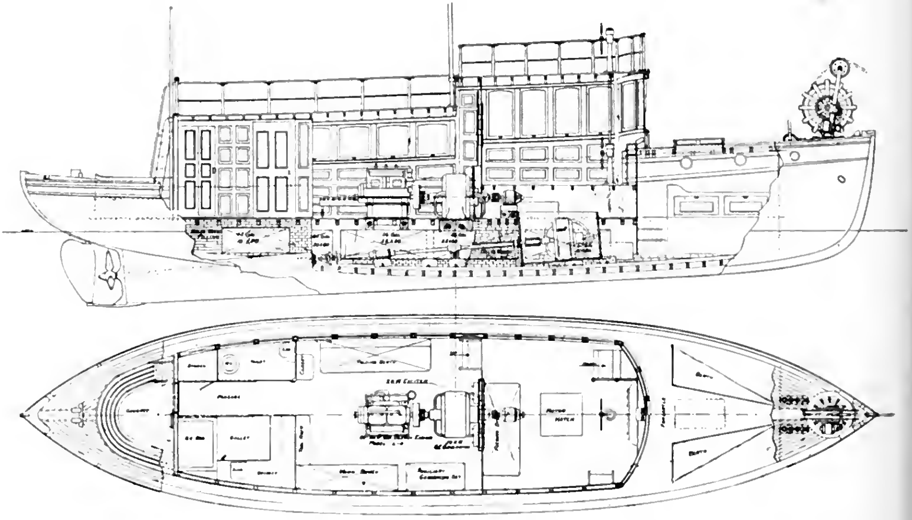

Fig. 1. Construction and Accommodation Plan of the *Dawn*

We spent four months in traveling down the coast through inland waterways, bays, harbors, rivers and sounds, from New York to Jacksonville, Florida, arriving in Jacksonville on the last day of January, and they were four months of continued pleasant weather, which could only be described to the northerner as October weather, with just enough warmth in the sun and air to make outdoor life a delight and without a care.

From Jacksonville, we voyaged to Sanford 200 miles further south up the St. Johns River which, as far as navigation is concerned, compares very favorably with our own Hudson. We remained at Sanford until the first day of April and then with spring all about us, and flowers and trees in full bloom, we started north again, spending two months on the way, and sailed into our own home port, the Bayside Yacht Club, on the opening day, the 28th of May, everyone in the best of health and spirits, and the vote unanimous to do it again next year.

Now I am fully aware this digression is totally out of place in such a serious publication dealing with the fearful struggles and anxieties of the electrical engineer in his endeavor to promote the electrical industry, but as a worker who has spent the best years of his life along with you in that struggle, and found just one opportunity in a life time in which it was possible to use an invention first of all to the highest enjoyment of himself and family, he makes no excuse and prays that in case the opportunity ever comes to any of his fellow workers in this or any other line, that they will not fail to grasp it; as he can assure them that there is nothing in life like dreaming a dream of far off travels to a sunny land far from ice and snow, and then to have that "dream come true."

Now back to our mechanical tale. How did the plant work out on the journey south? On the whole trip, we had just one mishap which from an electrical or mechanical point of view might be called such. Running aground on an intricate passage, we were delayed over a tide, and the *Dawn*, carrying the power plant, heeled over on her side. With the return tide, she righted and we proceeded merrily on our way, that is, for a short time, then the main bearing on the generator heated up and burned out. An investigation disclosed that while heeled over, the oil had run out of the bearing and the General Electric generator refused to operate satisfactorily at 1000 revolutions per minute without oil. The repair to this bearing delayed us about two weeks. This was the only mishap or unsatisfactory experience from an engineering point of view throughout the whole trip.

Very shortly after returning to New York, arrangements were made for a second cruise up the Hudson and through the Barge Canal, with Oswego on Lake Ontario and Ithaca on Lake Cayuga as objectives, not forgetting Albany, Schenectady and many other inland cities on the way. This cruise occupied five weeks of most delightful travel. It is a matter of record that at Schenectady we had the very great pleasure of entertaining and being entertained by all the officers and engineers o the General Electric Company from the president, Mr. E. W. Rice, down, not to overlook a trip to the Adirondack camp of Mr. J. H. Apperson.

While at Oswego, we were joined by Mr. Frank E. Kirby, well known naval architect, who signed on as one of the crew for the return voyage to New York, visiting on the

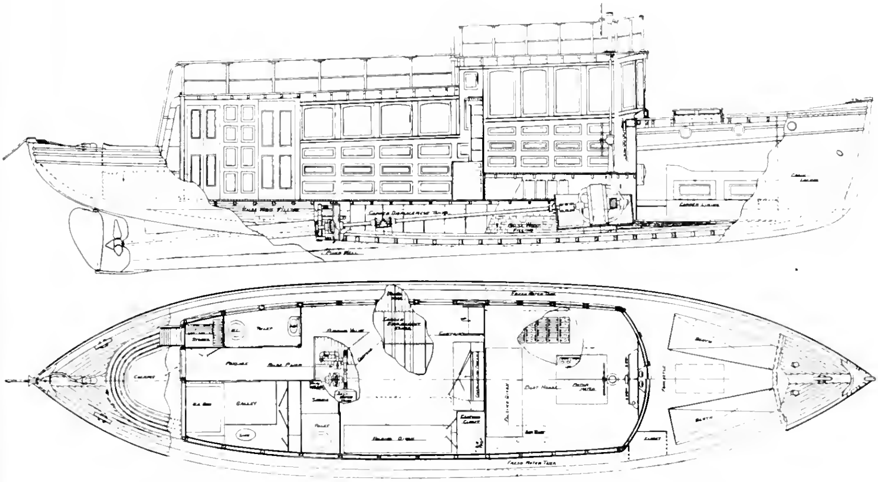

Fig. 2. General Plan of the *New Era*

way Ithaca at the head of Lake Cayuga, and making a side trip west to Little Falls, Waterloo and Geneva. At Waterloo, we had as guests for a short run to Geneva, Commissioner of the Port of New York, Murray Hulbert, with his wife and daughter. Everywhere the boats received every attention and were a delight to everybody who came aboard.

On the return trip down the Hudson, a landing was made at Kingston Point to pay a formal visit of respect and inspection to the replica or reconstructed first steamship *Clermont*, and the interest was very greatly enhanced from the fact that the designer of this craft, Frank E. Kirby, through whose untiring study and research the reconstruction was made possible, was one of the party.

It was interesting to note that the horse power of the plant as installed in the original *Clermont* by Fulton was approximately the same (20 horse power) as we used in the *Dawn* and *New Era*. Continuing our cruise, we left Kingston Point at eight o'clock at night and under a full moon made a wonderful night run to Newburgh arriving at twelve o'clock midnight.

The round trip to New York was completed in five weeks. The boats almost immediately sailed for eastern waters on the annual cruise of the Bayside Yacht Club, and continued their voyage east, visiting New Haven, New London, Newport, Fall River and Providence, and returned to New York just in time to refit for the second annual cruise south, which was commenced this year on the 11th of October, just one day later than last year. The run down the coast was uneventful other than delays due to unusually severe weather off the coast. A stop was made at Savannah for the meeting of the Atlantic Deeper Waterways Association, and the boats are now at Jacksonville, Florida, en route to Sanford. The total mileage to date is in the neighborhood of 6500 miles. The equipment is working perfectly and so far as design and operation is concerned, there is little or nothing to be asked or desired.

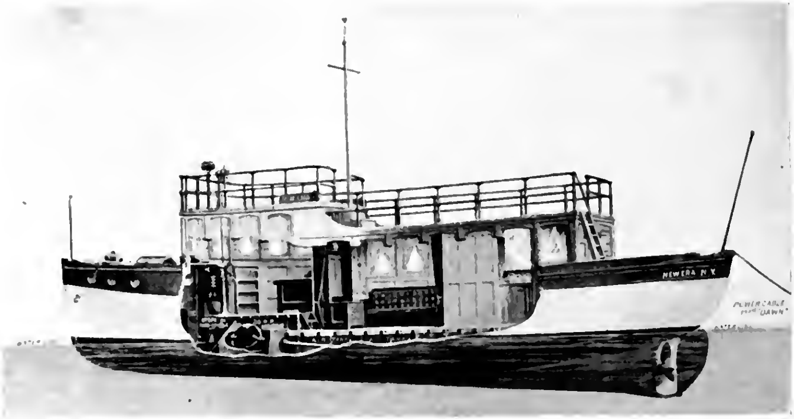

Fig. 3. Propelling Machinery of the *New Era*

Without going too much into technicalities which have been fully and carefully recorded in the engineering papers previously referred to, I will state that the electric equipment in the *Dawn* comprises a 50-kw. generator designed to operate at any voltage up to 220 under what is known as a Ward-Leonard system of control, that is, a separate 2-kw. exciter is driven from the main generator and used for energizing the fields of the generator and also the fields of the motor on the *Dawn*. It will, of course, be understood that to apply this system to the *New Era* it would be necessary to carry separate feed wires for energizing the fields of the motor on that boat, but this has not been found necessary or desirable and the much simpler method of providing a field rheostat on the *New Era* for varying the speed of that motor has been found to answer every purpose.

Besides the main generator on the *Dawn*, we have a 4-kw. Universal set running at approximately 1100 revolutions per minute and generating electricity at 110 to 140 volts. This is used for charging a 120-volt storage battery on each of the boats and can also be used direct for lighting, running motors or any other purpose.

The batteries are iron clad Exide and have given us excellent service. It is entirely practical to drive either one of the boats for several hours by the battery alone and the *Dawn* can be driven very satisfactorily by operating a 4-kw. generator and floating the battery on the line.

The current on the *Dawn* is led from the switchboard to a reel on the forward deck which carries 100 feet of flexible waterproof concentric cable, and it has been found entirely practical to run the boats anywhere between 50 and 70 feet apart. The first question asked by everyone is, of course, the possibility of operating in stormy or rough weather, and while it often raises quite a lot of discussion, it can be answered in a few words. So far as our experience has gone, and we have not run the boats 6500 miles without getting into some stormy weather which would be called severe, it would appear that the boats can be operated together in any weather that it is at all safe to operate them singly. When proceeding together in any kind of weather, the cable hangs slack to such an extent that there is a possible variance of 15 feet or more in their distance apart without bringing a possible strain upon the cable, and to prevent any such strain coming upon the cable, we also carry a Manila line which also hangs slack but not to such an extent as the cable. The leading boat, the *New Era*, is given just sufficient speed to get away from the *Dawn* and, upon trying to do so, commences first to pick up the Manila line and as soon as the boat commences to feel the weight of this line and long before it becomes tight or has any considerable pull placed upon it, the slight resistance will commence to decrease the speed of the leading boat, and of course, any pull, however slight, will tend to increase the speed of the following boat with the result that they will, to use a strictly electrical term, "synchronize," and a little consideration of the facts will show that the slight forced transmission through the line is used in a double capacity to produce a uniform speed.

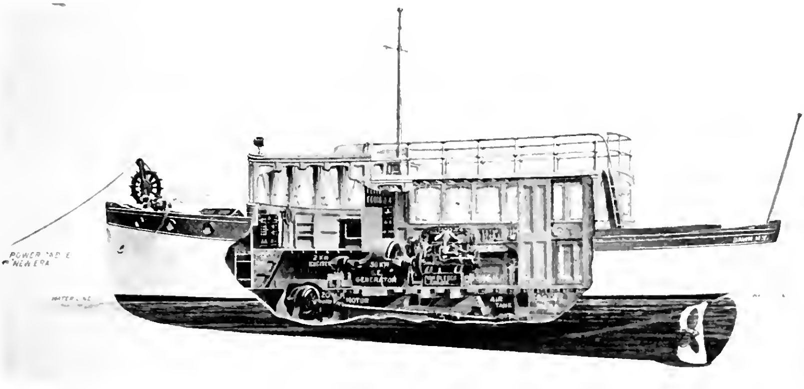

Fig. 4. Electric Power Generating Plant and Propelling Machinery on the *Dawn*

Comprehended as a whole, the matter of generating electricity on one boat and transmitting it to one or more other boats for their propulsion should not be considered as intricate or in any way a complicated procedure.

The writer very well remembers the first time that the trolley car, as such, was brought to his attention, and he was told that a small wheel sliding on a wire transmitted the current from an overhead wire to the motor, and that it returned through the rails of the track. In those days he was just as quick to make up his mind and just as free to express it as any other wandering worker on earth, and it took only a few seconds for him to reach the conclusion that while it might be practical to convey a small amount of electricity from a wire through a small wheel rolling in contact with it, it was a foregone certainty that any considerable amount of current would burn up the wheel at the point of contact. In spite of this certainty on his part, the trolley wheel and sliding shoe still transmit a very large current.

Comparing electric propulsion on the land with the proposed electric propulsion on the water, what do we find? On the water we are to have a positive and fixed contact at all times and our conductor both for supplying and returning the current is to be copper all the way. The form of conductor or concentric cable in which one conductor constitutes an armor over the insulation of the other is the best form of conductor that has ever been discovered or developed. Further than this, in our electric transportation on the land, it has been necessary to extend our roadbed, lay our rails, erect our trolley poles and distribute our copper for carrying the current over every mile of main line and siding that we propose to traverse, whereas for transportation upon the water, we have no roadbed, bridges, or tunnels, and no overhead copper requiring investment of an enormous amount of capital. Our distribution losses are only such as will result from a few hundred yards of distributing mains. And what of our load factor? It is well known to everyone that a central station on land has little prospect of ever being able to operate continuously upon a 50 per cent load factor or at one half its capacity, whereas distributing from a central station afloat conveying a fleet of ships, it will be entirely practical for the central station to have a load factor in the neighborhood of 90 per cent or more and it will operate continuously twenty-four hours around.

In October, 1920, the writer read a carefully prepared paper on comparison of cargo transportation by land and water before a meeting of the Atlantic Deeper Waterways Association at Atlantic City. This paper was published in *Marine Engineering*, November, 1920, and reprints can be obtained by those who would like to review the figures. In it there was inserted an analysis of the comparative figures of the cost of freight transportation, and of water transportation by the application of electricity distributed from an electric power generating station afloat.

What is to be said of the mechanical efficiency of marine transportation by the use of electricity distributed from a floating power plant as compared with the distribution of power to a fleet by a tow boat? On November 3, 1921, representatives of my staff aided by engineers from the plant of the General Electric Company made a test upon the steam propelled barge *Montgomery*, one of the barges designed and built by the United States Government for transportation on the Barge Canal. Tests were made upon the Barge Canal between Locks 17 and 19. The power barge *Montgomery* was towing three barges and the power consumed in towing was determined by inserting a dynamometer in the tow line and noting the pull and the speed of the tow.

Fig 5. The *Dawn* and *New Era* Going Up the Hudson River on the Cruise to Schenectady and Oswego

The speed of the tow was 2.43 miles per hour which is approximately the speed noted on numerous occasions when the *Dawn* and *New Era* passed tows during the last summer in the Canal and tributary waters. The total power generated was 169.87 indicated horse power as determined from indicator diagrams taken. The total power transmitted to the tow under these conditions was 36.74 horse power or 21.6 per cent. In addition to this, it was estimated that 6.3 horse power was used in propelling the power barge or tug. When allowance is made for this, the total horse power used in propulsion is 43.4, and the percentage of total indicated horse power appearing in work is 25.34 per cent.

Particular attention should be called to the speed of this tow, 2.43 miles per hour, as we have carefully worked out the fact that by applying the same horse power through the electric distribution, we shall be able to make with the same fleet a speed of five miles per hour which will actually increase the efficiency of the fleet or its carrying power more than 100 per cent.

One would naturally ask "where does the rest of the power go?" This is very easy to answer. It is absorbed in the stream of water driven in the opposite direction by the propeller in re-acting upon the water to obtain a thrust.

In contra-distinction to this, it is a well known fact that when proceeding alone, a screw can deliver in thrust as much as 65 per cent of the indicated horse power, or more than three times as much as is delivered under working conditions by a tow boat.

Fig. 6. Proposed Electrically Propelled Power Boat Supplying Current to Fleet of Four Barges

It is my experience after years of observation and study that practically all towing on both our coastwise and inland waters is done at efficiency at or below 25 per cent and much of it at even a lower figure.

One of the very considerable items of cost in marine transportation in the past has been the marine hazard, which has always been covered by an independent and extra charge. The paper above referred to points out a practical method of rendering the barge and her cargo safe against sinking and the further possibility of reducing the total insurance of something over 5 per cent per annum to less than 1 per cent. Such a development would add greatly to the possibility of extending water transportation.

One of the most important matters to be considered in connection with the application of electricity to marine transportation is the handling of perishable food cargoes, as it will readily be understood that the same conductor which is used to transmit current to propel barges will transmit current to refrigerate the cargo in transit, and can also be used to charge storage batteries in transit, which upon reaching a terminus can be transferred to an electric truck and deliver the

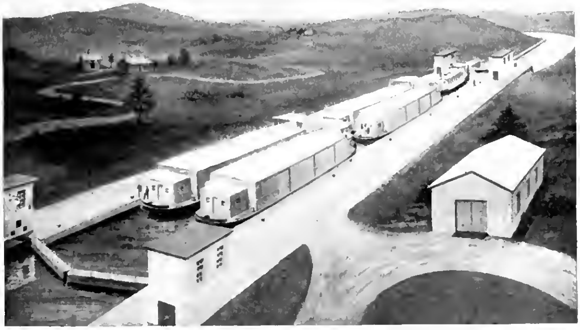

Fig. 7. Proposed Electrically Propelled Barge Fleet in a Canal Lock

goods within a considerable radius more economically than by any other method of transportation.

A further application is the manufacture of ice upon barges and its distribution for delivery to various points along the water front of large cities, and also for distribution to many small communities which otherwise would not be supplied with ice.

We are still far from the limit of the possibilities of the distribution of electric energy afloat. Consider for a moment the possible application to passenger transportation upon our inland waterways, and for this purpose we will consider the Hudson River and our day and night boats between New York and Albany. These boats now require about ten hours to make the trip of 140 miles, and then lay over fourteen hours before the return trip. There are two night and two day boats required to make the complete service, and of course these boats have four power plants, with four complete crews.

With the application of electricity to this work, we would have the same number of passenger boats but only two power plants. The boats would have removed from them the weight of the engines, boilers and fuel, retaining only electric motors for propulsion. An electric power plant or floating power station would propel a day boat from New York to Albany in the same time and then would have ample time to connect up with the night boat and propel that back to New York. A second power boat would operate the other pair of boats. In this way, two power plants would operate four boats, and the boats, both for day and night service, would be in every way superior from the fact that they were free from all the annoyances of heat, smoke and cinders which are incidental to a power plant. It should further be pointed out that these boats only operate through a part of the year, between four and five months, and the power plants lie idle the rest of the year, whereas the electric power generating boats could do any other work in open waters during the remainder of the year.

Now the writer is very well aware that many of the foregoing statements are made while looking ahead rather than as a record or history of what has been accomplished, but believes this is fully warranted in talking with those who have a part in developing one of the greatest industries that the world has ever known, and if more is to be accomplished, where will it be found, if not ahead of us?

Another very broad and important application of this system will be a large pleasure craft afloat, commonly known as excursion steamers, in waters surrounding large cities. The writer has under consideration at the present time, for the Port of New York, a fireproof, and non-sinkable excursion steamer to accommodate approximately 3000 passengers for day and evening excursions during the summer, this vessel to have one deck equipped with a motion picture theater, another deck or portion thereof, for dancing, a third deck for restaurant purposes in which full advantage will be taken of the possibilities of electric grill and other devices, and still another deck for observation purposes. This vessel would be open throughout without any machinery obstructions above deck whatever, and would be followed some hundred yards or so astern by the electric power boat furnishing ample power for all purposes. These boats will not only operate in the North during our summer but will proceed and operate in southern waters during the winter.

The broadest of all fields for the application of this system is the Atlantic Deeper Water Route for an inland water highway down the Atlantic coast from New York to Florida. Much of this route is already available and in a few years the highway will be open throughout the entire distance. Not only will the main highway be available for the movement of perishable food products from the north of Florida and from other states, but also for the distribution of all manufactured goods from the North, and it should be pointed out that every river, bay and sound on the Atlantic coast would be a feeder for this transportation route.

With electric power generating apparatus afloat and available, a dredge in any of our harbors or inland waters could comprise the barge with pumping or other machinery with electric motors to operate it, and when in use would purchase its power from electric generating stations afloat. It is a well known fact that floating equipment, such as dredges, pile drivers, coaling plants and other similar machinery, can be kept in operation but a comparatively small part of the time, and it must be apparent that a great saving would result from the possibility of reducing the power equipment to electric motors.

A Method of Determining Resultant Input from Individual Duty Cycles and of Determining Temperature Rating

By Bassett Jones

Consulting Electrical Engineer, New York City

Given a group of motors that are to start and stop more or less at random: What will be the amount of power necessary for their operation? What size of generating and transmission equipment will meet the temperature rating and yet not be oversize? In the solution of this problem it has been customary to call to mind the nearest parallel experience and then resort to guesswork. The following article treats comprehensively of a mathematical method which is based on the theory of probabilities and which will furnish a complete analysis of all the relevant data necessary to make a really intelligent selection of the equipment. The value of this article is indicated by the fact that it is to be presented at the Annual Convention of the A. I. E. E. at Niagara Falls, Ont., June 26–30, 1922.—Editor.

Introduction

Assuming a group of motors whose individual duty cycles are known, operating at random or nearly so, it is necessary to determine the resultant combined duty cycle in order to select the most suitable capacity of the conductors feeding the group, as well as the rating and type of the generating apparatus supplying the required energy, and of the protective apparatus. The average value and root-mean-square (r.m.s.) value of the resultant duty cycle are required, as well as the maximum peaks, their duration and probable frequency of occurrence, together with some knowledge of the probable time distribution of the input. With such information available, even if it be only reasonably approximate, some intelligent selection of generating, distributing and protective equipment is possible. If the standard duty rating and temperature rise of the current carrying parts of the equipment are known, then the desirable rating of such parts on a basis of temperature rise for any such calculated duty may be determined. Without such information the selection of equipment is largely a matter of guess work, more or less intelligent, depending upon experience and available records.

While the method proposed is worked out in detail for the case of a group of similar motors, all operating at random on the same duty cycle, it is obvious that, with suitable and not very serious complications, it can be applied to groups of dissimilar motors operating at random on different duty cycles, such as motors driving diversified machine tools. The method, as given, applies without change to traction systems.

The Individual Duty Cycle

The curve in Fig. 1 represents the average time distribution of the input to all of the individual motors in the group. The average time per cycle, or between starts, is T. The average time during the cycle when the motor is running is T_r. The average starting period is T_s. The average running input during the time T_r, omitting the starting peak, is i. The average input during the starting time is I_s. The average starting peak input above i is $I_P = I_s - i$.

If, in the resultant duty cycle of the group, the maximum value reached by the resultant peaks is of more importance than their duration, the value of I_s is to be changed to I_M, the maximum peak input; in which case $I_P = I_M - i$. As a first approximation, the duration of I_M is taken at T'_s so that the area A between I_M and i is equal to the area B enclosed by the actual curve of peak input and i. Then in both cases, the product of input and time is the same. But if the actual maximum input is of short duration, the resultant maximum peaks for the group found in this way will be too steep and of too long a duration.

For many cases, such as that shown in Fig. 2, this first approximation will be sufficient. This is an oscillograph of input to a direct drive 1 to 1 roping traction type elevator hoisting engine on resistance speed control. The error here introduced by considering the starting input to be constant and equal to the maximum input over a reduced starting period is negligible. But in cases like that shown in Fig. 3, a second approximation may be required. In this case the starting peak below I is averaged as I_s over the time T_s and the starting peak I_M above I is drawn of such duration, T'_s, that the area A enclosed is equal to the area B of the actual peak above I. The total area is then the same as the actual peak area above i.

Obviously some judgment will be required in determining the approximation to be used.

But without some such approximation the calculation of resultant duty cycle becomes too cumbersome for practical use.

Another approximation has been introduced in considering the duty cycle used as the average duty cycle for the group. If the group is divided into sub-groups in each of which the motors are operating on very different average duty cycles, the calculations must be carried out for each sub-group separately and then combined. This difference may be in the time-distribution of the input during the duty cycle, in the duration of the duty cycle, or in both.

If the motors vary widely in capacity then a second subdivision into groups of motors of approximately the same capacity must be introduced and a separate calculation made for each such sub-group.

When the motors in the group number 20 or more, in general no such subdivisions of average duty cycles or capacities are necessary, unless a few relatively large motors may introduce a periodic large increase in the resultant input. In such special cases the particular motors must be treated as a sub-group.

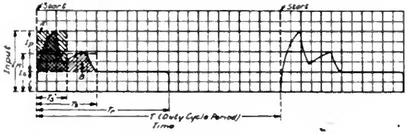

Fig. 1. Individual Duty Cycle; First Approximation

In special cases it may be advisable to introduce approximations other than those above indicated. Again, if the starting peaks are not material or are relatively short, and particularly where in such cases the number of motors is large, it may be sufficient to average the entire input during the duty cycle, including the peak, and to omit from consideration the peaks above this average. If the peaks are of moment then at least two calculations are necessary, one for the average running input, i, and, depending on the order of approximation introduced, one or more for the peaks. The resultant duty cycles, one obtained by each such calculation, are then to be combined to obtain the overall duty cycle. But in each case the method of calculation is the same and quite simple, as will be seen from the case worked out below.

Method of Calculation

The method proposed is precisely the same as that used in determining the probable frequency of occurrence of any number of points in any number of throws of a given number of dice. As is well known this method very closely approximates to actual experience when the number of throws or trials is sufficiently large.

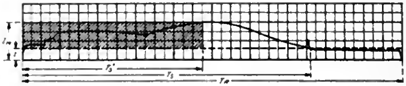

Fig. 2. Oscillogram: Direct-drive, 1:1 Roping, Traction-type Elevator

Let there be N motors in the group (or sub-group), the average duty cycle for which (Fig. 1) has the approximate values T, T_r, i, I_M, and let the duration of I_M be T'_s. Then, on the average, each motor is running a fraction of the time given as a decimal by

$$\frac{T_r}{T} = p \qquad (1)$$

This is also the average decimal of the total period considered, P, say 15 minutes or 1 hour as the case may be, during which any one motor in the group is running. If T and P be given in seconds, then $\frac{P}{T}$ is the average number of duty cycles performed by each motor in the group in the time P. Since there are N motors in the group the total number of starts or runs made is

$$\frac{P}{T} \times N = R \qquad (2)$$

The number R corresponds to the number of trials or throws of the dice in the analogous dice problem.

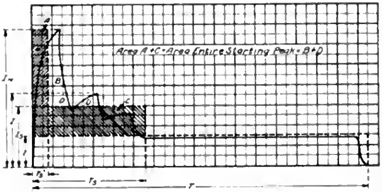

Fig. 3. Individual Duty Cycle; Second Approximation

Since, on the average, each motor is running a part of the time P denoted by p, the probability that any one particular motor is running at any particular time is p. But there are N motors in the group. So the relative frequency in the total number of trials or observations, R, that any one motor is running is $Np \times R$.

Since, on the average, each motor is running a part of the time P denoted by p, the probability that any motor is running at any particular time is p. The probability that it is standing still at any particular time is $(1-p)$.

The probability that any particular two motors are running simultaneously at any particular time is p^2. Similarly the probability that any particular set of r motors are running simultaneously at any particular time is p^r. Since there are N motors in the group, the probability that they are all running simultaneously at any particular time is p^N.

The probability that any particular set of r motors are standing still simultaneously is $(1-p)^r$. The probability that all of the N motors are standing still simultaneously is $(1-p)^N$.

The probability that any particular set of r motors are running simultaneously, while the remaining $(N-r)$ motors are standing still simultaneously is $p^r \times (1-p)^{N-r}$. But there are ${}^N C_r$ combinations of motors in the group taken either r or $(N-r)$ at a time, so the relative frequency with which the input due to r motors running simultaneously will occur, is

$$P_r = {}^N C_r \times p^r \times (1-p)^{N-r}\text{*} \qquad (3)$$

It is not difficult to compute and tabulate, or chart, values of equation (3) over a useful range of N, r, and p.

In general if $\{(1-p)+p\}^N$ be expanded as a binomial thus:

$$\{(1-p)+p\}^N = (1-p)^N + Np(1-p)^{N-1} + {}^N C_2 p^2 (1-p)^{N-2} + \ldots + {}^N C_r p^r (1-p)^{N-r} + \ldots + p^N \quad (4)$$

the first term is the probability that all the N motors are standing still; the second term is the probability that one motor is running and $(N-1)$ motors are standing still simultaneously; the third term is the probability that two motors are running simultaneously and $(N-2)$ motors are standing still simultaneously; ....; the last term is the probability that all the N motors are running simultaneously. The sum of the terms in (4) is 1.0.

All of this is quite obvious to those who are familiar with the elements of the Theory of Probabilities.

Having determined the values of the terms in equation (4) as $P_0, P_1, P_2, \ldots, P_r \ldots P_N$, they may be taken respectively as the probability that the input to the group at any time may be that due to no motors running or zero input, that due to one motor running, that due to two motors running simultaneously, ..., that due to r motors running simultaneously, ..., that due to all the N motors running simultaneously.

To determine the probable time distribution of the resultant input proceed as follows:

There are R chances in the period P that the input will change. (See equation 2.) Of these chances the input will be probably that due to no motors running (zero load), $P_0 \times R$ times; the input will be probably that due to one motor running $P_1 \times R$ times; the input will be probably that due to two motors running simultaneously $P_2 \times R$ times; . . . .; and the input will be probably that due to all the N motors running simultaneously $P_N \times R$ times.

Then, if $P = 1.0$ hour, the chances are that $P_0 \times R = F_0$ times per hour the input will reach zero; the chances are that $P_1 \times R = F_1$ times per hour the input will be that due to one motor running; the chances are that $P_2 \times R = F_2$ times per hour the input will be that due to two motors running simultaneously; . . . .; and the chances are that $P_N \times R = F_N$ times per hour the input will be that due to all the N motors running simultaneously. These results may be changed into time distribution by considering that n times per hour equals every $\frac{3600}{n}$ seconds.

Such calculations having been carried out for the running current, similar calculations are to be made for the starting peaks, repeated twice if two approximations have been introduced as has been explained. (See Individual Duty Cycle.)

In the case of the starting peaks

$$\frac{T_s}{T} = p_s, \text{ and } \frac{T'_s}{T} = p'_s \qquad (5)$$

giving the values of p for the two approximations both of which are different from the value of p found for the running current. The corresponding values of ${}^N C_r\, p_s^r (1-p_s)^{N-r}$, and ${}^N C_r\, p'^r_s (1-p'_s)^{N-r}$ will be different from each other and different from the values of ${}^N C_r\, p^r (1-p)^{N-r}$ found for the running input. In this case, the starting input per motor is $I_M - i = I_P$ if only one approximation is used (see Fig. 1). If two approximations are necessary the two values are $I_s - i$ for the first

---

* $\left({}^N C_r = \frac{N(N-1)\,(N-2) \qquad (N-r+1)}{r(r-1)\,(r-2)\;.\;.\;.\;.\;.\;1}\right)$

approximation, and $I_M - I_s$ for the second (see Fig. 3).

Average Input

The average input over the time P is found as follows: two calculations are necessary, one for the running input and one for the starting input.

First as to the running input:

Of the total time P, zero input exists for the time $P_0 \times P$; the input due to one motor running exists for the time $P_1 \times P$; the input due to two motors running simultaneously exists for the time $P_2 \times P$; . . . . . ; and the input due to all N motors running simultaneously exists for the time $P_N \times P$. Each of these results is to be multiplied by their respective values of input 0, i, $2i$, ..., Ni, and the sum of the products taken. This sum, divided by P, is the average input. It is

$$\frac{(P_0 \times P \times 0) + (P_1 \times P \times i) + (P_2 \times P \times 2i) + \quad + (P_N \times P \times Ni)}{P} = i(P_1 + 2P_2 + \ldots + NP_N) \tag{6}$$

Similar calculations, using I_P instead of i in (6), must be carried out for the average starting input which is to be added to the average running input to get the total average input.

Simplified Method of Determining the Average Input

If $pT \times R$ or $T_r \times R$ is greater than P, so that on the average at least one motor is always running, the average running input A_R may be determined by

$$A_R = iNp \tag{6a}$$

If $p_sT \times R$ or $T_s \times R$ is greater than P so that on the average at least one motor is always starting, the average starting input, A_s, may be determined by

$$A_s = I_pNp_s \tag{6b}$$

For, if at least one motor is running (or starting) and each motor on the average runs (or starts) during that part of the time measured by p then on the average, Np motors are running (or Np_s motors are starting). Otherwise, in time, either all the motors would be running (or starting) simultaneously, or all the motors would be standing still simultaneously (or no motor would be starting). Since on the average at least one motor is running (or starting) the latter cannot be true.

When the motors all perform one average duty cycle, the determination of A_R or A_s by equation (6a) or (6b) is simple. But when the duty cycles vary widely so that the ratings of the motors very widely, these formulas, like equation (6), must be applied separately to each group of motors for which an average duty cycle may be taken.

From the average input thus determined, the approximate power consumption in kilowatt-hours during the period P may be found. Determinations of this kind have proved to be within 10 per cent of the actual yearly power consumption of groups of motors in service.

Root-Mean-Square Input

As in finding the average input, separate calculations for the root-mean-square running input, and for the root-mean-square starting input are necessary.

The values of $P_0 \times P$, $P_1 \times P$, ..., and $P_N \times P$ are determined as above. Then each value is multiplied by the *square* of its respective input. The sum of these products divided by P is the mean-square input, and the square root of this is the root-mean-square input. It is

$$\left\{\frac{(P_0 \times P \times 0) + (P_1 \times P \times i^2) + (P_2 \times P \times 4i^2) + \ldots + (P_N \times P \times N^2 i^2)}{P}\right\}^{\frac{1}{2}} = i(P_1 + 4P_2 + 9P_3 + \ldots + N^2 P_N)^{\frac{1}{2}} \tag{7}$$

Similar calculations using I_P instead of i in equation (7) must be carried out for the root-mean-square value of the starting input, and added to the root-mean-square running input to get the total root-mean-square input.

Of course an error is introduced by treating a distributed series of equal load values as if the heating due to the distributed series is the same as a continuous load of the same amount, but lasting a single interval equal to the sum of the separate intervals. This error is not material for values of R equal to or greater than 1000. If R is much less than 1000 then it may be advisable to plot the actual load curve and determine temperature rise from the actual resultant duty cycle thus obtained.

The method assumes that the heating value of the distributed load as shown by curve T in Fig. 6 is the same as the heating value of the curve H shown in this same illustration. Curve H is obtained by assembling together in one interval, as expressed by equation (6), all the separate input intervals that fall within a given range of input for both running and starting. Thus all the separate intervals during which the input lies between 200 and 300 in the curve T have been assembled as a single interval in the curve H. The actual root-mean-square value of both curves is the same, but due to the heat absorption and radiation characteristics of the current carrying devices or equipment, in general the momentary temperature rise will be different for the assumed duty cycle H and the actual duty cycle T. Generally this difference will be in favor of the actual duty cycle. For instance, a fuse that would blow if subjected to the duty cycle H would not blow if subjected to the duty cycle T. A fuse subjected successfully to a current of 600 amperes for a second or two at comparatively long intervals would blow if subjected to this same current for 7.2 seconds continuously.

The curve H may be considered as the characteristic frequency curve of input distribution in the particular case for which it has been determined. If curve-drawing instrument charts, giving time distribution of input to any group of motors, is available, the H curve may be determined graphically from the observed input distribution, exactly as it is determined above from the calculated input distribution.

For various values of N and p taking i as 1.0, characteristic H curves may be computed and graphed for comparison with H curves determined by observation. A selection of the appropriate standard H curve for any observed value of N determines the approximate overall value of p for the group of motors under observation.

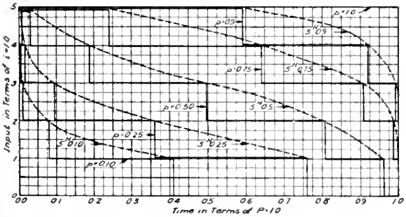

Fig. 4. Group Duty Cycles for $N=5$, $i=1.0$

Such standard group duty cycles for $N=5$ and various values of p are shown in Fig. 4. These curves assume $p_s=0$, or that the starting peaks are of no material moment. These curves are determined for $P=1.0$ and $i=1$.

Method of Plotting Time Distribution of Input

The various possible probable values of input as calculated above, namely, that due to one motor running, that due to two motors running simultaneously, ..., and that due to N motors running simultaneously, may then be spotted on a cross-section sheet taking one border as time and the other as input. These points establish the probable beginning of each change in input. The input remains constant till the next change occurs.

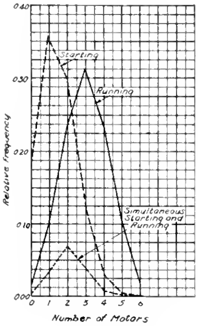

Fig. 5. Frequency Curves for Six Motors, $p=0.5$, $p_s=0.25$

This square topped input curve may then be converted into a curve more resembling an actual curve drawing instrument record by plotting the resultant input values at equal time intervals, say every two or five seconds, and by drawing straight lines between these points. If there are two groups or more for which the same calculations have been made, then the resultant input curves should be drawn on the same sheet for each group and their separate values at equal time intervals added to obtain points on the total curve.

A similar, and separate curve is then to be plotted for the peak input, and added to the running curve.

Such curves, plotted from computed probable values of input, may be compared properly with actual curve drawing instrument records of input only with the understanding in mind that the computed value of the input at any time during the resultant cycle is the most probable value at that time. It should be compared only with the average of the values of the actual input at the same or corresponding intervals. In other words, the form of the computed curve of time distribution of input is the most probable form of the actual record curve.

Frequency of Combined Running and Starting Inputs

Having, as explained above, determined the probable frequencies P_0, P_1, P_2, ... etc., for both running and starting inputs, the frequency with which any combination of running and starting inputs will probably occur can be determined by multiplying together their separate frequencies. Thus, to determine the probable frequency with which the input due to r motors running simultaneously, and the input due to q motors starting simultaneously will occur at the same time, the value of P_r for the running input, and the value of P_q for the starting input are to be multiplied to get P_{qr}. This may then be converted into terms of "times per hour."

Applications

The method outlined has been applied to actual installations of motors where the calculated results could be checked by comparison with records from curve drawing and integrating instruments. The computed values always compare very favorably with the actual operating averages. In this, there is nothing strange, for the method of probabilities always leads to results that closely correspond to experience, and experience consists of just such statistical averages.

A Case

Consider the case for which $N=6$, $T=20$ sec., $T_r=10$ sec., $P=3600$ sec., $i=100$, and, to the first approximation, let $I_M=200$, for $T'_s=5$ sec. Then $p=10/20=0.5$; $p_s=5/20=0.25$; $R=3600/20\times 6=1080$.

The first step in the calculation is to determine values of ${}^NC_r\ p^r\ (1-p)^{N-r}=P_r$ for $p=0.5$. They are

(A) $P_0= (1-p)^N=0.5^6=0.015625=0.0156$ nearly

$P_1={}^6C_1\times 0.5\times 0.5^5=0.093750=0.0938$ nearly

$P_2={}^6C_2\times 0.5^2\times 0.5^4=0.234375=0.2344$ nearly

$P_3={}^6C_3\times 0.5^3\times 0.5^3=0.312500=0.3125$ nearly

$P_4={}^6C_4\times 0.5^4\times 0.5^2=0.234375=0.2344$ nearly

$P_5={}^6C_5\times 0.5^5\times 0.5=0.093750=0.0938$ nearly

$P_6={}^6C_6\times 0.5^6=0.015625=0.0156$ nearly

$\overline{1.000000}$

These values of P_0, P_1, P_2, etc., have been plotted in Fig. 5. It will be seen that because $p=0.5=(1-p)$ the resulting curve is symmetrical with respect to the maximum value of P_3. The most probable running input is that due to three motors running simultaneously. In this case it is also the average input.

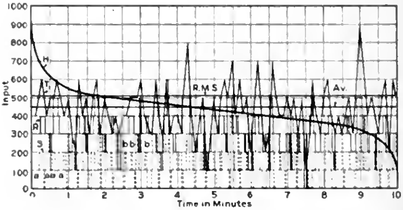

Fig. 6. Time Distribution of Input; $N=6$, $T=20$ sec., $T_r=10$ sec., $T_s=5$ sec., $p=0.5$, $p_s=0.25$, $i=100$, $I_p=100$. Curve T plotted in 6-sec. intervals

The next step is to determine values of $P_r\times R=F_r$. They are

(B) $F_0=0.0156\times 1080=$ 16.85 times
$F_1=0.0938\times 1080=101.30$ times
$F_2=0.2344\times 1080=253.05$ times
$F_3=0.3125\times 1080=337.50$ times
$F_4=0.2344\times 1080=263.05$ times
$F_5=0.0938\times 1080=101.30$ times
$F_6=0.0156\times 1080=$ 16.85 times

Now the trials, $R=1080$ occur in 3600 seconds or 1 hour, so from equation 2

(C) 16.85 times per hour is equivalent to every 213.6 sec.

101.30 times per hour is equivalent to every 35.5 sec.

253.05 times per hour is equivalent to every 14.2 sec.

337.50 times per hour is equivalent to every 10.7 sec.

253.05 times per hour is equivalent to every 14.2 sec.

101.30 times per hour is equivalent to every 35.5 sec.

16.85 times per hour is equivalent to every 213.6 sec.

Therefore the running input will probably reach that due to no motors running or zero input, every 213.6 sec; it will probably reach that due to one motor running, or 100 amp. every 35.5 sec.; it will probably reach that due to two motors running simultaneously, or 200 amp. every 14.2 sec.; . . . . . ; it will probably reach that due to all six motors running simultaneously, or 600 amp. every 213.6 sec.

It is to be noted that zero input and that due to all the six motors running simultaneously occur with the same frequency. This is also true of the input due to two motors running simultaneously, and the input due to four motors running simultaneously. In such cases either one or the other input is equally likely to occur.

The average running input by equation (6) is $100\ (0.0938+2\times0.2344+3\times0.3125+\ldots\ldots+6\times0.0156)=300$ amp.

Note that by equation (6a), $A_R=100\times3=300$.

The root-mean-square running input, by equation (7), is $100\ (0.0938+4\times0.2344+9\times0.3125+\ldots\ldots+36\times0.0156)^{\frac{1}{2}}=324$ amp.

Similar calculations must now be made for the starting peak input. Here $p_s=0.25$, so the values of ${}^N C_r\, p_s^r\, (1-p_s)^{N-r}$ are

$$\text{(D)}\quad \begin{aligned} P_0&=(1-p_a)^6=0.75^6 &&=0.1780\\ P_1&={}^6C_1\times0.25\times0.75^5 &&=0.3564\\ P_2&={}^6C_2\times0.25^2\times0.75^4 &&=0.2966\\ P_3&={}^6C_3\times0.25^3\times0.75^3 &&=0.1234\\ P_4&={}^6C_4\times0.25^4\times0.75^2 &&=0.3008\\ P_5&={}^6C_5\times0.25^5\times0.75 &&=0.00411\\ P_6&={}^6C_6\times0.25^6 &&=0.002285 \end{aligned}$$

These results have also been plotted in Fig. 5. The resulting curve is unsymmetrical with respect to the most probable value, F_1. The most probable starting input is that due to one motor starting.

The next step is, as before for the running inputs,

$$\text{(B)}\quad \begin{aligned} F_0&=0.1780\times1080=192.24 \text{ times}\\ F_1&=0.3564\times1080=384.91 \text{ times}\\ F_2&=0.2966\times1080=320.33 \text{ times}\\ F_3&=0.1234\times1080=133.27 \text{ times}\\ F_4&=0.0308\times1080=33.26 \text{ times}\\ F_5&=0.00411\times1080=4.44 \text{ times}\\ F_6&=0.00229\times1080=1.57 \text{ times} \end{aligned}$$

Then,

(C) 192.24 times per hour is equivalent to every 18.7 sec.

384.91 times per hour is equivalent to every 9.4 sec.

320.33 times per hour is equivalent to every 11.2 sec.

133.27 times per hour is equivalent to every 28.1 sec.

33.26 times per hour is equivalent to every 108.2 sec.

4.44 times per hour is equivalent to every 812.0 sec.

1.57 times per hour is equivalent to every 2300.0 sec.

Therefore the starting input will probably reach zero every 18.7 sec.; it will probably reach that due to one motor starting every 9.4 sec.; it will probably reach that due to two motors starting simultaneously every 11.2 sec.; . . . . ; it will probably reach that due to all six motors starting simultaneously every 2300 seconds.

The average starting input, by equation (6), is $100\ (0.356+2\times0.297+3\times0.123+\ldots\ldots+6\times0.0023)=146$ amp.

Note that by equation (6b), $A_s=100\times1.5=150$

This is to be added to the average running input of 300 amp. to get the total average. It is 448 amp.

The root-mean-square starting input, by equation (7), is $100\ (0.356+4\times0.297+9\times0.123+\ldots\ldots+36\times0.0023)^{\frac{1}{2}}=183$ amp. which is to be added to the root-mean-square running input of 324 amp. to get the total root-mean-square. It is 507 amp.

The kilowatt-hours consumed by the motors in any period during which these conditions hold can be determined from the total average input. It will be found to check very closely with the power consumption of the actual motors in actual service as measured by a watt-hour meter. The conductors feeding the group should be selected on the basis of the total root-mean-square input. The average drop in these conductors will be a function of the total average input.

The periodicity of peaks for this case may be worked out as follows:

The heaviest possible running input of 600 amp. due to six motors running simultaneously occurs every 213.6 seconds, the corresponding value of P_6 is 0.0156. Starting peaks may be added to this. Four motors start simultaneously every 108.2 seconds. The corresponding value of P_4 is 0.0308 The probability that both will occur together is the product $0.0156\times0.0308=0.0048$. This has a probable frequency of $0.0048\times1080=5.18$ times per hour, or once every 695 seconds which is equivalent to once every 11.6 minutes. Its duration will be less than $T'_s=5$ seconds.

For six motors running and five motors starting simultaneously, the probable frequency is $0.0156\times0.0041=0.000064$. This is equivalent to 0.069 times per hour, or once every 52174 seconds; which is equivalent to once every 14 hours and 30 minutes. The corresponding input is 1100 amp. It is probable that for most purposes this peak can be neglected.

The time distribution of input for this case is shown in Fig. 6. The curve *R* is the running input. The curve *S* is the starting input. The curve *T* is the total input. Greater peaks will appear if the curve is extended, due to the combinations of running and starting peaks.

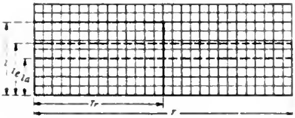

Fig. 7. Constant-current Duty Cycle

The method of plotting may be illustrated by the curve *R*. Referring to section (*C*) in the calculations for running input, it is found that zero input occurs every 213.6 seconds and that the input due to one motor running or 100 amp. occurs every 35.5 seconds. The corresponding points *a*, *a*, *a*, ... are plotted. Then the load of 200 amp. due to two motors running simultaneously is plotted every 14.2 seconds at *b*, *b*, *b*, ... Since the input every 35.5 seconds is equally likely to be either 100 or 500 amp., both have been plotted and this ambiguity noted. The same is true of the input every 14.2 seconds which is equally likely to be either 200 or 400 amp.

As explained previously (see Method of Plotting Time Distribution of Load), the square topped curve *R* is drawn through these points.

The starting input curve *S* is plotted and drawn in a similar manner.

Then, at every 6.0-second interval ordinates have been drawn and the sum of the input values given by the intercepts of these ordinates with the *R* and *S* curves, laid off as the corresponding ordinates of the curve *T*.

Demand Factor

From the above discussion it will be seen that unless a statement of so-called "demand factor" is coupled with a statement of frequency and duration, it means nothing and is more likely to be misleading than helpful.

In the above case, if the motors are rated for temperature rise, as they should be, by the root-mean-square input per motor, their rated input will be 84.5. If they are rated by the average input per motor their rated input will be 74.6, nearly 10 shy, and equivalent to a continuous overload of over 13 per cent involving an increase in temperature of about 23 per cent.

Commonly they will be rated by guess work and will be about twice too big for their work, involving increased annual charges and reduced efficiency.

If the motors are rated at 84.5, their united input is 507. A demand equal to 507 will probably occur at least every 15 minutes, for which the demand factor is 1.0. But the duration of this demand will be only a few seconds at most.

If the motors are rated by guess work this demand factor may drop to about 0.5 which is not an uncommon value to find with values of *p* approximating 0.6. A low demand factor should mean a low value of *p* not an excessive motor installation.

The probable maximum demand over any period of time, say 15 minutes, may be determined from the curve of time distribution of input. A mere statement of such demand, unless coupled with a statement of frequency, does not determine the character of the input, and is not a logical basis for the determination of rates.

Temperature Rating

Consider the individual duty cycle shown in Fig. 7. The input i is constant for the time $T_r = pT$. The equivalent input for the time T is i_a. The heat liberated by the current i for the time pT is $H_i = CWi^2pT$, where C is a constant and W the resistance of the circuit. Similarly, the heat liberated by the current i_a flowing for the time T is $H_a = CWi_a^2T$. The ratio of these is $\frac{H_i}{H_a} = \frac{i_2p}{i_a^2}$. But $i_a = pt$. Therefore $\frac{H_i}{H_a} = \frac{1}{p}$.

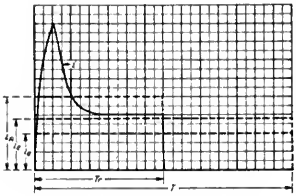

Fig. 8. Variable-current Duty Cycle

Obviously more heat is liberated by the current i flowing for the time pT than is liberated by the equivalent average current i_a flowing for the longer time T. The smaller is p the greater is this difference.

Assume that it is desired to determine the value of the current flowing for the time T that will liberate the same amount of heat as the current i flowing for the time pT. Let this desired current be i_e. Then $i^2pT = i_e^2T$, or $\frac{i^2}{i_e^2} = \frac{i}{p}$. Therefore $\frac{i}{i_e} = \left(\frac{1}{p}\right)^{\frac{1}{2}}$.

If as in Fig. 8 the current i is not reasonably constant during the time pT find its root-mean-square value i_r. Then $\frac{i_r}{i_e} = \left(\frac{1}{p}\right)^{\frac{1}{2}}$.

This is the basis on which conductor temperature rating may be established. The method is the result of certain approximations. Therefore, the results are approximate to at least the same degree. But, as will be seen below, the results compare so closely with test observations that for such duty cycles as are here considered, the variations may be neglected. Any more exact method of determining temperature rise leads to considerable mathematical or graphical complications, which, for laboratory or standardizing work are quite proper and necessary.

If the current i_e flows indefinitely, the conductor will reach maximum temperature t_e in the time P_t depending on its radiation constant, etc. If in case of conductors or fuses, the value of T should be greater than P_t, while pT is less than P_t, then a new value of p must be found. It is $p_t = \frac{pT}{P_t}$. Then, for equal heat generation, the basis for rating is $\frac{i_r}{i_{et}} = \left(\frac{1}{p_t}\right)^{\frac{1}{2}}$, where i_{et} is the equivalent constant current for the time P_t. If pT is longer than P_t then i_r is the same as the equivalent constant current. This would be the case for the distribution curve T in Fig. 6. Here the duty cycle period is taken at 15 minutes. But the input does not reach zero, so the root-mean-square value of input is the required equivalent constant-current rating. Otherwise, than as pointed out above, the value of T does not enter into the formulae. It does not matter whether pT be 5 seconds, 10 minutes or longer, provided T does not exceed P_t.

When, as in nearly all actual duty cycles, the starting peak is too pronounced to permit figuring it in as a slight increase in i during the time pT, the heat liberated by the peak must be computed separately. If the root-mean-square of the peak, in addition to the average running current i_a, is I_{pr} for the time p_sT, where, as above, $p_s = \frac{T_s}{T}$, then the equivalent constant current for the time T is $I_e = p_s^{\frac{1}{2}}\ I_{pr}$. The total equivalent constant current is then $I_{et} = i_e + I_e = ip^{\frac{1}{2}} + p_s^{\frac{1}{2}}I_{pr}$ (or if necessary, i_r may be used instead of i). The value of I_{pr} may be given in terms of i (or i_r) as $I_{pr} = ci$. Then $I_{et} = i\ (p^{\frac{1}{2}} + cp_s^{\frac{1}{2}})$. It is proposed to call the term $(p^{\frac{1}{2}} + cp_s^{\frac{1}{2}})$ the *Duty Cycle Factor*, and write it d. That is $I_{et} = id$, or $i = \frac{I_{et}}{d}$. By taking I_{et} to be the rated constant current given in the N. E. C. Table 1 in Rule 18-b, then, by giving various values to d the appropriate rating of all such conductors can be determined for the corresponding duty cycles for which the actual running current is i, and the duty cycle factor is d.

It is assumed that in no case does T exceed P_t, or the time required to bring any conductor to its maximum allowable temperature with rated constant current flowing. If T is longer than P_t, new values of p and p_s must be found. If T_r is longer than P_t, then i or i_r is the equivalent running current, but a new value $p_{st} = \frac{T_s}{P_t}$ must be found for p_s. The duty cycle factor then becomes $d = (1 + cp_{st}^{\frac{1}{2}})$.

The duty cycle factor of two terms as given above is for equivalent duty cycles obtained by one approximation as shown in Fig. 1. This will be sufficient for all but the most extreme cases of starting peaks, such as shown in Fig. 3, where two approximations are necessary. In such extreme cases the duty cycle factor becomes $d = (p^{\frac{1}{2}} + cp_s^{\frac{1}{2}} + c_i p'^{\frac{1}{2}}_s)$ where $c = \frac{I_s - i}{i}$, $c_i = \frac{I_m - I_s}{i}$, and $p'_s = \frac{T'_s}{T}$, the letters referring to Fig. 3.

When the starting peak is insignificant, the duty cycle factor reduces to $d = p^{\frac{1}{2}}$.

For the purpose of establishing standard duty rating data for conductors or for other current carrying devices, it is immaterial which form the duty cycle factor takes. Its numerical value alone is significant. Thus, if d is given the particular value 0.60, the value of $\frac{i_r}{0.6}$ is not affected by the make-up of d, which may be obtained for any particular case by computing the value of $p^{\frac{1}{2}}$, $(p^{\frac{1}{2}}+cp_s^{\frac{1}{2}})$. $(1+cp_s^{\frac{1}{2}})$ or $(p^{\frac{1}{2}}+cp_s^{\frac{1}{2}}+c_1p'^{\frac{1}{2}}_s)$ as the character of the actual duty cycle may require.

We may then write down such conductor ratings, giving quite arbitrary values to d. Table I gives the corresponding ratings for a few rubber covered conductors in conduit.

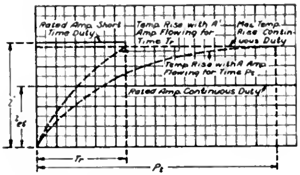

Fig. 9. Relation between continuous duty temperature and short time duty temperature

It is of interest to check these results with time ratings arrived at by test. Assume that $P_t=30$ minutes. This is a safe assumption particularly for the larger sizes. Assume a duty cycle such as shown in Fig. 7 and let T be equal to P_t. For this duty cycle I_{pr} and p_s vanish, and $d=p^{\frac{1}{2}}$. The time ratings will be given by $i_{et}=\frac{i}{p^{\frac{1}{2}}}$ where i is the N. E. C. rating. The value of p is given by $\frac{T_r}{P_t}$. These relations are shown in Fig. 9.

The calculated results are marked "Cal" and given in Table II for various values of T_r, together with test results marked "Rep" taken from the Report of the Committee on Demand Factor, Western Association of Electrical Inspectors, dated August 20, 1920.

The average deviation of the calculated results from the test results in the columns for 15 minutes, 10 minutes, and 5 minutes, respectively are -29 amp., $+9$ amp. and $+2$ amp. The overall agreement is remarkably close. Lack of knowledge of the method and refinement of the test referred to in the report mentioned makes it impossible to compare individual results.

It is evident that the assumption $P_t=30$ minutes is somewhat low and probably too general. If P_t is increased the calculated results for the same values of T_r will be reduced.

It will be seen that if the rated continuous current and the value of P_t for any current carrying device is given, the proper rating of the device for any other duty cycle for which d is known may be easily determined.

The duty cycle factor may be applied to a motor, thus: If the motor be name-plate rated at A amp. for M minutes, then M is the value of P_t for the motor. Let T, T_r, T_s, i_r and I_{pr} be determined for the duty cycle on which the motor is to operate. Then if T be no longer than P_t, the values of p and p_s may be taken from the duty cycle, and the duty cycle factor d determined. Then if A is no less than $\frac{i_r}{d}$, the given motor will carry the imposed duty for the time P_t without exceeding its rated temperature. If the duty cycle only is given then $A=\frac{i_r}{d}$ is the required rating for the time P_t of the proper motor for this duty. In general P_t will be taken as the time during which the duty will be imposed and may include a number of successive duty cycles.

If the value of P_t for a given type of motor is determined, the motor will carry the imposed duty cycle for a time P longer than P if $A=\frac{i_r}{d}\times\frac{P_t}{P}$ is the motor rating for the time P_t.

TABLE I

Size	N. E. C. Rating $d=1.0$	RATINGS FOR VALUE OF d			
		$d=0.866$	$d=0.706$	$d=0.50$	$d=0.25$
14	15	17	20	30	60
12	20	23	26	40	80
10	25	29	33	50	100
8	35	40	46	70	140
6	50	57	66	100	200
4	70	80	92	140	280
2	90	100	110	180	360
2/0	150	172	197	300	600
4/0	225	258	300	450	900
0.3 0 in.	275	316	362	550	1100
0.6 0 in.	450	518	592	900	1800

It should be noted that the only information about any current carrying device required to establish its availability for performing any duty without exceeding its rated temperature rise is the maximum constant current the device can carry for a determined time or operating period, P_t, and just reach its rated temperature rise. Then, for the same temperature rise and operating period its current rating for any duty cycle, whose duty cycle factor is d, can be obtained by dividing the rated constant current by d. It is therefore possible to give any such device a series of ampere ratings for perfectly arbitrary values of d. Its *standard ampere rating* is merely that for which $d = 1.0$. Also it is possible to re-rate the device for operating periods other than its rated period P_t.

The basic data required are illustrated in Fig. 10. Here i_{et} is the rated constant current for the time P_t resulting in the rated temperature rise t. This figure shows the temperature relations for a single cycle in which $T = P_t$. When a number of cycles occur in the time P_t, the temperature curve for the actual cycle oscillates along the temperature curve for the continuous input i_{et} until maximum conditions are reached when the actual temperature curve oscillates along the line of maximum temperature.

The Root-mean-square Rating of Fuses

All that has been said above is equally true of the rating of fuses. Thus a fuse rated at 100 amp. constant current will also properly serve to protect a properly rated motor, for which $d = 0.25$ and $I_{et} = 200$ amp. A larger fuse than this will not properly protect the motor against overheating. Therefore in selecting the proper fuse protection of a motor it is necessary to know not only its rating, but also its probable duty cycle of input and the corresponding value of d. Of course, P_t will be different for fuses and for conductors in conduit. It will be different for conductors in conduit and for exposed conductors.

In cases where T is relatively long, it will be found that usually the starting peak has little effect in determining the value of I_a and can be neglected. If, therefore, the rating of fuses, as now required by the Underwriter's Rules, is based rather on the average value of starting peak than upon the value of I_{et} or total equivalent constant current, a fuse will be selected that will not protect the motor against undue temperature rise due to prolonged overloads. Numerous cases of such failure of fuse protection have been noted.

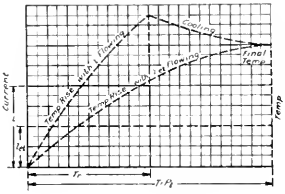

Fig. 10. Temperature conditions during a single duty cycle

Consider the case in which $p = \dfrac{T_r}{T} = 0.64$ and $p_s = \dfrac{T_s}{T} = 0.16$. Determine the average running current i during the time T_r. Assume it to be nearly constant during the time $T_r - T_s$ so its root-mean-square value i_r may be taken equal to i. The equivalent constant current value for the time T is $i_e = p^{\frac{1}{2}} i = 0.8i$, on which basis a fuse may be selected for the running current only.

Now determine the root-mean-square value of the starting input I_{pr} above i over the time

TABLE II

Size	N.E.C. Rating d = 1.0	RATINGS FOR VALUES OF T_r IN MINUTES							
		Cal 22.5 min.	Rep. 30.10 min.	Cal. 15 min.	Rep. 15 min.	Cal. 10 min.	Rep. 10 min.	Cal. 5 min.	Rep. 5 min.
14	15	17	19	20	22	26	24	36	30
12	20	23	24	25	26	33	29	49	35
10	25	29	30	33	35	43	40	61	45
8	35	40	43	46	50	61	60	85	65
6	50	57	60	66	73	85	80	121	105
4	70	80	77	92	97	120	110	170	140
2	90	100	106	110	130	156	155	210	195
2/0	150	172	179	197	220	264	260	365	340
4/0	225	258	256	300	325	389	395	550	515
0.3/0 in.	275	316	345	362	435	475	535	670	690
0.6/0 in.	450	518	610	592	750	780	915	1100	1225

T_s. Its equivalent constant current over the time T is $I_e = p_s^{\frac{1}{2}} I_{pr} = 0.4\ I_{pr}$. Assume that $I_{pr} = 2.0i$ (or $I_{pr} = 2.0i_r$ if the running input during the time $T_r - T_s$ had been irregular enough to require that i_r be used instead of i). Then $I_e = 0.8i$ and the total equivalent constant current $I_{e'}$ is 1.6i. Obviously the fuse to be selected would have little if any value during the running period as a protection to the motor against overloads up to 160 per cent of load.

Yet, if a smaller fuse be selected it will not carry the motor over its duty cycle. There are three possible solutions of this difficulty: (1) Let the motor start on one set of fuses and run on another set of different rating. Quite generally the proper capacity of the running fuses will be larger than the proper capacity of the starting fuses. (2) Instead of the fuses, use a circuit breaker set to come out only if an excessive overload lasts for a period sufficiently long to overheat the motor. This may be accomplished by the use of time-limit relays. (3) The usual solution is to use an oversized or under-rated motor, capable of standing overloads for sufficient time to bring to rupturing temperature the fuse of the capacity required to carry over the total duty cycle.

Table III gives the equivalent constant current rating of fuses in terms of the average (or root-mean-square) running input i, for various values of the root-mean-square of the starting peak I_{pr} expressed in terms of i as overload, and for various values of p_{st}. It is assumed that T, or the running time of the motor, exceeds P_t, or the time it takes the fuse, rated at i amp., to reach maximum rated temperature. In other words, so far as the fuse is concerned, after start the motor runs continuously. The rating formula then becomes $I_{et} = i + p_{st}^{\frac{1}{2}} I_{pr}$ or $I_{et} = i + p_{st}^{\frac{1}{2}} ci$, where $ci = I_{pr}$

Then $I_{et} = i(1 + c p_{st}^{\frac{1}{2}})$.

Thus, if the root-mean-square starting peak of any motor is 25 per cent overload (in terms of the actual constant running current i) that is, if $I_{pr} = ci = 0.25i$, and if the duration of this peak, T_s, is $p_{st} = 0.70$ of P_t, then a fuse must be used whose equivalent constant current rating is 1.21i. That is to say the motor may run continuously at 21 per cent overload (in terms of i) without exceeding the required fuse rating.

The Underwriter's Rules permit the marked rating of a fuse to be 80 per cent of its equivalent constant current rating. In other words the fuse will carry 25 per cent over its marked rating indefinitely. Such equivalent ratings are included above the upper dotted line in the table. A fuse whose marked rating is i will serve in all such cases. It is also understood that approved fuses shall blow instantly at 50 per cent overload. Equivalent ratings less than this are included above the lower dotted line. Thus, for $I_{pr} = 0.75i$ (75 per cent motor overload during start) and $p_{st} = 0.40$ or $T_s = 0.4\ P_t$, a fuse rating must be used that will permit a continuous running overload of 47 per cent. A fuse rated at less than this will not permit the motor to start and run for the time P_t. If, on the other hand, the motor can operate successfully at a continuous reasonable overload, a larger fuse must be selected provided it is concluded that the motor may start and carry this overload for any material part of the time P_t.

Assume this overload is 0.10i, then the formula becomes $I_{et} = 1.1i + p_{st}^{\frac{1}{2}}\ I_{pr}$. For $p_{st} = 0.70$, and $I_{pr} = 0.55i$, the value of I_{et} is found to be 1.56i. In other words, the fuse will permit the motor to run at 56 per cent overload. In general the root-mean-square value of the starting peak will also increase under such conditions, requiring a fuse still larger than this.

TABLE III

p_{st}	Values of $I_{pr} = ci$ (overload during start)					
	0.25i	0.50i	0.75i	1.00i	1.25i	1.50i
0.10	1.08i	1.16i	1.24i	1.32i	1.39i	1.48i
0.20	1.11i	1.22i	1.34i	1.45i	1.56i	1.67i
0.30	1.14i	1.27i	1.41i	1.58i	1.69i	1.82i
0.40	1.16i	1.32i	1.47i	1.63i	1.79i	1.95i
0.50	1.18i	1.35i	1.53i	1.71i	1.89i	2.06i
0.60	1.19i	1.39i	1.58i	1.77i		
0.70	1.21i	1.42i	1.63i			
0.80	1.22i	1.45i				
0.90	1.23i	1.47i				
1.00	1.250i	1.50i				

It is probable that for all conditions contained between the broken lines in the table such double fuse arrangements should be used, either this or circuit breakers with time-limit relays, the latter being always used for cases below the second dotted line.

As an example, consider an induction motor driving a pump. Assume that the running input after the water is in motion at normal velocity is 100 amp. per phase at 80 per cent power factor; therefore, the heating value of the input must be based on $i=125$ amp. per phase. Let the motor be started by a compensator, or step reactance, so that the root-mean-square starting input will be 250 amp. at an average power factor of 60 per cent. The heating value of this input must be based on 425 amp. Then, $I_{pr}=425-125=300$ amp. Therefore $I_{pr}=300/125=2.4i$ (a value not given in the table). Assume that the duration of the starting period T_s is 5 seconds. Assume $P_t=15$ seconds. Then $p_{st}=\frac{T_s}{P_t}=0.33$, and $p_{st}^{\frac{1}{2}}=0.57$.

The resulting value of $I_{et}=i+p_{st}^{\frac{1}{2}}\ I_{pr}$ is $125+0.57\times2.4\times125=296$ amp. Therefore a fuse whose actual rating at $P_t=15$ seconds is 300 amp. will serve to start the motor and run it, but will also permit 300 amp., or more than double full load running input, to flow continuously. If a fuse marked at 300 amp. for the same value of P_t were used it would pass 375 amp. continuously. A fuse marked 250 amp. will pass 300 amp. continuously and is probably the best rating to use, if a single set of fuses is required. As a matter of protecting the motor against prolonged overloads, one set of starting fuses rated at $0.57\times2.4\times125=171$ amp. may be used. Actually a fuse marked 150 amp. would serve. For the running side, a fuse marked 125 amp. would be the nearest safe size. Of course, if the name plate continuous duty rating of the motor exceeds 100 amp. at 80 per cent power factor, larger fuses can be used with safety on both starting and running sides, remembering that since the motor will be operating at fractional load, the power factor during both start and run, under the actual duty conditions, will be lower than those given. If P_t is greater or less than the assumed value of 15 seconds, the value of I_{et} will be altered correspondingly.

The Operating Factor p

The factor p is here designated as the *operating factor* because it determines that part of the time the motor is actually operating. Similarly $(1-p)$ determines that part of the time the motor is standing still. It is "dead time" when the driven machine is producing nothing. The higher the value of p, the more nearly continuous is the machine operation, the more the machine produces per day, and the less the overhead charges per unit of work accomplished. Every live factory manager spends much of his time in efforts to increase the value of p in his shop. By working the above method of computing resultant duty cycles backward, he can determine the existing average value of p from a curve drawing instrument chart of input to his shop.

Let us say that $(1-p)$ is a measure of the time when work is being removed from tools and being replaced. It is therefore a measure of man power hours, just as p is a measure of horse power hours. Roughly speaking, $p=0.5$ means that half the time is spent in manual work. Also the higher the value of p the more nearly constant is the load on the generating plant. Its efficiency is thereby increased. Fewer interruptions due to momentary excessive overloads will occur. The distributing system costs less per kilowatt-hour transmitted.

The Nature of Tribo-electricity or Electricity of Friction and Other Kindred Matters

By Elihu Thomson

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Professor Elihu Thomson always writes interestingly—in this contribution he reviews some of the work of the early pioneers in the electrical field. Some of this work is of such fundamental importance to a correct understanding of electrical phenomena that all students of electricity should familiarize themselves with it. Our present contribution is based on a lecture delivered by Professor Elihu Thomson before the Lynn Section of the A. I. E. E. on March 15, 1922.—Editor.

Before the days of the discovery of the voltaic battery or the generation of electricity by contact of two different metals, the only source of electricity and the only knowledge which we had or which the world possessed depended on the development of electrical charges on the surface of non-conductors by friction. At least, the charges were the accompaniment of friction, the earliest manifestation of which was the ancient observation of Thales that amber (electron) when rubbed would attract light bodies. In the early part of the eighteenth century, experimentation in this field of the generation of electricity by friction really led to the discovery of some of the most fundamental principles of the science, such as the division of substances into conductors and non-conductors, electrics and dielectrics, positive and negative charges, and discharges uniting the two. Von Guericke constructed an electrical generator and frictional machine consisting of a revolving globe of sulphur, rubbed generally by the hand, while Franklin carried on many of his original experiments by the rubbing of glass rods or tubes, using fibrous material or fur as a rubber, and Franklin's famous machine for the generation of electricity was the well-known form consisting of a revolving glass sphere provided with a rubber on the one end of the diameter, and a collector at the other end communicating a charge from the rubbing surface of the globe to what was known as the "prime conductor." This machine was soon succeeded by the revolving glass cylinder of the cylinder machine, which, in the hands of Ramsden, Von Marum, and others, became modified into the plate machine, where a circular glass plate instead of a cylinder was mounted so as to be rubbed on both sides, while the collector was a set of points on both sides connected with a prime conductor. The glass plate was found to be superior to the cylinder. I have not, however, noticed any reason having been given for this in the literature with which I am acquainted, other than that the plate gave the possibility of a greater velocity of travel, and with it gave greater length of rubbing surfaces in moderate space, since both sides were rubbed. It had been noticed that if the revolving plate was too thick it was not effective as when it was of moderate thickness. We can now readily ascribe the true cause for the superiority of the plate machine in that when both sides were subjected to the action of the rubber, and if the sides were not too far apart, as would be the case in too thick a plate, the electrification would inductively act through the plate, or more properly, the capacity of the plate after it left the rubber would be less than in the case of the cylinder where only one side of the glass was charged by the friction, which charge would tend to bind to itself through the glass an opposite charge on the other side. There could not, therefore, be, when the glass left the rubber, anything like the elevation of potential which must occur in the case of the plate, for be it understood that when the rubber and the glass surfaces are in contact, the electricity developed is "bound," and does not manifest itself until the separation of the charges by the movement of rotation, attended by an enormous change of capacity leading by the diminution of capacity to the electrification taking on a high tension or voltage.

Further on, this action of changed capacity will be analyzed, and in it will be found the secret of the high tension or high voltage producible in the so-called "frictional" apparatus. It was early found, however, that for example the pressure of a dry cork on a glass surface, or other smooth surface, gave rise to the separation of electricities, such that the cork acquired a charge on the surface which had been in contact with the glass, while the glass surface had acquired an opposite charge. It was found that other substances could be pressed against smooth surfaces and removed with the possession of a charge. It was then discovered that a piece of glass plate dipped into clean, dry mercury, and removed, came away with its surface highly charged. Here, then, was electrification without any considerable friction. This experiment with mercury led later to the introduction of some mercury into a tube which had been exhausted by an air pump, and sealed, with the result that on shaking such a tube in the dark, the electrification of the glass by the running of the mercury over the surface would, in neutralizing itself, together with the charge which the mercury acquired, illuminate the interior of the tube in much the same way that the Geissler tube is illuminated by the passage of an electric discharge. It was this observation of the effect of dipping glass into the clean, dry mercury which led to the use of mercury amalgams of tin or zinc as a facing for the rubbers on the cylinder, or plate type of so-called "frictional machines," and in my early experience I used the tin mercury amalgam scraped from the back of the old-fashioned looking glass, which was made into a paste with a little grease, and spread upon the rubber, with the result of greatly enhancing the output and the voltage of the frictional charge, so called. It was later found that bisulphide of tin, known commercially as "Mosaic Gold" (on account of its golden appearance), was, if anything, more effective than mercury amalgams as a facing for the rubbers. Now, these expedients of facings, while they enhanced the effect greatly, did not increase the friction, but in fact, diminished it. Further, an increase of pressure of the rubbers beyond a certain point did not increase the electricity generated but did increase the friction greatly, and might be made so great as to cause heating. Evidently, then, the term "frictional electricity" is not a proper one, since an increase of pressure increasing the friction did not, when it exceeded that amount which was required to make a close contact, have any perceptible effect on the electrical output. The output, however, of the early frictional types of machines could be greatly increased by speeding them up, but when we speak of output in this connection, we mean not an increase of voltage or tension, as it was formerly called, but an increase of the charging capacity, say in large Leyden jars or condensers. In these days, we would practically say that the current output was increased, but the natural current output in such machines was so small as to be immeasurably small by any instruments then known. The so-called static machines of the early days, therefore, were simply means of obtaining electricity of comparatively high tension representing an exceedingly small output of energy, and it was not until about two-thirds of the nineteenth century had passed by when such machines as the Holtz influence machine were produced that there was any possibility in view of obtaining a measurable current. With an influence machine, however, of say a dozen plates, all actively at work and revolving at a fair rate, the output becomes measurable by a milliammeter.

What has been said in the above leads to a consideration of the development of electricity as due to something different from friction, and makes the term "frictional electricity" or "tribo-electricity" as it is sometimes called, hardly applicable in the strict sense.

Reference has been made to the electrification caused by dipping a glass plate into clean, dry mercury, but if we take a turpentine varnish as a film and dry it upon metal or glass, and use enough varnish so that it becomes of such thickness as to be stripped off when nearly dry, it will be found that such a film comes away from the metal or glass in a high state of charge, so that it will stick to any surface nearby by electrostatic attraction. The same is true when a collodion film is dried against a glass surface and stripped off. Here, the pyroxyline comes away in a high state of charge. Such actions do not involve friction. The shavings from a wood plane, when the air is dry and the wood very dry, are even very highly electrified, and even paring wood with a knife gives chips under similar conditions which are charged. Combing the hair, brushing surfaces, scuffling over a carpet, result in a separation of electrical charges. Even the movement of a belt over a smooth pulley, if the belt be dry and the surrounding air be dry, will often give rise to the very decided manifestation of an electrical charge, as the belt moves away from the pulley surfaces, and, in fact, in the presence of gasoline or alcohol vapors, a moving belt is often a source of great danger of fire. The electricity developed in belts has often been attributed to the friction on the pulley, but it is a notable fact that even when the belt is not slipping, a charge is developed and is not notably increased if the belt does slip. The true state of the case is that such electrification is developed as in the case of the varnish or collodion film by the mere contact of the belt with the pulley surface rolling off it, and as it rolls away, there is a great reduction of the capacity of the system, so that the charge which is bound to its opposite when the belt is upon the pulley is separated with great reduction of capacity, and consequent enormous increase of its tension or potential. In this view of the case, manifestly the belt action is no different from that of the early frictional machines. The friction in these early frictional machines becomes evident as a means of merely getting a continued contact and separation. A reduction of capacity and rise of potential is the consequence thereof.

Let us look, for a moment, into the action of fur or a collection of hairs or fibers as a rubber. It is known to be quite effective in obtaining what are called frictional charges, but the case is no different from that of the belt. The fur fibers roll upon the surface of glass (assuming that to be the medium rubbed) and different parts of the hair in this way come in contact and become charged, the rolling action being somewhat like the rolling of the belt over the pulley. The fur then presents a charged surface much larger than a flat surface would present to electrification by *contact*, not *friction*. The friction merely rolls the fibers about and insures their receiving on all sides the contact charge. We are now ready to take another step in the understanding of the matter. When Galvani noticed the effect of metal in causing the convulsion of the frog's leg muscles, Volta took up the matter, and showed that the contact of two metals and the generation by the mere fact of contact of an electrical difference of potential between them would account for the frog's leg contraction. It was on this basis that the voltaic battery was developed. It came practically out of Volta's work, but it was with some difficulty that Volta was able to prove that such a pair of metals as say copper and zinc, or zinc and gold, by merely being placed together would generate an electromotive force, and he invented his condenser electroscope for the purpose of making the proof. This today might be called an amplifier of charges. He arranged a condenser so that it would be charged by the contact of one of its sides, say with copper, and the other with the zinc of a pair or couple united. In this case he obtained a charge in the condenser but of such low voltage that it was not to be detected by any ordinary means. However, by lifting one of the plates of the condenser from the other, the capacity of the system underwent such a very large change that the one volt charge became many volts, and manifested itself by deflecting a gold leaf electroscope in connection with one of the condenser plates, kept insulated, of course, during the test. It was this admirable device of Volta which really made it possible for him to show that the contact of dissimilar metals was sufficient to cause electrification. Volta's ideas were criticised when it was shown that the convulsion in the frog's leg could be obtained without using two metals. He then modified his theory after considerable experimentation, and broadened the statement, so that it became "contact between heterogeneous materials is attended by separation of the electricities." Now, if it were possible to lay a sheet of zinc upon a sheet of copper, and have the surfaces very close, almost, say, molecularly close, we would have the zinc positive and the copper negative, or the difference of potential would be one volt approximately. If, now, these parallel sheets could be lifted away from each other so that the motion, say, was absolutely the same at all points, we would get the effect of the Volta condenser electroscope; that is, as the metals separated, the voltage difference between them would rise. This is, however, not possible in the case of conductors which easily short-circuit. It is possible even with irregular separation only when one of them at least is a good non-conductor, because in this case any development of an increased potential can not distribute itself to other parts and short-circuit the system.

Let us assume that two materials, say a collodion film upon a glass surface, or varnish film upon a smooth metal surface, have, according to Volta's principle, a small difference of potential at the contact. Assume it to be two or three volts only. The distance apart is molecular. It would be far below one-millionth of an inch, or even one-millionth of a millimeter. If we double that almost infinitesimal distance, the voltage rises to double, if the surfaces are fairly large. If we double it again, the voltage will again double, etc. It will evidently take a great many doublings of such a small distance to give any perceptible separation, and as at each doubling the voltage rises almost in proportion, the voltage which was at first small (as two or three volts) to begin with, may now become many thousand. Here, then, I think we have the secret of the generation of high-tension electricity, due not to friction, but to contact through the agency of friction and effects due to contact without the agency of friction. To a limited extent, the spreading charge effect from sides and edges soon comes in to lessen the increase of potential and limits the lowering of capacity as the charged bodies are separated more and more. At last we reach a separation which if increased gives hardly any further lowering of the capacity. The limit of rise of potential then has been reached largely through the edge effect. We are now in a position to understand why it is that a narrow dry belt of leather leaves a pulley and acquires only a moderate potential, even when the surrounding air is very dry. It does not yield anything like the potential that is obtained from a much wider belt under similar circumstances. Moreover, if the belt runs over too small a pulley, the separation of the belt from it is too abrupt, and a recombination of the electricity of the belt with that of the pulley surfaces of opposite name takes place as the belt is leaving. When the diameter of the pulley is large, the separation is not so rapid, and the recombination cannot take place so readily. I remember occasions when it was easily possible to obtain spark discharges of eight or ten inches in length from a moderate-size belt running over a smooth pulley, but in the case of a very wide belt, such as four or five feet or more in width. I have noticed occasions when such a belt would give sparks over four or five feet, indicating the presence of an enormous voltage, possibly as much as 1,000,000 volts or more. Here the charges on the surfaces acquired by contact were gradually separated, and the change in capacity effect was so slight that the potential kept rising without disruptive sparks as the belt left the pulley surface, followed by reduction of capacity. In fact, the potential rise was so gradually increased that the belt and pulley did not spark one to the other or short-circuit over the increasing space between them. The separation was made at a rate safe enough to conserve the charge on the belt. Here, then, was an accidentally constituted static machine on a grand scale and operating without friction, but by the mere rolling of the pulley on the belt, so as to speak, or by the rolling of the belt over the pulley, perhaps, to state the matter more accurately.

There are many reasons for believing that the arrangement of the molecules at the bounding surfaces of bodies is different in many cases from the interior arrangement. The remarkable phenomena of surface tension are to be explained on this basis. Dr. Irving Langmuir in some of his investigations has shown the tendency of some of the molecules, in liquids especially, to present themselves in a manner so that certain groups of atomic constituents may be presented outwardly. There is no time to go into details of these investigations, but they tend to show that the surface conditions bulk large in many of the phenomena of nature. Surface actions are often spoken of as due to surface tension, a particular kind of polarization of the surface. When two surfaces are brought together, therefore, so intimately that one can imagine the molecules approaching close enough so as to intrude on each other's spheres of influence, it should not be difficult, in accordance with the electrical theory of matter, to infer differences of electrical state existing at contacts, especially when the substances themselves are very different, as when the contact, according to Volta, is of heterogeneous materials. The contacting surfaces acquire a certain sort of electrical equilibrium which involves the existence of the plus or minus charges in a bound state between the two surfaces, and possible exchange of electrons.

We may say that electrons are displaced in the process such that one body loses negative electrons and becomes positive, and the other gains the lost electrons. During incipient separation the charges continue to be measurably bound, but cannot reunite across the space of separation on account of the air insulation which has been established between them. As the separation is attended with lowered capacity, the potential rises. The intimate relation which exists between the surface tension and the electrical state is well exemplified in numerous experiments. Among them may be mentioned the well-known phenomenon of "variations of mercury surface tension by electrification" discovered by Lippman. It may also be mentioned in conclusion that the old Armstrong hydroelectric machine whereby steam, issuing from a boiler, produces a cloud in a high state of electrification, resembling a thunder cloud on a small scale, is probably dependent upon modification of surfaces or surface tension, and lastly, the investigation of Simpson into the nature of the separation of electricity in a thunder cloud leads us to the consideration of the surface of the rain drops undergoing modification and separation of electricities in two parts of the cloud. It is, however, not the present intention to deal with this phase of the subject, but to point out in an emphatic way that to begin the study of electricity perhaps the most suitable procedure would be the study of Volta's contact theory and its application, not only to the Voltaic battery operation, but also to the much older methods of developing electric charge, as by the contact machines long called "frictional."

It may be said in conclusion that it is probable that there is no such thing as frictional electricity, as distinguished from that produced at the contact of dissimilar surfaces. On this basis, we can dispense with the term "tribo-electricity."

Mazda Lamps for Approach Lighting in Railway Signal Service

By L. C. Porter and F. Pollard

Edison Lamp Works, General Electric Company

This article describes the development and application of miniature Mazda lamps for railway signal lighting to replace the oil burner in existing signal lanterns. These incandescent lamps will be operated in most cases from battery circuits; and in order to conserve batteries the lamps will be automatically lighted only on the approach of trains and extinguished when the trains have passed. Results obtained from actual installations over several years indicate that these electric lamps will effect material economy in maintenance and cost of inspection and replacement; and with the development of new designs of lanterns to replace existing oil signal lanterns as they wear out the useful illumination will be increased from 15 per cent to 60 or 70 per cent of the total light flux.—Editor.

During the past few years the high cost of labor has made it desirable to develop a signal lamp that would not need as frequent attention as the oil lamp. The logical solution of that problem has been the use of incandescent lamps operated from power lines wherever possible and from batteries where direct power is not available. Several types of lamps operated on power circuits and a few on batteries have been in very successful use for a number of years. The Baltimore and Ohio Railroad was the pioneer in the field, having 80 miles of battery operated signal lights in operation in 1907.

In working out the lamp problem several factors have been given consideration. First of all, the lamp must be of such candlepower as to give an adequate signal; second, the lamp must be reliable and as free from early burnouts as possible; third, as the cost of battery energy is relatively very high, the lamp must be as efficient as practical so as to give the maximum light for the minimum energy consumption; fourth, it is desirable to make a lamp that can replace the flame of the long time oil burner in present signal lanterns, giving a light as good as or better than the best oil flame.

In this development the lamp manufacturers have co-operated with the railroad signal engineers and the battery and lens manufacturers, as naturally each one is dependent upon the other for success.

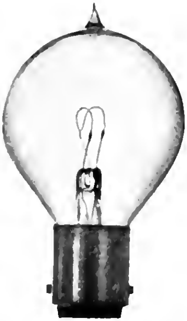


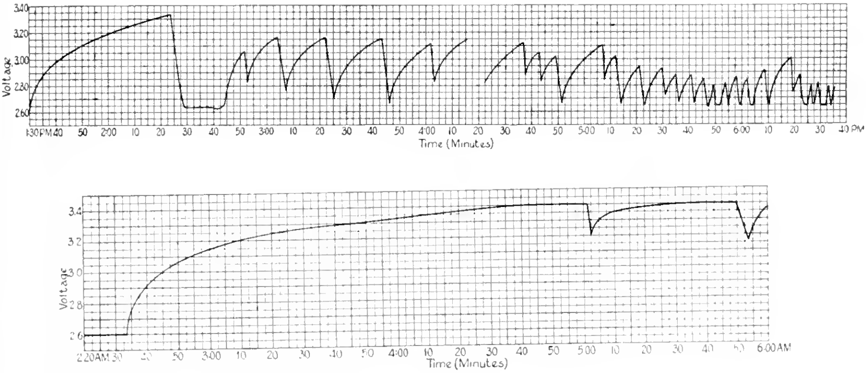
Fig. 1 8 and 10-volt, 0.25-amp., C-3 Filament, S-11 Bulb, Mazda Lamp for Railroad Signal Service

Fig 2. $3\frac{1}{2}$-volt, 0.3-amp., C-2 Filament, S-11 Bulb, Mazda Lamp for Railroad Signal Service

Various systems of battery signal lighting have been developed, one of which uses four cells of lead storage battery and another five cells of lead storage battery. For these two the lamp problem has been fairly simple. Eight- and ten-volt lamps, consuming 0.25 ampere and having what is known as C-3 or bent back loop filaments, have been developed in S-11 bulbs to give a life of approximately 1000 hours (Fig. 1). These lamps have the advantage that when battery signalling is replaced by power lines, small transformers can be built to operate these same lamps, enabling them to be used interchangeably during the transition period.

Two other battery systems use 16 and four cells of primary battery respectively, the former operating the signal motors and the lamps and the latter operating the lamps only. There are relatively few installations of lamps operated on the motor batteries in comparison with those operated on four cells. For the former work a $13\frac{1}{2}$-volt, 0.25-ampere lamp, very similar in appearance to those in Fig. 1, is in use.

The construction of the best lamp for the four-cell work, however, was no simple problem. The available energy is limited to the smallest amount in order to keep the battery cost low enough to show an attractive saving over oil. This means that a low candle-power lamp must be used. As a starting basis to find out how low this could be accomplished, numerous photometric tests were made of oil signal lamps in service. These indicated that the average candle-power of the oil flame is well below one. Then the spread of the beam was studied and the opinions of signal engineers obtained as to what spread of beam would be satisfactory for signal service. About eight feet per hundred seemed to allow an ample margin for safety.



Figs. 3 and 4. Curves Showing Fluctuation of Battery Voltage as Affected by Traffic Conditions

With these data available different filament shapes were tried and photometric distribution curves made from these when placed in back of the regular 5-in. and $5\frac{3}{8}$-in. signal lenses in common use with the oil lamp. The C-2 filament, having a spacing of 5 mm. at the leading-in wires and a height of approximately 3 mm., is at present in use with the $3\frac{1}{2}$-volt lamps (Fig. 2).

Then came the real problem in lamp design, i.e., to make the lamp of the proper efficiency to operate satisfactorily on a variable energy source.

Primary batteries have an initial voltage of approximately 0.98 volt per cell. As soon as the battery starts discharging through a lamp, for example, this voltage starts to drop and continues falling, though at a decreasing rate, until the current is turned off. If this is done before the battery is exhausted the voltage builds up again, though it never goes back to the initial point.

In order to conserve battery energy in approach lighting, the lamp is lighted upon the approach of a train and extinguished after the train passes the signal. Thus the lamp is subjected to a series of voltages starting at some point and falling, each time going a little bit lower. The lamp must be built so that the filament will not be burned out by the peak or highest voltage of the battery, and will also give sufficient light at the lowest voltage at the end of the battery life.

In order to find out what these conditions would be in actual service, voltmeter readings were taken on one of the railroads both during the day when trains were frequent and at night when they were infrequent. The curves shown in Figs. 3 and 4 are very interesting, indicating how the battery voltage falls rapidly on the approach of a train and builds up gradually after the train leaves the signal. Along towards evening as the commuters' trains come through at more and more frequent intervals, the battery has decreasing periods for recuperation, and the average as well as the peak voltage keeps dropping. Then at night when there are long intervals between trains, the voltage builds up again to its maximum.

There is, of course, some voltage drop between the battery and the lamp and in order to determine this, simultaneous voltage readings were taken at the battery and at the lamp socket at a number of different signal locations. Operating one $3\frac{1}{2}$-volt, 0.3-ampere lamp from 4 cells of 500-ampere-hour Edison primary battery, these tests showed an average drop of 0.099 volt between the battery and the lamp, with a maximum of 0.24 and a minimum of 0.05.

With these data available in addition to continuous discharge curves of the batteries, the lamps were designed at an equivalent voltage of 3.3. This means that if constant potential of 3.3 volts is applied to the lamps, their life will be the same as that obtained with the varying voltage on which they operate under service conditions. The design life on these lamps is 1200 hours, but to insure maximum freedom from failures when two $3\frac{1}{2}$-volt lamps are burned in multiple and only lighted upon the approach of a train, it is advisable to renew the lamps when renewing the four-cell lighting battery. When one lamp is burned alone and only lighted upon the approach of a train, it should be renewed when the battery is approximately 50 per cent exhausted: while if *one* lamp is burned continuously, it need not be renewed until the battery is completely exhausted.

There will probably always be a few early burnouts. We have not yet found out how to manufacture lamps 100 per cent perfect. These failures, however, are relatively few, and three years' service with this system of signalling has proved that the lamps give far less failures than were previously obtained with oil lamps.

Because of the limited energy available the filaments of these lamps are necessarily small and must therefore be accurately located at the focal point of the lens. There are good focusing devices available for doing this. It is possible that the time is coming when lamps can be made so accurately that when a burned out lamp is replaced, the filament of the replacing lamp will come in practically the same position as that of the lamp it replaces. Remarkable progress has recently been made in that direction. Even with the mechanics of the lamp so perfected it is doubtful if the electrical characteristics of one lamp can be made to exactly duplicate those of another. For this reason comparisons of the candle-power or life of one individual lamp with another mean little. One lamp might be at the minimum manufacturing tolerance and the other at the maximum. The average of a large number of lamps should, however, come pretty close to what they are designed for.

There is no question but what electric lighting of railroad signals will eventually displace oil, at first probably by battery installations, and as the roads electrify, by power through small transformers. The tendency of signalling will also be steadily upward as regards candle-power and brilliancy of the signals.

During the transition period from oil to electric the old oil signal lanterns will undoubtedly be converted to electric, but as they wear out and new signal lanterns have to be purchased it is probable that some more efficient type of lantern will be installed utilizing 60 or 70 per cent of the total light flux from the lamp instead of about 15 per cent as does the converted oil lamp.

The Mazda lamp interests are keenly awake to this situation and anxious to do everything possible to co-operate with the railroads and the manufacturers of signal equipment to develop the best possible combination of lamps and equipment for the signal field.

The Corrosion of Iron and Steel

By T. S. Fuller

Research Laboratory, General Electric Company

The immense losses caused annually by the corrosion of iron and steel are hard to appreciate. The rapid loss of iron by corrosion has made many a page of history blank which otherwise might be full of instruction for this and future generations. There are many theories of corrosion and the author briefly reviews these. He concludes his interesting contribution by disclosing how much has been learned concerning this phenomenon by the action of drops of water on polished surfaces.—Editor.

The corrosion of iron and steel is a very old and broad subject, and one which has puzzled mankind throughout the centuries. It is because of this active tendency of things made of iron and steel to corrode and eventually to disintegrate that the early history of the metal is so much in doubt, and that it is so difficult to determine to what extent it was used by the ancients. The Pyramids of Egypt, which have been standing for five thousand years, were built of granite blocks probably hewn out with iron tools; and records show that during blasting operations in one of the pyramids in the year 1837, a wrought iron tool was discovered. Iron is mentioned in the Holy Scriptures in connection with the date 1200 B.C., and was known to the Chinese as far back as 2357 B.C. Probably the best known classical example of ancient iron is the pillar standing at Delhi, India, said to have been erected in 912 B.C. Nevertheless, in the face of this evidence, the early history of the metal is very much in doubt because of its disappearance through corrosion and subsequent disintegration.

For many years we of this country and the inhabitants of other countries have heard much of the so-called Conservation of Natural Resources, and of the substitution of materials which are found in large quantities for those which are less plentiful. May I ask what can be more important in the light of conservation than the saving of the materials iron and coal? When we consider that four tons of coal are required for the smelting of every ton of finished iron, and that the coal supply in the United States is estimated to be sufficient for our needs for the next six thousand years, at the present rate of consumption, or for but one hundred and fifty years if the present rate of increase continues, the importance of the problem becomes immediately apparent.

To those of us who may not have been initiated into the various problems of corrosion, that yellowish brown substance which forms when moisture is allowed to act on the surface of articles made of iron or steel is rust; and that is very often as far as our inquisitiveness takes us. To the person who has carefully observed and studied the mechanism of corrosion, the nature and the distribution of the rust are of the greatest importance.

But first let us consider briefly some of the theories which have been advanced in efforts to explain the various corrosion phenomena:

Corrosion was first considered to be a case of simple oxidation, similar to that taking place when iron is heated in air. It was soon discovered, however, that not only was the presence of oxygen necessary, but also the presence of liquid water.

This discovery led to the acid theory of corrosion which takes into account the necessary liquid water and oxygen, and postulates, in addition to these, the presence of an acid, usually carbonic. The acid is assumed to unite chemically with the iron, forming a soluble ferrous salt, which is later oxidized to ferric hydrate or rust, liberating the acid radical for further attack upon the iron. By this method it is quite evident that very minute quantities of acid will be sufficient to cause corrosion.

In 1903, Whitney* announced the results of experiments which led to the Electrolytic Theory of Corrosion. Distilled water was boiled in test tubes to expel all the air and CO_2; polished samples of iron were added and the tubes sealed while the water was boiling. These tubes were left in this manner for weeks without the slightest appearance of rust on the surface of the iron or appearance of a corrosion product on the glass or in the solution. At the end of several weeks the tubes were opened and a small amount of air admitted. A precipitate of ferric hydrate quickly settled out. Dr. Whitney's interpretation of the results follows:

Iron goes into solution in pure liquid water until the water becomes saturated with iron ions and a state of equilibrium is

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* Jour. Amer. Chem. Soc., 1903, 25, 394.

established. Until oxygen is admitted no precipitation of iron takes place. The conclusion is reached that iron goes into solution in liquid water in the absence of both an acid radical and oxygen and that corrosion is, therefore, essentially an electrolytic phenomenon.

The hydrogen peroxide theory postulates the presence of this substance as an intermediate product in the formation of rust, and the biological theory regards the corrosion of iron as a phenomenon due primarily to micro-organisms.

A brand new assumption in the list of corrosion theories is that recently announced by J. Newton Friend, presented at the last meeting of the American Electrochemical Society, and called by him an Auto-Colloid Catalytic Theory of Corrosion. Friend regards the corrosion of iron as a colloidial phenomenon, corrosion taking place by alternate reduction and oxidation of ferric hydroxide hydrosol.

Friend's theory is of too recent origin to have attracted a great deal of discussion at this time, and of the others, only two, the Acid and Electrolytic Theories, have been seriously considered by students of corrosion. It is a very difficult matter to say which of these two views is correct because of the difficulty of getting extremely pure substances to work with, but the writer believes that it is safe to say that ninety per cent of the students of the corrosion of iron prefer to regard it as an electrochemical phenomenon.

Considerable impetus was given to the study of corrosion by the experiments of Whitney, which led to the Electrolytic Theory. Later, Cushman and Walker developed a reagent which became known as Ferroxyl Indicator, which demonstrates quite clearly the nature of ferrous corrosion.

The indicator has been described in detail in a book by Cushman and Gardner, entitled "Corrosion and Preservation of Iron and Steel." Briefly, it may be prepared by mixing dilute water solutions of phenolphthalein and potassium ferricyanide. If a more or less permanent record is desired, the solution is thickened with gelatin or agar-agar. The action of the ferroxyl indicator is this—a solution containing phenolphthalein becomes pink in the presence of an excess of hydroxyl ions; potassium ferricyanide in the presence of ferrous ions forms the characteristic Turnbull's blue compound. Therefore, with the indicator in contact with an iron surface, the positive areas—e.g., points where iron is going into solution in the ferrous condition—are colored blue, and the negative areas, where there is a predominance of hydroxyl ions, are colored pink by these ions.

The writer suggests that those who are inclined to doubt the electrolytic nature of corrosion phenomena try a few experiments with the ferroxyl indicator. The results are startling.

The rate of corrosion of every piece of iron or steel depends upon the individual conditions existing in the particular locality in which the metal is in use, as well as upon the means which have been taken to prevent corrosion.

Bearing in mind that the two substances besides iron, necessary for ferrous corrosion, are liquid water and oxygen, corrosion phenomena are of many types. Iron samples, wholly immersed, corrode faster if the water is moving rapidly than they do if it is in a state of rest. The rate of corrosion of iron tanks or pipes holding water is much less if they are kept full than if they are alternately wet and dry. Atmospheric corrosion proceeds much more rapidly in districts where the atmosphere is chemically polluted by sulphur vapors and the like, than it does in districts where the atmosphere is free from contamination. The corrosion of iron or steel is accelerated by contact with an element, such as copper or tin, electropositive with respect to iron, while on the other hand, corrosion is retarded by contact with an element more electronegative than iron, such as zinc. The corrosion rate increases with rising temperature.

The rate of corrosion is also dependent upon the character of the steel as determined by its chemical composition and heat treatment. Steel containing small amounts of copper or nickel resists atmospheric corrosion better than pure iron. The well known stainless steels containing large amounts of chromium are highly resistant to corrosion.

The writer has found that much may be learned in a very short time about the corrosion resisting properties of a steel by observing the action of a drop of water upon the polished surface of the metal. These experiments have been described in detail before the meeting of the American Electrochemical Society in April, 1921, and will be briefly reviewed here.

Drops of distilled water in equilibrium with the air of the laboratory were placed upon various steel surfaces. In the case of pure iron corrosion began almost immediately, and at the end of a few minutes the corrosion product could be seen distributing itself, always according to the same pattern. Three distinct zones developed: an outer one, which has been called by us the "immune" zone, an inner one, which occupied a large part of the area of the drop, and a "wall" zone, which lay between the outer and the inner zones. The outer zone was perhaps a half millimeter in width and the "wall" zone was best described as a line. The iron rust was evenly distributed over the inner zone, was piled up to a high level on the "wall" zone, and the outer or "immune" zone was entirely free from deposits of any kind. Ferroxyl indicator showed pink over the outer zone, indicating a negative area and that at this point no iron was going into solution, and blue over the inner zone, showing that corrosion was taking place over the entire central portion of the drop.

The length of time elapsing before the first appearance of rust, and the amount of rust present after the drop has evaporated, vary greatly with different steels and form the criterion for judging the corrosion excellence of the particular steel under examination by this simple test.

Much has already been accomplished in the manufacture of rust resisting steels, or at least steels which rust less than pure iron, and much remains to be done. Examples are the steels containing chromium and the copper bearing steels which have been mentioned elsewhere in this article. Of course, the ideal steel would be one having a low cost and showing no corrosion—a goal to be striven for, but probably never to be attained.

Protective coatings for iron and steel form an important section of metal technology. Various specially prepared paints are in use, together with coatings of zinc, tin, or copper applied in different ways.

Of late much has been said and written about the deactivation of water. In general, the scheme consists in passing the water to be used in a given closed system over scrap iron, to remove the dissolved oxygen. Once the oxygen has been removed theoretically the water may go on circulating indefinitely in the system without corrosive action. Such installations have proved to be very successful.

Iron may be made immune to corrosion by making it cathode, that is, by making it the negative pole in a cell, with a potential just sufficient to balance the solution pressure of the metal. This method is not used extensively because it is costly.

The general problem of corrosion is one which should be of the very greatest interest to all users of iron and steel—and that includes all of civilized mankind—and it is most desirable that all should have as comprehensive an understanding of the subject as possible. There are many things which are as yet unexplained, but certain facts are so well established that they may be wisely borne in mind, as follows:

Two substances, liquid water and oxygen are necessary for the corrosion of iron.

The rusting of iron may be best regarded as an electrochemical phenomenon.

The rate of corrosion of every piece of iron or steel depends upon its composition, upon the means taken for its protection, and upon the individual conditions existing in the particular locality in which it is in use.

Much may be learned in a very short time about the corrosion resisting properties of any sample of iron or steel by observing its behavior under the action of a drop of water.

It is to be hoped that the efforts of those now at work on the various problems of corrosion, and the efforts of the investigators to come will help to clear up the anomalies which yet stand in the way of a complete understanding of the subject.

Adapting Electrical Cleaning to Blast Furnace Gases

By N. H. Gellert

Gellert Engineering Company, Philadelphia, Pa.

This is the fourth article of a series which we are running on the general subject of electrical precipitation. The first described the theory of the Cottrell process, the equipment and its operation; the second, a specific installation for the recovery of fume losses from furnaces treating tin ore and drosses; and the third, the application of the process to the precipitation of cement mill dust. These appeared respectively in our issues of November, December, 1921, and February, 1922. The present article, which is an abstract of a paper read before the Cleveland section of the Association of Iron and Steel Electrical Engineers, discusses the difficulties encountered in the problem of cleaning blast-furnace gas, briefly explains the method of making the gas measurements necessary to determine the required capacity of the cleaning equipment, and then describes the various features of an electrical precipitation plant for the cleaning of this combustible gas.—Editor.

GENERAL GAS CLEANING PROBLEM

The general gas cleaning problem, including that of other gases besides those that issue from a blast furnace, may be split into two parts:

1. The cleaning of non-combustible gases
2. The cleaning of combustible gases.

Non-combustible gases usually issue from furnaces or stacks in which gas either has been utilized for combustion purposes or has been driven off by heat primarily as inert gases.

The second part of the general problem of cleaning gases includes gases used for industrial purposes, manufactured in producers in coal-gas and water-gas plants, and also includes the gases issuing from blast furnaces.

The blast furnace, in addition to being an instrument for the conversion of iron ore to metallic iron, is a gas producer on an enormous scale since practically 50 per cent of the coke that enters a blast furnace leaves in the form of a combustible gas.

BLAST-FURNACE GAS PROBLEM

The problem of cleaning gases issuing from a blast furnace has never been a simple one. There have been continual attempts at improvements ever since the blast furnace was first put into operation, and these attempts have resulted in better and better cleaning apparatus. Various methods of cleaning gases have been discussed so thoroughly in papers which have been read in the past before technical societies that there is no need of reviewing the general subject at this time. However, what must be of interest to everybody concerned in the blast-furnace industry is the method of attack and the adaptation of various processes of cleaning to blast-furnace gases.

It is, of course, essential in the very beginning to know the condition of the blast-furnace gas before there can be any intelligent attempt to clean the dust and fume from the gas. In general, blast-furnace gases contain from two to ten grains of dust per cubic foot of gas at standard conditions of temperature and pressure, namely at 62 deg. F. and 29.92 in. mercury which is atmospheric pressure. This material exists in the form of both dust and fume. The fume is so finely sub-divided, however, that in a great many respects it acts as a perfect gas.

In order to determine how to apply a cleaner to the blast-furnace gas, there are at least four factors which must be investigated.

1. Temperature
2. Velocity and Volume
3. Dust Content
4. Moisture Content.

It is very evident that since the measurements are made under the most difficult conditions, usually out in the open air and under a varying condition of load with variations in temperature, velocities, dust content, and moisture content, the data must be taken over a long period of time in order to make them of any real value. In addition, there are inaccuracies to be encountered in the actual measurements due to the fact that it is not as a rule possible to take these measurements under the conditions necessary for extreme accuracy. Nevertheless, the measurements obtained give sufficient information to make it possible for a blast-furnace operator to get a fairly good indication of what he is doing and how to make any needed correction of conditions.

Temperature

In the measurement of temperature, pyrometers and thermometers are used, depending on the temperatures existing in the mains. Care should be taken in the use of a pyrometer that the deposit of dust does not become so heavy that it insulates, fairly effectively, the thermo-couple and causes inaccuracies in reading.

Determination of Velocity and Volume of Gas

The equipment necessary to make a volumetric determination is, as a rule, a Pitot tube of a standard type, a manometer tube, and measuring rule. A gas measuring station location should be selected in the gas main where the most uniform gas flow conditions are approximated. It is seldom that a station can be selected in blast-furnace gas main systems which will give the ideal flow conditions assumed in theoretical discussions. If there can be found a straight portion of main which in length is four to ten times its diameter and without valves, offtakes, or some other interfering object, the conditions may be assumed to be good for gas measurements.

After this station has been located, it is necessary to determine the inside dimensions of the main in which the flow of gas is to be measured. If the main is horizontal, care should be used in sounding the inside bottom of the main for any deposits of flue dust which may reduce the total cross-sectional area. The area of the circular main should then be calculated. The velocity of the gas flowing through the main is greater at the center than near the walls. Therefore to get the average gas velocity it is necessary to take a large number of velocity readings across one or preferably two diameters of the main. By dividing the main into equal areas, as shown in Fig. 1, it is possible to get the average main velocity in the simplest way and with the least expenditure of time. The average velocity of the total gas flow will be the average of the velocities obtained at the mean velocity points of the equal area zones.

The two independent outlets of the Pitot tube are connected to opposite ends of the manometer tube. The reading on the manometer represents the difference between the static plus the velocity pressure transmitted through the inner tube and the static pressure transmitted through the outer tube. This difference will consequently represent the pressure due to the velocity in the main or, in other words, will be the velocity head of the gases. Under normal conditions of blast-furnace operation, the following simple formula which has been used with sufficient accuracy for air measurements will be found to apply without appreciable error to blast-furnace gases.

$V = 2.9 \times \sqrt{TH}$

V = Gas velocity in ft. per sec.

T = Temperature in deg. F. (t) plus 460 (more closely 459.6)

H = Velocity head in inches of water.

Dust Content

Whenever making a dust determination, as in the velocity and volume determination, the same care should be exercised in seeing that the point of sampling is not too close to a bend as the possibility of getting erroneous data will then exist. There are two usual and satisfactory methods of making dust extraction tests. One method is that which uses the simple extraction apparatus and the other uses the balanced filtration tube.

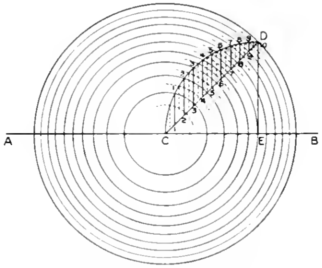

Fig. 1. Graphical Method for Dividing a Pipe into Annular Rings of Equal Areas

The simple filtration apparatus employs a bent tube about 1/4 in. internal diameter and about three feet long, the bent portion being at one end and about 12 in. long. Smaller or larger diameter tubes are used if the conditions warrant, the area of the tube being determined by the velocity of the gases in the mains and the capacity of the gas measuring meter. In all dust determinations it is necessary, where fairly accurate results are desired, that the velocity of the gases entering the tube should be the same as in the main gas stream, otherwise the dust content as measured will be totally different from the true value. Due to the fact that gas meters have a limited flow capacity above which they become inaccurate, it is readily apparent that in gas mains having high velocities it is necessary to use smaller sampling tubes which permit drawing a gas sample at proper velocity and still remain within the capacity of the meter.

In making measurements, the necessary equipment is connected as shown in Fig. 2. The method used in making the dust extraction with this apparatus is as follows:

The thimble is dried in an oven for 30 minutes or longer and repeatedly weighed until there is no further change. After recording its final weight, it is then inserted in the thimble holder and the bushing and cap are placed in position. The filtration apparatus is then ready for the test. The short end of the bent sampling tube is inserted in the opening in the main and is placed approximately in the center of the main with the open end facing directly against the current of gas. The suction pump is started and gas is drawn through the opening in the sampling tube at a velocity approximately that of the velocity in the main. In order to obtain this condition, it is necessary first to obtain the velocity in the gas main by Pitot tube readings and to adjust the suction of the pump to give a gas flow through the known cross-sectional area of the sampling tube equal to the velocity in the main.

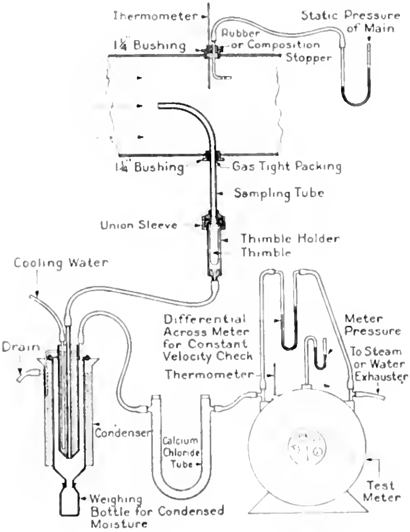

Fig. 2. Method of Sampling Gas

When the gases are very dirty, a short time may suffice to secure a satisfactory weight of dust sample. When the gases are almost clean, a much longer time is necessary. Ten cu. ft. extracted through the thimble will in most cases give very satisfactory results when the gases are taken directly out of the downcomer, and 20 cu. ft. should be drawn when the gases are sampled beyond the dust catcher, while 50 to 70 cu. ft. should be drawn if the gases are sampled beyond the wet washers, scrubbers or other such cleaning devices.

After the test run has been made the thimble is removed from the thimble holder and taken in a dessicator to the laboratory where it should be dried in an oven until it has attained constant weight. The difference between the original dry weight of the thimble alone and the final dry weight of the thimble plus the dust is the net weight of the thimble dust. To this should be added the dust removed from the sampling tube after each dust determination. The amount of dust carried by the gases is always expressed in grains per cubic foot. As weighed on the laboratory balances, the weight will be in grammes which must be multiplied by 15.4 in order to convert to grains.

Moisture Determination

But the velocity, volume, and dust content of the gases are not all that it is necessary for the operator to know. The moisture content of the gas plays a most important part both in regard to the actual utilization of the gas and also in regard to the correct measurement of the gas. Due to the high temperatures found in blast-furnace gases, it is impossible to use with accuracy any hygrometric apparatus for moisture determination. However, a simple fundamental method to determine the moisture is as follows:

A simple gas condenser is used, through which the gas is passed after it has been drawn through the thimble and thimble holder. This condenser consists of a copper coil for conducting the gas and a surrounding steel jacket through which water is allowed to circulate freely so as to cool the gas within the coil to a point where it will drop most of its moisture. The gas is then drawn through a calcium chloride bottle where the last trace of moisture is removed. Most of the moisture will be deposited in the condenser, from which it is collected in a graduated glass tube and the quantity of moisture read directly in cubic centimeters. An additional amount of moisture will be deposited in the calcium chloride tube while a certain amount will have been collected initially in the thimble and in the dust within the thimble and sampling tube. When the thimble with the collected dust is removed from the holder, it should be immediately weighed and then be dried to constant weight. The difference between its initial weight when taken from the holder and its final weight after drying is the amount of moisture contained in the thimble and in the dust. To this should be added the moisture contained in the glass graduate of the condenser. The calcium chloride tube should be weighed before and after the test. The difference in weight is moisture and this should be added to the other two items. The total of these three gives the total amount of water by weight contained in the gases drawn through the meter. By dividing this weight by the cubic feet of gas as indicated on the meter, the moisture per cubic foot of gas at meter temperature and pressure may be obtained. The laboratory balances give the weight in grammes; but since moisture is always expressed in grains per cubic foot, it will be necessary to multiply the weight in grammes by the factor 15.4.

Moisture in a vapor form occupies space in addition to that occupied by the gas. Two gases or vapors cannot occupy the same space. If, therefore, moisture in vapor form is added to a gas, the resulting mixture will be of greater volume. The inaccuracy due to overlooking this moisture correction may readily amount to 7 per cent in gases having but a moderate moisture content and to 20 per cent in gases having a fairly high moisture content. Such inaccuracies may lead to serious consequences when the volumetric capacity of a proposed gas treating apparatus is based upon gas measurements made at meter conditions without proper moisture corrections. Furthermore, statements of the dust content per cubic foot of gas at main conditions will be in error unless proper moisture corrections are made to the gas as measured at meter conditions.

When the temperature, velocity and volume, dust content, and moisture content determinations have been made, it is possible to proceed with the general design of a cleaning plant.

METHODS OF CLEANING BLAST FURNACE GASES

The methods of cleaning blast-furnace gases may be divided into the wet cleaning and the dry cleaning types.

WET CLEANERS

Much money has been spent in this country in the development of wet cleaning methods and a great many wet cleaners are now installed in blast-furnace plants throughout the country. Nevertheless, because of certain fundamental undesirable factors in connection with wet cleaning there has been a tendency on the part of blast-furnace operators to go to dry cleaning.

DRY CLEANERS

In Europe, the practice has been somewhat different from that in the United States as there were early efforts to develop dry cleaners. As a matter of fact, dry cleaners have been operating in Europe for some time and have been mainly objectionable from two standpoints:

1. Their high cost
2. Possible damage to the cleaner.

The cleaners built in Europe were of the bag type and while they cleaned the gas more effectively than any primary cleaner could, and even went so far as to prepare the gases for gas engine purposes, the bags being of an inflammable nature necessarily were subject to destruction whenever the heats put through the cleaners exceeded the safe limits of the material of which the bags were made. The high cost also of installation of this type of cleaner militated very greatly against their adoption and perhaps was the chief reason why such dry cleaners were not installed in this country.

Perhaps a third feature which militated against the use of these dry cleaners was the fact that the sensible heat lost in the cooling of the gas robbed the gas of a great deal of the economies which might be obtained were the sensible heat retained.

With dry cleaners that are able to pass the gas without any considerable reduction in temperature, there is to be added to the efficiency caused by the cleaning of the gas the efficiencies effected by the use of the sensible heat. Certain difficulties, however, in the cleaning of gases by the dry process must be taken care of.

Any screen type of cleaner which attempts to filter out particles of dust and fume, even when the filtering medium is not destroyed by the normal heats of the blast-furnace gas, must be sufficiently fine in nature to present a hole smaller than the finest particle of dust and fume going through in order successfully to remove the objectionable solid material in the gas. If the screen is so fine that it will remove the particles of fume, the back pressure will be high and the screen will clog up quickly. If the screen is designed with apertures large enough to prevent any considerable back pressure, the fine particles of fume and dust will go through. The problem, therefore, of screening the fume and dust out of blast-furnace gas is not a simple one.

Handling of Hot Gases

It is very evident that when the gas discharging from the furnace top is very hot, the cleaning medium of any system of dry cleaning will be destroyed. For instance in the manufacture of ferromanganese, the gases discharging from the furnaces have temperatures running as high as 1500 deg. F. As steel glows red hot at such temperatures, some necessity arises for cooling the gas to such a point that destruction of the steel does not take place. Some means must be devised to cool the gases to such a point that they may be safely passed through the cleaner.

This problem is not at all present in furnaces manufacturing pig iron as the temperatures rarely run over 400 to 500 deg., and even in exceptional cases they rarely run over 700 to 900 deg. and steel can be made to stand the strain. With the hotter gases, however, it is necessary to design coolers that will function without the addition of moisture to the gases. If it is desirable to cool the gas which is as high as 1300 deg. F. to a temperature between 400 and 500 deg., so as not to lose the sensible heat which is present in the gas at this lower temperature, care must be taken not to add water for cooling purposes as the amount of water present when the gas is saturated at 400 deg. is so great that it would seriously handicap combustion in the stoves and boilers. A cooler, therefore, must be of such a type that the heat is transferred from the gas into the water through tubes and not by direct contact.

ELECTRICAL GAS CLEANING

The electrical cleaning of gases, as developed several years ago by Dr. F. G. Cottrell, is a very simple process making use of a few fundamental facts in physics.

"The principle involved is not a difficult one and can most easily be understood by conceiving of a gas passing through an invisible electrical screen so fine that the finest particle of fume cannot pass through, yet occupying no space, having no material body and consequently presenting no source for back pressure. It is by means of this electrical screen interposed between the outlet of the furnace and the inlet to the hot stoves and boilers that blast-furnace gas may be cleaned of its dust and fume content to a degree finer than any mechanical screen can clean it without considerable loss by back pressure.

"The reason for this is that the electrical screen is not woven of wires, but is woven of lines of electrical force. The threads of force constituting the screen are so closely knit together that a substance must drop below its molecular form to get through when conditions are correct for the screen to operate. Yet, these lines of force, having no material body, do not interrupt the flow of gas on which they have no effect whatever." In brief, the action of the electrical cleaner may be described as follows:

The gas is passed through a vertical pipe in the exact center of which is suspended an electrode chain or wire. This electrode is suspended from insulators and is charged with high tension unidirectional current. The pipe itself is grounded. The dirty gas in passing through the pipe becomes ionized. The gas molecules carry the charge to the dust and fume particles which, immediately upon being charged, are repelled by the negative chain electrode and are deposited on the sides of the pipe where they are held by electrostatic force.*

ELECTRICAL EQUIPMENT

In order to develop the current necessary to operate an electrical cleaner, certain electrical apparatus has been specially developed. The larger electric companies have spent a great deal of money in the research work necessary to develop the particular apparatus which is wholly dependable under the severe usage that it must withstand. The pieces of electrical equipment, however, are exceptionally few in number.

One of the units consists of a switchboard, transformer, rectifier, motor and the necessary insulators and conductors for getting current into the precipitator. The switchboard consists of a special panel having on it: a circuit breaker, ammeter, voltmeter, double-throw, double-pole switch, set of sockets for voltmeter blocks, three-pole starting switch and a five-point transformer switch. In the back of the panel are the starting rheostats for the synchronous motor, and below

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* A detailed description of this process was given in the article "The Cottrell Process of Electrical Precipitation," by H. A. Winne, GENERAL ELECTRIC REVIEW, November, 1921, p. 910—EDITOR.

the panel are the resistances in series with the transformer. All the connections on the panel are of low-tension. All the high-tension connections are inside steel guard work to prevent the operator from coming in contact with such equipment. The circuit breaker is used to break the transformer primary circuit when the voltage exceeds a safe limit for the transformer, while the double-throw switch underneath the instruments is used to cut in the line on the right polarity. The five-point switch is used for the purpose of obtaining a different transformer ratio without leaving the operating position at the switchboard.

All this electrical equipment is built to special specifications and is so carefully put together that, in operating both plants now in existence for the cleaning of blast-furnace gases, there has been no electrical difficulty excepting the sort that would normally occur in running electrical apparatus.

Rectifier

The rectifier consists of a rotor and a stator, the former revolving in direct unison with the synchronous motor as the motor is directly connected to the rectifier. Since the four-pole synchronous motor, running on 60 cycles, revolves at 1800 r.p.m., and since there are 3600 cycles in each minute, there are two cycles of alternating current to every revolution of the motor and consequently of the rectifier.

The rotor and stator each consists of four arms, the rotor having four brass copper tips and the stator having four shoes. Consequently the rotor arms have four positions in which each one of these is opposite the stator shoe. These four positions correspond to the four alternations passed through during every revolution, two positive and two negative. Each two adjacent rotor arms are connected by means of a fine copper wire so that there are two pairs of rotor arms, consequently the wire connections will be in four different positions during a complete revolution of the rotor. In one pair of these positions, one side of the transformer is connected to the ground shoe and the other to the rectifier; and in the other pair of positions the connections are reversed. The rectifier, therefore, acts much the same as a commutator on a direct-current generator since it revolves in synchronism with the motor and consequently with the alternating current.

Transformer

Of especial interest is the transformer used to supply the high-voltage alternating current to the rectifier. It is very compact, though considerably larger for the same power output than are transformers used on lower voltages. The service represented by a Cottrell precipitator, with a mechanical rectifier in circuit, is the most severe which can be imposed upon a transformer. Consequently the greatest care is exercised by the electrical manufacturer in the design, selection of materials for, building, inspecting, and testing of this apparatus.

Fig. 3. Precipitator Transformer and Synchronous-motor-driven Mechanical Rectifier

Particular attention is given to the high-tension winding and terminals. This winding is ordinarily made up of several separately wound and insulated coils, the end or buffer coils having much heavier insulation than the middle portion of the winding. The terminals are especially designed and built for this service.

During manufacture the transformer is subjected to very rigid inspection, and after being completed is given very severe tests to determine its reliability for the service involved.

Electrical House and Precipitator

All the electrical equipment is housed in a small building in which the entire electrical operation takes place. To demonstrate clearly just how the electrical cleaning plant works and what is the method of procedure in its operation, the small demonstrating model shown in Fig. 4 was set up. First, there is the precipitator which consists of a number of pipes in a shell with an electrode chain hung in each one of the pipes. The precipitators may be set up singly or in multiples depending on the requirements of the plant. If more than one are used, they are all of the same size; and the capacity of the plant is increased by increasing the number of precipitator units and likewise the number of electrical units.

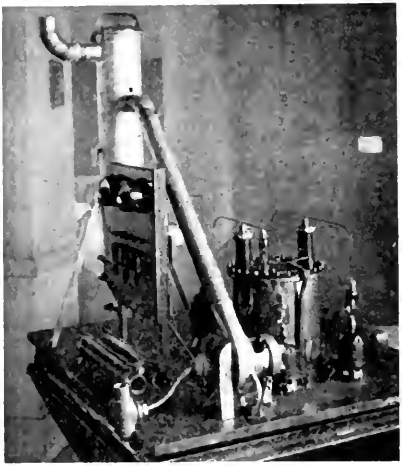

Fig. 4. Model Electrical Precipitator Using Miniature Kenotrons for Rectifiers

Gas is fed to the precipitator under the header plate and leaves the precipitator above the header plate. In order to get into the upper chamber, the gas must circulate around the pipes downward, then go up through them into the electrical field before it can make its escape at the outlet. As the gas goes in, it contains all the dirt carried with it after leaving the primary dust catcher. As the gas leaves the precipitator cleaned, it is distributed to the boilers and hot stoves as it may be needed. After the dirty gas has filled the precipitator and is making its way out, the rectifier is started by throwing in the synchronous motor switch and the circuit breaker is closed. The five-tap switch is adjusted so that the proper tap on the transformer is put into service and the double-throw switch is then closed. If considerable

Fig. 5. Gas Issuing from Blast Furnace Precipitator When the Current is Off

Fig. 6. Gas Issuing from Blast Furnace Precipitator When the Current ² On

arcing takes place and only a low primary voltage can be carried, it is usually prima facie evidence that the wrong polarity is being applied. The double-throw switch is then pulled out and thrown to the other contacts. If the right polarity is then impressed, the voltage will stay up and arcing will be absent. Clean up then takes place.

Special Features

Some special features in connection with the development of the equipment for precipitation are present in the installation erected at Sheridan, Pa. The electrical house as originally built was 22½ ft. square and independent of any other building. After it had been erected, however, one end wall was torn down and the house in which the generator sets were placed was built onto it so that the whole electrical equipment would be together. These generators not only were used for furnishing power to the precipitator sets, but also for furnishing power to the cars at the bins supplying the skip hoist. Inside the house there is sufficient room for a duplicate set of electrical equipment should that at some future time be desirable.

Fig. 7. Two Precipitator Units Handling Blast Furnace Gases

The three major insulators that are placed in the high-tension compartment, and are the only insulators exposed to the gas, are of the floor bushing type. It is necessary to clean these about once a month; and in order to get at them without shutting off the gas from the precipitator, the compartments are equipped with small valves which can be quickly closed and small doors which can be readily opened. The operator by standing in the open air and extending his hand into the compartment can readily clean the insulator in a short time. The adoption of this type of insulation has made it possible to operate much more continuously than was possible before, when there were thirteen insulators located on the inside of the precipitator and when cleaning these insulators necessitated the complete shutting down of the plant and the cooling of the precipitator.

Results Obtained

The results obtained both at Sheridan and at Dunbar, Pa., have been satisfactory. At Sheridan the precipitator has been operating continuously and collecting approximately 5000 barrels of dust per day from approximately one-half of the gas output of a 250-ton furnace. This dust is extremely fine in nature and ignites on exposure to air. It has consequently been impossible to determine the fineness of the dust as it sinters as soon as it is dumped and screen tests taken after the dust has cooled off do not indicate the condition of the dust when collected.

When tests were made on the Dunbar plant, running on pig iron before it was turned on ferromanganese, the indications were that the precipitator could clean ordinary gases from a pig-iron blast furnace to less than 1/10 grain. The two plants now running have clearly indicated that electrical precipitation is on the right road as an effective method of cleaning gases from blast furnaces.

Electric Busses and Electric Taxicabs

By Joseph A. Anglada
Electrocar Corporation, New York

Our recent Electric Vehicle issue (April) called special attention to the fact that this type of vehicle possesses a longer life, is more reliable, and more economical than the horse-drawn wagon, truck or pleasure car of other motive power. The reason given for this superiority over its competitors is the general engineering excellence of the electric vehicle, made possible by a remarkable simplicity of design and ideal inherent operating characteristics. What was said of the electric pleasure car and truck is equally true of the electric bus and taxicab which Mr. Anglada discusses in the following article.—Editor.

There are certain fundamental reasons why the automobile engineer should pause in his intensive efforts to further improve the gasoline power plant and consider whether he is directing his energies to the most sensible solution of the problem of providing public vehicles for the transportation of passengers at the lowest cost. It is the function of the engineer to not only apply the achievements of the arts and sciences for the benefit of the public, but to do so in a way that will conserve natural resources and produce results at a minimum cost. That is, he should not merely provide a technical solution of the problem, but a commercial solution. This raises the question, whether in the field of the bus and taxicab the horizon of the engineer and business man has not been clouded by their close familiarity with the internal combustion engine type of vehicle to such an extent as to cause them to lose sight of the applicability of the electric vehicle to this arduous service.

If the broad unbiased mental outlook referred to above is preserved, the characteristic features of lower operating cost, long life, low maintenance cost, simplicity, cleanliness and safety of the electric vehicle are recognized as being essential to providing the best bus and taxicab service from the standpoint of the public and the operators of the service. It may, of course, be argued that someone at sometime has tried electric vehicles in this service without success, but an investigation of the causes will show that under the same conditions any other type of vehicle would not have succeeded.

Fig. 1. Typical Electric Taxicab (Electrocar Corporation)

A survey of conditions under which busses and taxicabs operate in urban districts reveals a close similarity between electric street car service conditions and bus, and to some extent taxicab operating conditions. The frequent stopping and starting of the vehicle, as often as fifteen times to the mile traveled, and averaging six times to the mile, imposes a service on the propelling and speed controlling machinery of the vehicle which in severity exceeds that due to continued high speed operation on good roads. The gasoline engine vehicle compared to the electric vehicle is not adapted, nor in the light of present knowledge can it be adapted, to withstand the high duty of bus or taxicab service as efficiently as the simpler and more reliable electric vehicle. For proof of this statement, it is necessary to consider the few gasoline bus or taxicab installations extant which have made money for their operators over a period of years and ascertain the reason for this condition. Analysis will reveal that for the first year or so the gasoline equipment operated satisfactorily because it was new. After the second year the depreciation on the equipment, due to the nature of the service and the high speed performances indulged in by the drivers, increased greatly, while the necessity for adjustments and repairs became annoyingly important; and after a period of from three to five years the maintenance charges became so great as to prohibit the safe use of the vehicles for public service by responsible organizations, with the result that the so-called "outlaw or jitney operator" entered the field and the service suffered still further.

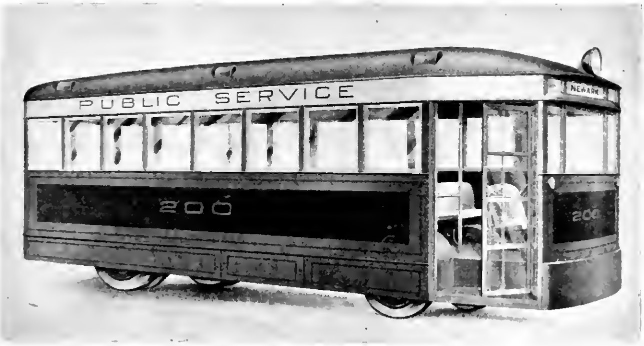

Fig. 2. Twenty-five Passenger Electric Bus (Electrocar Corporation)

The operation of electric street cars in the dangerous physical condition existing in many busses and taxicabs would not be tolerated by the public or the operating companies, and when it is known that the electric street cars are from three to five times as old as the gasoline vehicles and have during their life cost decidedly less to maintain, it will be conceded that electric propulsion of passenger carrying vehicles operating on tracks in city service possesses fundamental advantages which can be applied to vehicles operating on rubber tires.

The fundamental advantages of electric vehicles, whether of the storage battery, trackless trolley or self charging type, are long life, low operating cost, low maintenance cost, and ease of control. In addition, flexibility of chassis construction permits of great passenger accommodation with low floor level in a simple inexpensive chassis having a short wheel base and consequently a short turning radius, and also with body overhang beyond axles reduced to sensible proportions.

Mention electric vehicles to the average man and he will smile and picture a vehicle resembling the single cylinder gasoline cars of the early days rather than the snappy, well proportioned, handsome gasoline cars of today; or he will say that electrics are nice for old ladies to ride in or drive. The electric passenger vehicle makers are to blame for this state of affairs because it is possible to design electric passenger cars in which the battery is carried below the chassis frame, thus permitting of fitting bodies of the accepted form, free from projections, at the front and rear for the disposal of the battery. For operation in city or town and suburbs, the modern electric leaves little to be desired in the way of speed and acceleration, and with ordinary driving, mileages of from 60 to 80 miles per charge can be depended upon in daily operation. Electric private car performance can be duplicated in electric taxicabs and busses, and as an indication of the long life and continuous satisfactory performance of electric cars it might be mentioned that the dealers of one make of electric car who were not able to get deliveries of new cars from the manufacturer during the war found it profitable to purchase any make of used electric and overhaul and paint it and re-sell it in many cases as a new car. The performance of these reconditioned cars was just as satisfactory as that of new cars.

The following extract from a letter written in February, this year, by an official of a trade organization to an English engineer concisely states the position of the electric truck:

"In the metropolitan area of New York City, there are approximately 52,000 commercial motor trucks of which 10 per cent or about 5200 are of the electric type. During the year ending December 31, 1920, over 400 per cent more electric trucks were sold than during any similar period and although the year ending December 31, 1921, was marked by a protracted period of extreme business depression, the number of electric trucks sold in this district was approximately 80 per cent of the number sold during the previous record breaking year, and this year a very much larger volume of business in electric trucks will be done because business concerns are beginning to appreciate the fact that transportation must be regarded as an engineering operation, and for this reason are giving more consideration to the use of electric transportation.

"When electric vehicles are subjected to analysis covering initial cost and cost of operation, such analysis usually leads to the adoption of electric vehicles.

"One of the largest, if not the largest fleet of motor vehicles in this country is operated by the American Railway Express Company. This company is the result of the merging of a number of express organizations whose business is solely that of transportation—transportation not being merely an incidental phase of their business, such as is the case in a number of other organizations, and consequently their equipment must necessarily be efficient in order for their business to be conducted successfully. This company operates approximately 2000 gasoline vehicles and over 1200 electric vehicles and recently placed an order for 160 additional electric vehicles to be followed by other orders for similar quantities. It is the tendency of this company to standardize on electric trucks.

"Another large user of electric trucks in this country is the firm of Marshall Field & Company of Chicago, doing a normal annual retail business of $76,000,000. This company operates 268 electric trucks as contrasted with 55 gasoline trucks. This company makes the statement that their electric truck units cost them on an average of slightly more than half the cost of operating similar size gasoline trucks and this ratio of operating expense, favorable to the electric, is experienced by many other operators of both gasoline and electric equipment in all parts of the world.

"In addition to the companies now manufacturing electric trucks, all of whom have greatly enlarged their plants in the last few years, there are now several new companies entering the electric truck manufacturing field some of whom are now building gasoline trucks exclusively. This expansion in itself indicates that the existing business warrants greater manufacturing facilities and that the future (and this is important) of the electric vehicle is getting greater consideration on the part of large users.

"The electric truck is unostentatious and accomplishes its work without much fuss and noise and generally its quiet performance does not attract the attention which its accomplishments merit."

It is the writer's conclusion that the remarkable efficiency and low operating cost of the electric truck cannot be neglected by the engineer as applying to other transportation vehicles, such as busses and taxicabs. If the electric truck, as has been abundantly demonstrated, will show an operating cost only slightly in excess of 50 per cent of that of its gasoline competitor of similar capacity in parallel service, it is reasonable to assume that a proper application of electric vehicles to the passenger transportation field will show an economy which may well be the difference between success and failure in the operation of passenger transportation systems. It is the writer's conviction that during the next five years electric passenger vehicles will, to a large extent, supplant gasoline vehicles in city transportation services and will be applied to new services where the operating cost of gasoline vehicles would be prohibitive.

Electrification of Main Line Railroads

By S. T. Dodd

Railway Engineering Department, General Electric Company

This brief survey of the main line electric traction field will be of both interest and use to many of our readers. It is not burdened with many details, but gives in a compact form a picture of main line electrification already accomplished and contemplated.—Editor.

For nearly 30 years electrical engineers have discussed the advantages which would be offered to steam railway lines by electrical operation. The first lines which used this form of motive power were forced to do so by special conditions. Among these may be mentioned the Baltimore & Ohio electrification of 1895 through the tunnel under the city of Baltimore; The New York Central electrification in 1906 in the New York terminus; and the electrification of the Great Northern Railway in 1909 through the Cascade Tunnel. All of these developments were forced by the impossibility of carrying on traffic through the tunnels on account of the smoke produced by steam locomotives. However, those most interested in the subject have always maintained that the most important reasons for railway electrification lay in its economic advantages and that when these were really appreciated main line electrification on a large scale could be expected to begin. It is only within the last few years that this economic value has begun to be generally understood and this accounts for the present widespread interest in the subject.

The electrification of the Norfolk and Western Rwy. and of the Chicago, Milwaukee & St. Paul Ry. are illustrations of instances where sections of steam railroads were electrified principally for economic considerations. The Chicago, Milwaukee & St. Paul electrification is the most extensive in existence in any part of the world. Among those who have not seen it, it is not generally understood that in the mountain sections of the trans-continental lines of the Milwaukee Railroad there is a section in electrical operation covering four former steam engine divisions. From Harlowton on the eastern slope of the Belt Mountains to Avery on the western slope of the Bitter Roots there is a distance of 440 miles crossing the ranges of the Belt Mountains, the Rocky Mountains and the Bitter Root Mountains where all train movements, freight, passenger and switching, are carried on with electric locomotives. When one realizes that this is a distance comparable to that from New York to Buffalo or from Boston to Washington, he sees that it is an application of electrification on a scale which is unknown elsewhere.

The power for operation of this railroad system is furnished by the Montana Power Company. It is principally derived from hydro-electric stations scattered over the State of Montana. Fourteen of these stations with an aggregate installed capacity of 175,000 kw. take their power from the watersheds of the Missouri, the Yellowstone and the Columbia Rivers and furnish power for a high tension transmission system which supplies light and power to various cities and industries through the state. Among these the 440 miles of the Milwaukee Railroad requires a maximum of 30,000 kw. and an average of approximately one half that amount. The records of operation of this line for the last five years show remarkable confirmation of engineering predictions. The amount of coal formerly used by steam locomotives on this section was at the rate of 400,000 tons yearly. Today the cost of electric power on these divisions is 52 per cent of the cost of fuel on adjacent divisions for the same service. The repair of motive power equipment is 45 per cent of that on adjacent divisions and the total cost of operation including the maintenance of trolley and substation attendance is 65 per cent of the cost of operation of similar adjacent divisions.

In addition to this section of 440 miles there is a second electrified section of 207 miles from Seattle east over the Cascade Mountains. When the intervening gap is electrified as it will be within a few years, the Milwaukee road will have a continuous stretch of 1000 miles of track electrically operated.

With such a record of accomplishment and confirmation of predicted results, it is no wonder that there is a widespread interest in the subject of electrification of steam railroads.

The Illinois Central Railroad is now actively engaged in a study of the possibilities of electrifying its Chicago terminus, of handling all suburban traffic out its 12th Street Station with multiple unit electric trains, and of operating its through passenger trains and the freight in its switching yards with electric locomotives.

The Delaware, Lackawanna & Western is studying the electrification of its heavy grade sections in the neighborhood of Scranton, over which a heavy coal traffic is handled. If this electrification is installed, it will be extended to Jersey City to handle the passenger and suburban traffic radiating from New York City.

An Engineering Committee appointed by Congress last year has recently submitted a report on the so-called Super-Power Zone. This is a proposal to tie together in one general transmission system all the large power houses from Boston to Washington and to furnish from a common transmission system the power required for lighting, industries and railroads throughout that territory. There is nothing untried in such a plan. The zone from Boston to Washington extending 150 miles inland is similar in extent to that covered by the Montana Power system, although there is a vastly greater use of power in the Super-Power territory.

It is, however, very probable that other parts of the world may anticipate the United States in the early application of electricity to trunk line service on a large scale. The greater price of coal as compared with this country, the possession of coal by some nations and the necessity of its importation by others, and the existence of ample water powers in many of the mountainous sections of the world all contribute to this end.

In South America the Paulista Railway, forced by the high price of fuel, has electrified 28 miles of its line from Campinas to Jundiahy. The Government of Chile has recently placed a contract for the electrification of 142 miles of the Chilean State Railways from Valparaiso to Santiago. The Central Railway of Brazil is inviting tenders for the electrical equipment of its suburban lines radiating out of Rio de Janeiro, a total of 90 miles of route.

Italy has for a number of years used electric locomotives for handling its trains in the northern section and along the approaches to the Alps. The Italian State Railway system now has in operation or on order a total of 222 electric locomotives. The traveler from Italy to Switzerland is hauled by electric locomotives through the Simplon Tunnel, a distance of 13 miles. From Brieg at the Swiss end of the Tunnel he is taken by Swiss electric locomotives down the Rhone valley and through the Loetschberg Tunnel to Bern and the Lake of Thun, a distance of 55 miles. Switzerland with its entire lack of coal and abundant supply of water power is rapidly extending its plans for railroad electrification. At present it is electrifying the line of the old route from Italy through the St. Gotthard Tunnel and the traveler will soon find electric trains on this route as far as the Lake of Luzerne.

The Scandinavian peninsula is another section where great interest is being manifested in electrification. In Sweden the heaviest locomotives in Europe are in operation inside the Arctic Circle and handling heavy trains of iron ore from the iron mines at Riksgransen to Kiruna, a distance of 78 miles. This line is now being extended eastward to the Baltic Sea and when completed will be 270 miles in length. In Norway the suburban lines from Christiania to Drammen, a distance of 25 to 30 miles, are now being electrified. Probably the next section to be undertaken will be a stretch of 25 miles from Riksgransen to the Norwegian port of Narvik, all of which is on a steady grade of 2.6 per cent.

France, with its war time experience of dependence on other countries for coal, has embarked on a definite program of electrification, which will require perhaps 20 years for completion. Power for this purpose is being developed from water on the slopes of the Central plateau of France. The Paris-Orleans Railway has for over 20 years handled its traffic from the Quai d'Orsay Station in the center of Paris to the Austerlitz Station, a distance of 2.4 miles, by electric locomotives. It is planned to extend this zone as far as Orleans, a distance of 78 miles, and orders have been placed for locomotives and motor cars. The Midi Railway, running across the southern section of France from the Mediterranean to the Atlantic at Bayonne and Bordeaux and serving numerous short branch lines running up into the valleys of the Pyrenees is planning to electrify a large portion of its lines and has ordered locomotives and substations. The Paris-Lyons-Mediterranean R. R. serving the eastern border of France, is also planning the installation of electric equipment of its lines, particularly on the lines extending up to the Mt. Cenis Tunnel where it connects with the electric lines of Italy.

The electrification plans which have been discussed above are not intended in any way as an exhaustive list of the studies which are being made on the electrification of steam railways, but they have been presented to illustrate the extent to which interest has been excited throughout the world by this very important department of engineering.

The Tanning Industry

By E. L. Judkins

Power and Mining Engineering Department, General Electric Company

After describing the accomplishments of the ancients in tanning leather, the following article briefly traces the history of that industry to date and cites federal census figures to show that electric drive is rapidly supplanting steam drive in the modern tannery. In this industry, as in others, electrification possesses distinct advantages with respect to economy, flexibility, and reliability of operation. In a forthcoming issue will appear an article which describes in detail the application of electric drive to the vegetable process and to the mineral process of tanning.—Editor.

The art of preparing not only common leather, but even very good and often finely colored varieties, similar to our Morocco and Cordovan, was understood by the ancient Orientals. Persian and Babylonian leather has been noted from time immemorial. Many centuries ago such leathers were brought from Asia into Europe; first into Turkey, Prussia and Hungary; later into Germany, Holland, England, France, and Spain, these countries subsequently learning to manufacture leather themselves. In the first centuries of Christianity, the Turks, Russians, and Hungarians were the most celebrated tanners, and later England, the Netherlands, and Spain endeavored to equal them.

Fig. 1. Electrically Operated Lime Reel

Among the different kinds of leather of foreign origin, Cordovan, Morocco, and Russian have all at times been specially famous. Cordovan, a soft, small-grained, colored leather, had been prepared by the ancient Orientals. Its name is derived from the Spanish city of Cordover, whence it was probably first introduced into Europe, and where it was chiefly manufactured for a long time afterwards. From the gradual improvement of Cordovan, sprang Morocco, a beautiful colored and brilliant leather, which has been excellently manufactured in Morocco, in European and Asiatic Turkey, and very well also in Russia, Poland, Hungary, and Spain, but especially in England, France, Holland, and Germany.

The Hungarians, in ancient times, were especially celebrated for their white tanned leather, which was imitated in France some three hundred years ago.

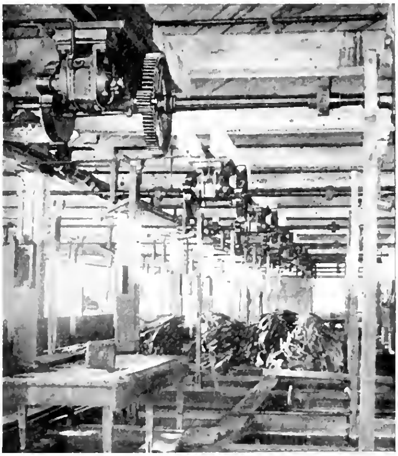

Fig. 2. 5-h.p. Back-geared Induction Motors, each operating rockers for twelve tanning vats

At some later period, the Romans appear to have acquired a knowledge of leather manufacture and to have pursued it with great success. It is said that boots and shoes equal to those of the present age were worn by the Roman ladies, and Pliny alludes to hides being tanned with bark, and also states that gall nuts, sumach, and lotus bark were employed in tanning.

About 1300 A.D. embossed leather of great beauty was produced. Specimens in the form of tapestry are still preserved in some of the old English mansions. Spain, Italy, Flanders, and England were famous for the production of richly colored embossed leather. This art,

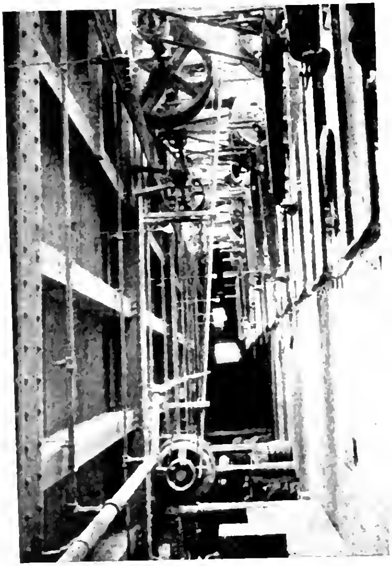

Fig 3. 50-h.p. Induction Motor Driving 33 Staking or Softening Machines

Fig 4. 15-h.p. Induction Motor Driving Two Oil Mills in a Tannery

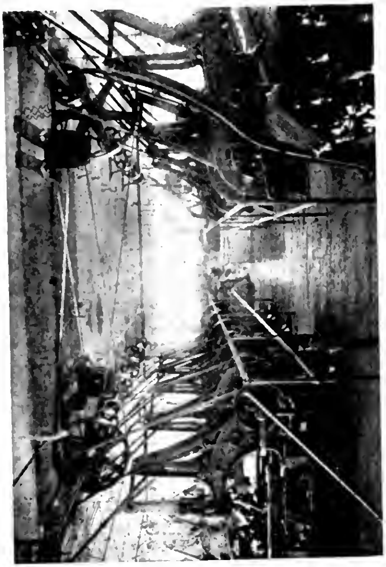

Fig. 5. One 5-h.p. and One 7½-h.p. Induction Motor Driving Five and Six Glazing Jacks Respectively

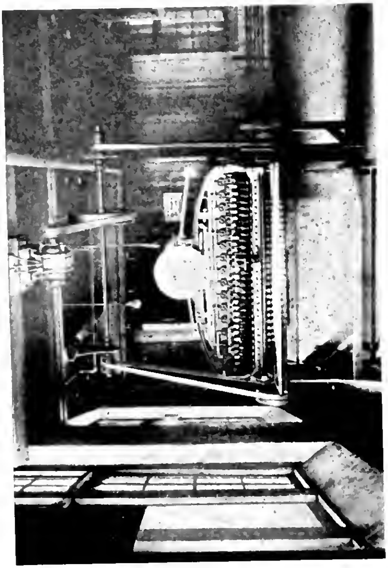

Fig. 6. 1½-h.p. Induction Motor Driving Two Measuring Machines

however, had been practiced by the early Egyptians nearly three thousand years ago, and it is probable that these countries may have revived and improved upon the Egyptian art.

It was not until the commencement of the nineteenth century that the subject of tanning received the attention of scientific men, the principles of the process of tanning fully developed, and the chemical action of the tanning agents upon the hide or skin definitely determined. The researches of Lewis, Seguin, Macbride, Prevost, Deyeux, and Sir Humphrey Davy established the fact that the process of tanning was a chemical art and should be conducted by scientific methods. It was nearly half a century, however, before tanners would recognize any suggested improvement.

Up to about eighty years ago, the tanners were men of small means, scattered about the country, without the advantages of machinery, railroads, or any knowledge of chemical principles. As a contrast to this condition of the trade, we now have in the United States, according to the census of 1914, seven hundred and forty-one tanneries, the majority of which are situated near the great ports and railroad centers, where the raw materials are landed, and which represent an investment of several millions of dollars.

The census of 1869 gives 7,569 tanneries in the United States, representing an investment of approximately sixty-one million dollars as against 741 tanneries in 1914 and a capital of three-hundred and thirty-two million dollars. Thus, during this forty-five year period, there was a decrease in the number of tanneries of ninety per cent, due primarily to the gradual concentration of the industry into larger and more perfectly equipped establishments, and an increase in capital invested of 543 per cent.

The tanning industry is divided into ten principal groupings, namely, sole and belting, side upper (cattle, calf, and kip), patent upper, harness, bag and strap, upholstery, sheep and lamb, goat and cabretta, fancy, and glove leather.

The tanning process is carried out by one of two methods, vegetable or mineral. The process consists essentially in forming a chemical combination of the corium, or true skin of the animal, with the tanning agent which in the former case is a vegetable astringent called tannin while in the latter method chromic acid is used, which by means of suitable reagents produces chromic oxide in the skin.

TABLE I

DISTRIBUTION OF GENERATED POWER IN THE TANNING INDUSTRY*

Power	Number of Engines or Motors			Horse Power: Amount			Horse Power: Per Cent Distribution		
	1914	1909	1904	1914	1909	1904	1914	1909	1904
Total primary power	2,908	2,065	1,807	172,712	148,140	117,450	100.0	100.0	100.0
Owned	1,332	1,590	1,665	150,164	140,238	114,591	86.9	94.7	97.6
Steam engines and turbines	1,210	1,440	1,524	140,299	131,451	107,550	81.2	88.7	91.6
Internal combustion engines	91	104	77	7,997	7,231	5,086	4.6	4.9	4.3
Waterwheels, turbines and motors	31	46	64	1,868	1,556	1,955	1.1	1.1	1.7
Rented	1,576	475	142	22,548	7,902	2,859	13.1	5.3	2.4
Electric	1,576	475	142	21,570	6,487	2,014	12.5	4.4	1.7
Other				978	1,415	845	0.6	0.9	0.7
Electric	4,838	2,340	731	73,424	35,919	14,539	100.0	100.0	100.0
Rented	1,576	475	142	21,570	6,487	2,014	29.4	18.1	13.9
Generated by establishments	3,262	1,865	589	51,854	29,432	12,525	70.6	81.9	86.1

* From U. S. 1914 Census Report

The general procedure of the process of tanning and finishing the hides and skins is the same by either method, differing only in minor details. The preliminary operations in converting hides and skins into leather are: liming and unhairing, fleshing, puering or de-liming, scudding, tanning operations, striking out and shaving, dyeing, putting out, oiling and drying, staking or softening, seasoning, and glazing.

To aid in these different operations, formerly performed by hand, the following are some of the principal machines now used: The unhairing and fleshing machine, tanning, oil and wash drums, paddle wheels, scudding, putting-out, and shaving machines, staking, rolling, stoning and glazing jacks, splitting, embossing, and measuring machines, buffing wheels, leather presses, dryers, fans, pumps, etc. Some of these machines are shown in Figs. 1 to 6. In addition to these machines, large quantities of steam are used in the washing, dyeing, and tanning operations.

Before the advent of the electric motor, all of these machines were steam driven. The buildings and machinery are usually distributed over a considerable area, being arranged with reference to the requirements of the process involved. In the case of steam drive, several power plants with long lines of shafting and numerous belts are required and the losses due to friction and belt transmission frequently constitute from 25 to 70 per cent of the total energy consumed. In addition to this loss, there is the high cost for attendance and maintenance for the several plants. With motor drive the major portion of this power cost may be eliminated by the application of direct drive to the various machines; the cost of energy thus becomes proportional to the work done.

Electric drive gives the utmost flexibility, permitting the various machines to be located in any desired part of the factory, in order to facilitate the handling of the work. The electric motor permits the uniform maintenance of the proper operating speeds, and prevents delays and break-downs incident to a drive employing engines and an involved mechanical power transmission system; so that increased production follows with the use of electric motors.

The electric motor is the most rugged and reliable driving unit in use today. The renewal of parts and repairs necessitated by natural wear and tear are easily made, due to the extreme simplicity of construction and the small number of parts involved.

The load characteristic of the tanning industry is rather variable, due to the intermittent nature of the operations performed by many of the machines used in the different steps of the tanning and finishing process.

Tests of the power consumption of twelve existing installations gives a ratio of average load to connected load of 21 to 66 per cent, or an average plant factor of 34.8 per cent.

Table 1 shows the number and horse power of engines and motors employed in the leather industry for the years 1914, 1909, and 1904. In addition to the electric motors operated by purchased current, it shows the number and horse power of motors operated by power generated by the private tannery plants. It also shows an increase in primary power from 1904 to 1909 of 25.6 per cent and a 16.6 per cent increase for the five-year period from 1909 to 1914, or for the decade from 1904 to 1914 of 47.1 per cent. It will also be seen that steam power formed 81.2 per cent of the total horse power in 1914. Rented power, which was mostly electric, increased rapidly since 1904. It formed 13.1 per cent of the total power in 1914 as compared with 5.3 per cent in 1909, and 2.4 per cent in 1904. There has also been a large increase in the use of electric motors run by privately generated current.

Although large quantities of steam are used in the tanning operations for washing, heating, dyeing, etc., there is a good field for the central station as against the small isolated plant with its lower efficiency and, consequently, higher cost of producing electric current. The steam requirements could be taken care of by a small centralized low-pressure boiler plant which could be economically operated.

Chemical Reactions on Surfaces*

By Irving Langmuir

Research Laboratory, General Electric Company

Catalysis is usually regarded as one of the most mysterious of chemical phenomena. In this paper Dr. Langmuir describes the mechanism of typical catalytic reactions on surfaces in such a way as to make us feel that these reactions may now be at least understood as well as any other types of reactions. The new viewpoint also seems to correlate chemical properties with so-called physical phenomena such as surface tension evaporation and adsorption.—Editor.

According to the usual interpretation of the law of mass action the velocity of a chemical reaction is proportional to the concentration of the reacting substance or to a product of concentrations if more than one substance is involved. It is frequently taken for granted that the same principle would apply unaltered to heterogeneous reactions: that is, it was assumed that the reaction velocity of a substance in contact with a solid would be proportional to the concentration of one or more of the reacting substances. Subsequent work, however, showed that other factors than the mere mass action effect were important in determining the velocity of these reactions.

It was shown by Noyes and Whitney[1] that the rate of solution of solid substances in liquids is often limited by the rate of diffusion of the dissolved substances away from the surface. At this surface, therefore, the solution remains practically saturated at all times.

Nernst extended this theory to cover heterogeneous reactions in general. He assumed that all solid surfaces were covered with adsorbed films, and that the reacting substances must diffuse through these films before coming in contact with the underlying metal or other substance constituting the solid. He assumed that in general the rate of reaction was limited by this diffusion and that the reaction would be practically instantaneous if it were not for the adsorbed film.

Bodenstein and Fink[2] adopted the general features of this theory, but considered that the film varied in thickness, depending upon the partial pressure of the gases in contact with the solid. In this way they were able to account for cases where the reaction velocity is not proportional to the concentrations of the reacting substances. For example, it was found experimentally that the velocity of the oxidation of sulphur dioxide with a platinum catalyser, as in the "contact process," was inversely proportional to the square root of the pressure of the sulphur trioxide. They explained this by assuming that the platinum was covered by an adsorbed film of SO_3, whose thickness was proportional to the square root of the pressure of this component.

Although this theory suggests a possible mechanism for the effect of catalytic poisons, it has not proved to be a satisfactory general theory of catalytic action. Thus, there is no logical reason for assuming, in some reactions, that the thickness of the adsorbed film is proportional to the square root of the pressure, while in other reactions, it is proportional to the first power of the pressure.

These theories of diffusion through films required the existence of films relatively thick in proportion to the dimensions of molecules, for we find experimentally that the reaction velocities can vary a thousand if not a millionfold in reactions where we have to account for this change by a variation in the thickness of a film. In such cases it would be necessary to have films so thick that we should be able to see them. Fink, however, measured the amount of SO_3 adsorbed by the platinum per unit area, and found it to be of the order of magnitude of a single layer of molecules. It is, then, hardly logical to assume that the thickness of this film can vary in proportion with the square root of the pressure for a wide range of pressures.

Evidence for the Existence of very Stable Adsorbed Films.—Experiments which the writer began in 1912 showed that the effect of residual gases on the electron emission from heated tungsten filaments in vacuum was generally to decrease the emission, instead of to increase it. Oxygen, or traces of water vapor, had a really remarkable effect in decreasing the current. Thus, at temperatures of about 1900 deg. K., the emission was decreased many thousandfold by pressure of oxygen as low as one bar (one dyne per square centimeter, or approximately 10^{-6} atmospheres). It did not seem possible that the oxygen could prevent the emission of the electrons unless it covered in some form the larger part of the surface. This film, however, must have been an extraordinarily stable one, to remain on a filament in such good vacuum at this high temperature. At temperatures even as low as 1000 deg. K. no visible film is formed on the surface of tungsten by

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* Reprinted from the *Transactions of the Faraday Society*, Vol. XVII, Part 3, 1921.

[1] Z. Physik. Chem., *23*, 689 (1897).

[2] Ibid., *60*, 46 (1907).

introducing oxygen, for the WO_3 which is produced distils off and leaves the surface apparently clean.

Since that time a long series of investigations has been made on the effect of low pressures of oxygen in altering the properties of tungsten at high temperatures. All of this work confirms the view that even at the highest temperatures, in the presence of traces of oxygen, the surface of the filament is practically completely covered with a film of oxygen.

Thus, when the filament is heated to 3300 deg. K. and a pressure of oxygen of a few bars is admitted to the bulb, the rate of disappearance of the oxygen shows that about 50 per cent of all the oxygen molecules which strike the filament react with it to form WO_3, which distils onto the bulb. Since there are three atoms of oxygen in the molecule of this compound and only two in the oxygen molecule, it is clear that *at least one-half* of the tungsten surface, even at this high temperature, must be covered with oxygen in some form.

The chemical effects of this adsorbed oxygen film are as striking as the effects on the electron emission. If a tungsten filament is heated to 1500 deg. K., or more, in pure, dry hydrogen at low pressure, the hydrogen is gradually dissociated into atoms and the atomic hydrogen is adsorbed by the glass walls of the vessel or reacts with any WO_3 which may previously have been distilled on to the bulb. The hydrogen pressure therefore gradually decreases. This effect is entirely prevented by minute traces of oxygen. Thus, if a mixture of oxygen and hydrogen be introduced into a bulb and the filament heated to 1500 deg., instead of the gases reacting to form water vapor, as they would in contact with a platinum filament, the oxygen reacts gradually with the tungsten to form WO_3. While this is going on, the dissociation of the hydrogen by the filament is entirely prevented, so that finally nearly pure hydrogen remains and the pressure becomes constant. After ten or fifteen minutes the pressure of the oxygen decreases to such a point (a minute fraction of one bar) that it no longer is able to prevent the dissociation of the hydrogen. This then begins *suddenly* to dissociate, and in a few minutes more all of the hydrogen has disappeared.

The oxygen film on the tungsten surface thus consists of oxygen in a form which cannot react with hydrogen even at 1500 deg. It certainly does not behave like a layer of either tungsten oxide or of highly compressed ygen gas. Its chemical properties have been completely modified by its adsorption on the tungsten.

The function of the oxygen in preventing the dissociation of the hydrogen is clearly that of a *catalytic poison*. This effect of the oxygen on tungsten is observed with several other reactions. For example, methane is decomposed by tungsten, giving hydrogen, while the carbon is taken up by the tungsten filament, but if the methane is mixed with oxygen, it is not decomposed until all the oxygen has reacted with the tungsten to form WO_3 and it is then decomposed as though no oxygen had been present. The same thing happens with ammonia, which, alone, is decomposed easily by a tungsten filament at 900 deg. K., but in presence of oxygen is not decomposed unless the filament temperature is raised above about 1300 deg. K.

If the electron emission is measured while a mixture of hydrogen and oxygen is in contact with the filament, it is found that the electron emission increases suddenly at the same instant that the dissociation of the hydrogen begins.

The remarkable stability of these oxygen films, as well as the complete change in the chemical properties of the oxygen, gives reason for believing that the surface is covered with individual oxygen atoms chemically combined with the underlying tungsten atoms. This film cannot be regarded as consisting of an oxide of tungsten, nor as atomic oxygen, in the sense in which we think of free oxygen atoms. The oxygen atoms are probably held to the surface by four pairs of electrons, just as the oxygen atom is held to the carbon atom in CO_2. The oxygen atoms are thus chemically saturated, but the tungsten atoms are not saturated, so that they are held by strong forces to the tungsten atoms that lie below them. This kind of structure is quite in accord with the conception of the structure of solids to which we are led by the work of the Braggs, on crystal structure.

Work with other metals has shown that stable films of the kind we have just been discussing are of very common occurrence. Oxygen forms a similar film on carbon; carbon monoxide, hydrogen, cyanogen, hydrogen sulphide, phosphine, and arsine form stable films on platinum. It is probable that all substances that have a poisoning effect on catalytic surfaces form films of this kind.

Evidence that these Stable Films are Monomolecular and that the Molecules tend to be Oriented on the Surface.—According to our present conceptions, atoms consist of electrons arranged in space about a positively charged nucleus. Whether we assume that the electrons are moving or not, it is certain that the electrons nearly completely surround the nucleus. In most molecules, atoms share pairs of electrons (duplets) with each other. In any electrically neutral molecule, the field of force must decrease in intensity with a very high power of the distance from the center. Born has calculated that the electric force around a group of eight electrons, arranged at the corners of a cube and surrounding a nucleus having an equivalent charge, is inversely proportional to the tenth power of the distance from the nucleus. Debye, from an entirely different viewpoint, reaches the conclusion that the force of attraction between molecules is inversely proportional to the eighth power of the distance between them. From considerations of this kind, it can be shown that the electric force near the surface of an atom must decrease from a maximum value at the surface to a value one-half as great within a distance of about 0.3×10^{-8} cm. In fact, an analysis of Debye's and other data show that this force decreases in about the same way on receding from the surface of the atom, for molecules of widely differing type. In other words, this distance of 0.3×10^{-8} is a nearly universal constant, and in this way we get a much better conception of actual conditions close to the surface of an atom than by assuming that the force decreases with a power of the distance.

If magnetic forces exist within the atom it can be readily calculated that these forces must decrease even more rapidly as the distance from the atom increases.

It must be said, therefore, that our present conception of the structure of atoms and molecules makes it impossible for us to conceive of any appreciable force which one atom or molecule can exert directly on others at distances greater than two or three Ångstrom units (10^{-8} cm.). Where effects are transmitted to greater distances than these, it must be the result of a transmission through and by atoms or molecules of matter. In view of the structure of atoms from positive and negative particles, it is clear that atoms should have the properties of a dielectric. Thus, if we have a chain of atoms linked together by duplets—as, for example, in the hydro-carbon chain of an organic compound—and we bring a positively charged body near one end of the chain, the electrons will be attracted and the nuclei repelled, so that a certain displacement of these particles with respect to one another will result. This effect is then transmitted with gradually decreasing intensity from atom to atom throughout the length of the chain, resulting in an accumulation of positive charge at the opposite end of the chain. The chemical evidence indicates clearly that effects of this kind are sometimes transmitted relatively great distances. The many facts which have led some chemists to assume polar valences, such as directed valences in organic compounds, receive a simple explanation on the basis of these transmitted effects.

In cases where atoms are not joined firmly to one another by the sharing of duplets, we should never expect the transmission of electric force to extend through more than about one atom. On this basis, we are led to deny the existence of thick, stable, adsorbed films of gas molecules such as those which were assumed in the Nernst and in the Bodenstein-Fink theory of heterogeneous reactions. If, for example, a surface is covered with a layer of oxygen *molecules* then there should be little if any more tendency for other molecules to form a second layer than there would be for these molecules to remain in the surface of liquid oxygen at the same temperature. Thus, only when we have nearly saturated vapors should we ever obtain films of gas molecules which exceed monomolecular thickness.

The general opinion among colloid chemists and others who have worked with adsorption effects, at least up to a few years ago, seems to have been that adsorbed films were usually of a thickness of 100 to 1000 Å. According to the views we have reached here, such thick films cannot be regarded as the result of true adsorption, but can result only from condensation in capillary spaces in presence of nearly saturated vapors or are due to sorption or solution. For example, it can be shown that glass, just like glue, can sorb large quantities of water vapor, but this is a real penetration of the water molecules into the solid material and is not a strictly surface action.

There is no good reason for believing that it is only at low pressures and high temperatures that adsorbed films are of monomolecular thickness. The effect of catalytic poisons (as studied, for example, by Faraday), surface tension effects, the lubricating properties of thin oil films, passivity phenomena in electrochemical actions, electrolytic overvoltage, etc., all point unmistakably to the existence at atmospheric pressure of stable films quite analogous to those observed in high vacuum and at high temperatures.

Lord Rayleigh, in 1899, on the basis of some beautiful experiments on surface tension, showed that the film of olive oil on water contaminated with this substance has a thickness of 10 Å., and is therefore probably of monomolecular thickness. This work was later extended by Devaux, Labrouste, and others. These results were of particular interest to the writer, because of their important bearing on the question of the range of atomic and molecular forces and the structure of adsorbed films in general.

Experimental results on the spreading of oils on water surfaces have completely confirmed the views outlined above. The only oils which spread on water are those whose molecules have active groups, such as the $-COOH$, $-OH$, etc., which normally increase the solubility of a substance in water. The spreading therefore occurs because the active group has an affinity for water, while the hydrocarbon chain tends to remain in contact with other chains of the same kind. The molecules on the surface must, therefore, be *oriented*, so that the actual surface consists of the hydrocarbon part of the molecules, while the active groups are all turned downward towards the surface of the water. It is evident that if we have a series of substances having the same active group, but different lengths of hydrocarbon chain, the number of molecules per unit area in the oil film should remain about constant, while the length of the molecule in the vertical direction, and therefore the thickness of the film, should increase in proportion to the length of the hydrocarbon chain. Numerous experiments have completely verified these theoretical deductions.[3] In this way it becomes possible to measure the lengths and cross-sections of the molecules of oil films on surfaces, and to prove conclusively that the films are not only monomolecular, but that orientation of the molecules is a factor of vital importance in their formation. Very accurate measurements of the forces involved in the formation of these films and valuable additional information in regard to their structural changes have recently been obtained in England by N. K. Adam.[4]

Evidence that surface films are monomolecular and that the molecules are oriented is also obtained from surface tension data on pure liquids. While spreading of oil films on water depends upon the most active group in the molecule, the surface tension of a liquid —which is a measure of the potential energy of its surface—depends primarily on the least active group in the molecule, for the group with the lowest stray field of force will tend to form the actual surface layer, in order to make the potential energy a minimum. An analysis of practically all available published data on surface tension leads to a verification of this hypothesis.

The interfacial surface tension between two liquids, such as water and mercury, or water and oil, gives, as W. B. Hardy has shown, a measure of the energy changes involved in the formation of the surface. W. D. Harkins[5] has made numerous measurements of interfacial surface tensions which show that the work done in the formation of such interfaces is a measure of the activity of the most active part of the molecule, for the molecules become oriented at the interface.

A fourth method of determining the thickness of surface films, and proving that they are oriented in the surface, depends upon the use of Gibb's thermodynamic equation, giving the total amount of material adsorbed in the surface of a solution in terms of the change in the surface tension of the solution as the concentration of the solute is altered. By measuring the surface tension of solutions at various concentrations it is thus possible to determine the amount of material adsorbed per unit area. As the concentration is increased, the amount adsorbed increases and approaches a definite limit. The results show that in all such cases the maximum amount adsorbed corresponds to that in a monomolecular film. It is thus possible to determine the number of molecules adsorbed per unit area and thus find the cross-section of the molecules. The length is then obtained from the known volume of the film. This method is applicable to adsorbed films on liquids formed either from substances dissolved in the liquids, or from substances present as vapor above the liquid. When the solution has a lower surface tension than the pure solvent, the surface has a monomolecular film of the dissolved substance, but where the solution has a higher surface tension than the solvent the surface of the solution consists of a monomolecular film containing nothing but pure solvent.

Direct experiments have also been made by the writer to determine the maximum amount of gases that can be adsorbed by plane surfaces of glass, mica, and platinum.[6] At ordinary temperatures, with pressures of nitrogen, hydrogen, argon, carbon dioxide, etc., up to a few hundred bars at least, there is no measurable adsorption by glass or mica—that is, less than 1 per cent of the surface is covered by a single layer of molecules. At the temperature of liquid air, however, and at pressures of the order of a hundred bars, the surfaces become saturated by an adsorbed film which never exceeds one molecule

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[3] Langmuir, Met. Chem. Eng., *15*, 468 (1916); Jour. Amer. Chem. Soc., *39*, 1848 (1917). A brief summary was published in Trans. Faraday Soc., *15*, *1* (1920).

[4] Proc. Roy. Soc. A *99*, 336 (1921).

[5] Jour. Amer. Chem. Soc., *39*, 354, 541 (1917).

[6] Jour. Amer. Chem. Soc., *40*, 1361 (1918).

in thickness. The evidence is that these films consist of *molecules* and that primary valences are not involved in their formation. The forces involved are unquestionably the result of the stray field of force around the molecule, and involve no radical rearrangement of the electrons. The forces are probably very much like those involved in the formation of substances containing water of crystallisation or ammonia of crystallisation.

With a clean platinum surface which had been made catalytically active by bringing it into contact with a mixture of oxygen and hydrogen at low pressures at a temperature of about 300 deg. C., the adsorption phenomena were totally different from those observed with glass and mica, at least in the case of the gases hydrogen, oxygen, and carbon monoxide. When small amounts of oxygen were allowed to come in contact with the platinum surface, the oxygen disappeared almost instantly, until the total amount adsorbed corresponded to a monomolecular or monatomic film, and then no further amount of this gas could be adsorbed even with a great increase in pressure. No trace of oxygen could be pumped off by heating the platinum to 360 deg. in the best vacuum.

If the platinum in this condition was allowed to come in contact with hydrogen or carbon monoxide at low pressure, the oxygen film was removed and water vapor or carbon dioxide was produced, even at room temperature, and then an additional amount of hydrogen or carbon monoxide was adsorbed sufficient to produce a monomolecular film of these substances. The carbon monoxide film could be very gradually pumped off at a temperature above 300 deg. No measurable amounts of nitrogen or carbon dioxide were adsorbed by the platinum at any time.

These remarkably stable films on the platinum surface are of the same type as the oxygen films adsorbed on tungsten surfaces. Primary valences are unquestionably involved in their formation. In the case of the carbon monoxide, the carbon atom must be directly attached to the platinum, while the oxygen is thus above the carbon. The carbon monoxide molecules—if we can so speak of them—are thus oriented on the surface, very much as the molecules in an oil film. The experiments with platinum give a direct proof that these stable films are of monomolecular thickness.

The evidence for the existence of monomolecular films is thus by no means confined to experiments at low pressures for equally striking evidence is furnished by the surface tension phenomena. The orientation of molecules in surface layers follows as a necessary result from the conclusion that the range of atomic and molecular forces is of the order of 1 Å. The orientation in surface films is a phenomenon with which we must constantly reckon, just as we must consider structural relationships in the molecules of organic compounds. Of course there are cases where the adsorbed film consists of single atoms, or of various symmetrical molecules, such as CH_4 or CCl_4, where we do not need to consider orientation. But wherever different parts of the surface of a molecule may be assumed to have different properties, we must take into account the probability of orientation in all adsorption phenomena and therefore in all catalytic actions on surfaces.

Mechanism of Adsorption.—We have discussed the structure of adsorbed films and the forces involved. Let us now consider the mechanism by which these films form on a surface or disappear from the surface.

When the adsorbed film of carbon monoxide on platinum gradually disappears, on heating the metal to 300 deg. in the highest vacuum, it is logical to look upon this as an evaporation process. When a filament of platinum, or tungsten, or other metal is heated to a sufficiently high temperature in vacuum the material evaporates. If the metal is placed in a uniformly heated enclosure, the evaporation from the surface—which we may consider continues unchanged—will be gradually offset by the return of atoms of metal from the vapor which accumulates in the space. Finally, an equilibrium is reached in which the rate of condensation of the vapor is equal to the rate of evaporation.

If we can assume that all the atoms of the vapor which strike the surface of the metal condense on the first collision, we may calculate the rate of condensation from the vapor pressure by means of the kinetic theory of gases. The formula usually given for the rate of effusion of gases through small openings can readily be put in the form

$$m = \sqrt{\frac{M}{2\pi RT}}\,p$$

where M is the molecular weight of the vapor, R is the gas constant, p is the pressure of the vapor, and m is the rate at which the gas molecules strike against the surface, in grams of vapor per square centimeter per second. Expressing p in bars, and placing $R = 83.15 \times 10^6$ ergs per degree, this reduces to

$$m = 43.74 \times 10^{-6}\sqrt{\frac{M}{T}}\,p.$$

This equation gives the rate at which the molecules of a vapor strike against the surface. If every molecule condenses, and if we have equilibrium, then the rate of evaporation must also be given by this equation, so that we obtain a direct relation between the vapor pressure of a substance and its rate of evaporation in perfect vacuum.

Experiments with many different metals have shown close agreement between the vapor pressures determined in this way from the rate of evaporation and the vapor pressures measured by processes which involve the formation of saturated vapors. Knudsen has made careful experiments of this kind with mercury vapor, while A. S. Egerton[7] has carried out work with cadmium and zinc. Their results indicate that every atom of vapor condenses.

Knudsen and R. W. Wood independently arrived at the conclusion that mercury or cadmium atoms condense on a glass surface only if this surface is cooled below a certain critical temperature. Below this temperature, practically every atom is supposed to condense, while at temperatures materially above this critical point not one atom, out of thousands which strike the surface, condenses. This conclusion is not only inherently improbable in many ways, but is not capable of accounting for numerous experimental facts. Wood's and Knudsen's experiments are better explained by assuming that all the atoms of cadmium and mercury which strike a glass surface even at high temperature, condense on the surface, but that at temperatures above the "critical temperature," the atoms re-evaporate before they have a chance to be struck by other atoms of the vapor. The writer has discussed this question in detail in a paper in the *Physical Review*, 8, 149, (1916), and subsequently carried on experiments with cadmium vapor[8] which demonstrate conclusively that cadmium atoms evaporate rapidly from a clean glass surface at room temperature. There is no real reason for believing that cadmium may not also evaporate from glass at temperatures only slightly above the critical temperature of −90 deg. C. cited by Wood. Since molten cadmium does not wet glass it is clear that the forces between a cadmium atom and a glass surface are much less than between cadmium atoms, and the rate of evaporation should therefore be much higher than from a cadmium surface.

In most cases of adsorption we are dealing with a solid surface having a strong field of force, or a high potential energy per unit area, while on this solid is condensed a substance whose molecules possess a rather weak stray field of force. These are the conditions when ordinary gases condense on cooled surfaces of glass or metals. The forces which might tend to hold a second layer of molecules are so weak that evaporation from the second layer occurs at a rate high compared with that from the first. Only with nearly saturated vapors, then, can a second layer form.

With cadmium and mercury vapors condensing on glass, however, we have a case in which the evaporation from the second layer takes place much more slowly than from the first layer. We see, therefore, that a kind of instability necessarily results. There is considerable difficulty in getting the first layer to form, because the atoms tend to evaporate before the others are able to condense on top of them or beside them. If the first layer ever does form, then the evaporation practically ceases and successive layers are then formed with ease. This view seems to give a clear picture of the mechanism of the formation of nuclei on which condensation occurs. The formation of frost crystals on a greasy window pane, or Moser's breath figures on glass, are illustrations of effects of this kind.

We might suppose that when molecules of a gas strike a surface, only a certain fraction α condense on the surface, while the others are reflected. Experimentally, however, it seems hard to find examples where α is appreciably different from unity. Soddy, Knudsen, and others have found, however, that in heat conduction from a solid surface to a gas at low pressure, the gas molecules which strike the surface do not always reach thermal equilibrium with the surface before leaving it. Knudsen has given the name "accommodation coefficient" to the fraction which expresses the ratio of the actual heat conduction to that calculated on the assumption of heat equilibrium. It is to be noted, however, that these coefficients are usually of the order of magnitude of 0.8, and they are determined under conditions in which the rate of evaporation of the gas from the surface is unusually high. We should probably therefore look upon these as rather exceptional cases, and, in normal cases, unless we have definite evidence to the contrary, should assume that the coefficient α is unity.

When gas molecules of any kind strike a surface, we should therefore not expect them to rebound elastically, but rather expect them to condense. Adsorption is thus the result of the time lag between condensation and evaporation. In some

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[7] Phil. Mag., 33, 33 (1917).
[8] Proc. Nat. Acad. Sci., 3, 141 (1917).

cases the rate of evaporation is so low that evaporation practically never occurs. This is what happens, for example, when a catalyst is poisoned by sulphur or arsenic compounds. In other cases, the rate of evaporation may be so high that the time that elapses between condensation and evaporation may be of the order of 10^{-12} seconds or even less.

The Mechanism of Chemical Reactions on Surfaces.—The clean surface of a solid crystalline body must consist of atoms or molecules arranged in a surface lattice, or kind of checkerboard. Non-crystalline bodies, such as glass, must have surfaces in which the atoms are probably not in regular lattices. We may also have surfaces which are porous, or consist of irregular filamentary projections and interlocking chains of atoms or molecules. In such cases the extent of the surface cannot be defined, except in a purely arbitrary manner. Most finely divided catalysts, such as platinum black, or activated charcoal, etc., must have structures of great complexity and it is probable that the atoms are attached to each other in the form of branching chains so that there are hardly any groups of as little as three or four atoms which are as closely packed as they would be in the crystalline solid. In order to simplify our theoretical consideration of reactions on surfaces, let us confine our attention mainly to reactions on plane surfaces. If the principles in this case are well understood, it should then be possible to extend the theory to the case of porous bodies.

In general, we should look upon the surface of a catalyst as consisting of a checkerboard in which some of the spaces are vacant, while others are filled with atoms or molecules. Some of these molecules, or atoms, may be so firmly attached that they do not evaporate at an appreciable rate. Others leave the surface from time to time, and the vacant spaces thus left are sooner or later filled by other molecules which strike the surface and condense.

If we have a surface such as that of platinum, and we allow to come in contact with it a gas, which forms an adsorbed film that evaporates slowly, or not at all, the surface is no longer a platinum surface as far as possible interaction with other gas molecules is concerned. The catalytic activity of the platinum has thus been lost, or the catalyst has been poisoned. Arsenic sulphur, or. phosphorous compounds have this effect, for the atoms of these elements presumably combine directly with the atoms of the platinum and do not evaporate at an appreciable rate. Cyanogen and carbon monoxide have a similar, but more transient effect on platinum, for only as long as these gases remain present in the gas phase does the poisoning influence persist.

Faraday studied the effect of various substances in poisoning the catalytic activity of platinum on the reaction between oxygen and hydrogen. By boiling platinum foil in concentrated sulphuric acid, and then washing with distilled water, it is brought into a condition where it causes the combination of oxygen and hydrogen at room temperature. The presence of carbon dioxide did not retard this action, but a trace of carbon monoxide stopped the action entirely, although on placing the platinum in a mixture of fresh gas, free from monoxide, the reaction proceeded in a normal manner. Hydrogen sulphide, or arsine, not only prevented the action while they were present, but produced a permanent alteration in the platinum, so that it was necessary to boil it again in acid before it could be made active. The poisoning effect of oxygen on the catalytic activity of tungsten at high temperature is of the transient kind produced by carbon monoxide on platinum.

In the presence of a gas which has a poisoning effect on a catalyst, the reaction velocity depends on that fraction of the surface which is *not* covered by molecules of this gas. If the temperature is high enough and the catalyst poison is of the kind that has a transient effect, the adsorbed molecules evaporate at a certain rate. If much of the gas is present, the vacant spaces thus produced tend to be refilled by these molecules. The fraction of the surface which is in an active condition is thus directly proportional to the rate of evaporation of the film, and inversely proportional to the partial pressure of the gas producing the poisoning effect. We are thus led to an understanding of the mechanism of the type of reaction which was explained by Bodenstein and Fink by assuming adsorbed films having a thickness varying in proportion to the pressure of a gas.

When gas molecules condense on a solid surface in such a way that they are held on the surface by primary valence forces, involving a rearrangement of their electrons, their chemical properties become completely modified. It is not surprising, therefore, that in some cases such adsorbed films should be extremely reactive, while in other cases they may be very inert to outside influences. Thus oxygen adsorbed on platinum reacts readily with hydrogen or carbon monoxide, while oxygen on tungsten, or carbon monoxide on platinum, show very little tendency to react with gases brought into contact with their surfaces. The specific nature of the behavior of these various films is quite consistent with the theory that the adsorption depends on typical chemical action. In many cases, especially where we deal with adsorption of large molecules, the orientation of the molecules on the surface is a factor of vital importance in determining the activity of the surface towards reacting gases.

The reaction which takes place at the surface of a catalyst may occur by interaction between molecules or atoms adsorbed in adjacent spaces on the surface, or it may occur between an adsorbed film and the atoms of the underlying solid or, again, it may take place directly as a result of a collision between a gas molecule and an adsorbed molecule or atom on the surface. This third kind of action is perhaps indistinguishable from one in which the incident gas molecules condense on top of those already on the surface and then react before they have a chance to evaporate.

When a surface is covered by different kinds of adsorbed molecules distributed at random over the surface, we may expect in general that adsorbed molecules in adjacent spaces should be able to react with one another at a rate which is proportional to the chance that the given molecules shall lie in adjacent spaces. This kind of mechanism has been discussed at length by the writer in connection with a study of dissociation of hydrogen in contact with a tungsten filament.[9] When the hydrogen molecule strikes a tungsten surface at high temperature, at least 68 per cent of the molecules condense on the surface and are held there as individual atoms. After the action has proceeded for a time, the distribution of atomic hydrogen over the surface is given by the probability laws. If θ_1 is the fraction of the surface covered by this atomic hydrogen, then the chance that any given elementary space on the surface shall contain a hydrogen atom is θ_1. The hydrogen atoms have a very strong field of force, since they are unsaturated chemically (for the electrons are not arranged in duplets). These atoms, therefore, have a relatively low rate of evaporation from the surface. Two atoms in adjacent spaces on the surface, however, may react with one another to form a hydrogen molecule. This is chemically saturated, and has therefore a weak field of force, so that it evaporates rapidly from the surface. The rate of evaporation of molecular hydrogen is thus proportional to its rate of formation from the atomic hydrogen, and this, in turn is proportional to θ_1^2, for the chance that *two* atoms shall lie in adjacent spaces is proportional to the square of the chance that an atom shall be in any given space. This statement of the problem lends itself readily to mathematical treatment, and the equations that were obtained for the dependence of the reaction velocity on the temperature and pressure are in full accord with experimental facts over a temperature range from 1500 deg. K. to 3500 deg. K. and pressures from 10 bars up to atmospheric pressure.

It is probable that the decomposition of ammonia, and also the formation of ammonia in contact with solid catalysts, depends upon similar interaction between adjacent adsorbed atoms. Reactions of this sort should be extremely sensitive to the actual distances between, and the arrangement of, the atoms in the surface of the catalyst. If these atoms are a little too far apart, or if their electrons are not sufficiently mobile to permit of the electron rearrangement involved in surface reactions, the reaction will be much retarded. It is the opinion of the writer that these differences in the geometrical arrangement of the atoms in the surface is responsible for the "activation" of catalysts which is brought about by the action that takes place upon them. For example, if a plane surface of platinum be heated for the first time in a mixture of hydrogen and oxygen, the temperature has to be raised quite high before the reaction begins. When the reaction has occurred, however, even in gases at very low pressures so that no appreciable heating effect takes place, the catalyst becomes modified and the reaction then proceeds, even at room temperature. In many cases, such effects are due to catalytic poisons, but there is good evidence that the effect is frequently caused by changes in the structure of the surface itself, brought about by the reaction. This is particularly noticeable in the catalytic oxidation of ammonia in contact with platinum wire. After the wire has been used, the surface becomes very rough, and gradually a disintegration of the wire occurs, because of the surface changes taking place. The catalytic activity of the wire is very low when first used, but becomes much greater after it has become activated by the reaction itself.

The changes that occur in the surface of the platinum under these conditions seem to be exactly similar to those that are caused by rapid fluctuation of temperature. When tantalum filaments, or certain improperly made tungsten filaments, are run in lamps on alternating current, the wire shows a tendency to "offset,"

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[9] Jour. Amer. Chem. Soc., 38 1145 (1916).

but this effect is entirely absent if the wire is heated to the same temperature by continuous current. This offsetting consists of a slipping of the crystals of the metal along the boundary planes. In extreme cases it leads to an early complete disintegration of the structure of the metal. Experiments show that this effect is directly dependent upon the rapidity of temperature fluctuation. Anything that increases the rapidity of temperature fluctuation, such as the introduction of hydrogen into the bulb, increases the rate at which offsetting occurs, so that it is possible in a few minutes to produce as much offsetting as would otherwise occur during hundreds of hours. Under these extreme conditions, the rate of cooling of the filament is of the order of a million degrees per second.

If a Coolidge X-ray tube is operated exclusively with direct current, even during manufacture, the surface of the target retains its high polish, even after long use. A few minutes' running with alternating current roughens the surface of the target, and it is well known that the focal spot in the target assumes an appearance which is quite analogous to that of the platinum surface used as a catalyst for the oxidation of ammonia. It is highly probable that the cause is the same in both cases, namely, sudden fluctuations in temperature between adjacent atoms in the material.

In a surface of crystalline platinum, where the atoms are presumably arranged in a definite surface lattice, the distances between adsorbed atoms which occupy adjacent spaces is probably a nearly fixed quantity, and in general it is unlikely that this fortuitous spacing is the best adapted to the interaction between the adsorbed molecules. When the surface atoms have been pushed around and made to assume new positions arranged more or less at random, the distances between adjacent adsorbed molecules vary over a wide range, and some of these distances will be exactly right for the reaction to occur at the highest possible speed. The surface thus becomes composite, and there is then a relatively small fraction of the surface at which the reaction occurs with extreme rapidity, while over the larger part of the surface it takes place at a very slow rate.

When a surface has become so roughened that it is porous, the effective surface area increases, and the number of favorable locations for the reaction to occur may become much greater.

There is good evidence, however, that the activation is not merely due to an increase in the surface, for a surface which becomes activated for one reaction may not become activated for another reaction. For example, a plane surface of platinum, by a single treatment in a hydrogen-oxygen mixture at low pressure, can have its activity so much increased that the temperature at which the reaction begins is lowered from 150 deg. C. to room temperature, but this increase in activity for the hydrogen-oxygen reaction is not accompanied by any change in the velocity observed in the reaction between carbon monoxide and oxygen.

The experiments seem to indicate that the reaction between oxygen and hydrogen on platinum results from interaction between adjacent adsorbed atoms, while the reaction between carbon monoxide and oxygen takes place between oxygen atoms adsorbed on the surface and carbon monoxide molecules from the gas phase which strike them. This difference in mechanism probably accounts for the different sensitiveness to surface conditions. It would also suggest that the energy imparted to the individual platinum atoms as a result of the reaction may be much less in the carbon monoxide reaction than in the hydrogen reaction. If this is so, the monoxide reaction should produce little change in the surface, and thus should not activate the catalyst for the hydrogen reaction.

The experimental evidence with carbon monoxide and oxygen on platinum proves that nearly, but not quite all of the reaction between these gases occurs during collision of carbon monoxide molecules with the oxygen covered surface. In reactions of this kind, which occur as the result of collisions, we may expect that in some cases the exposure of the "flanks" of an adsorbed film to attack by colliding molecules may render them much more susceptible to chemical action. For example, it is conceivable—although in this particular case there is no experimental evidence for it—that, if the whole surface of platinum were covered by oxygen atoms, incident carbon monoxide molecules should be unable to react, while if only a certain limited portion of the surface were covered with oxygen, the monoxide molecules striking the oxygen atoms close to the place where they are attached to the platinum might be able to react. In this case the oxygen film would be removed progressively from its bounding edge inward. It seems quite possible that this kind of action may be involved in some of the passivity phenomena observed with iron in electrochemical action, and may also be effective in causing the *sudden* beginning of the dissociation of hydrogen by a tungsten filament after small traces of oxygen have been consumed by the filament.

If we consider catalytic surface reactions with more or less complicated organic molecules, we should naturally expect that the orientation of the molecules and steric hindrance effects should become more important as factors in the mechanism of the reaction. For example, when ethyl acetate is heated with different solid catalysts, it may give—

(A.) $CH_3CO_2H + C_2H_4$
(B.) $CH_3CH_2CH_3 + CO_2$
(C.) $CH_3COCH_3 + CO_2 + C_2H_5OH + C_2H_4$.

In all these cases, the —COO— group is unquestionably directly attached to the surface, while the rest of the hydrocarbon chain is located above this group. It is probable that the —COO— group is attached to the surface by primary valences, so that the bonds between these atoms disappear when the substance is adsorbed. Depending upon the different manners in which interaction between atoms and evaporation may occur, the resulting products differ. Reaction (A) involves only a shift in the position of a hydrogen nucleus, to allow the products to evaporate separately. In reaction (B) it is only necessary for a few electrons to shift their positions. Reaction (C) involves interaction between two molecules which must be adsorbed in adjacent positions in definite geometrical relations to one another.

Reactions at Boundaries of Phases—Faraday observed that a perfect crystal of sodium carbonate or sodium sulphate[10] refuses to effloresce until the surface is scratched or broken, and that the efflorescence then spreads from the injured place. Similar phenomena have been observed with copper sulphate and other crystals. In all such cases it is necessary to assume that the reaction (dehydration) *takes place only at the boundary between two phases.* Careful analysis[11] shows that wherever we have to deal, according to the Phase Rule, with separate phases of constant composition, the reaction occurs only at the boundaries of phases. Thus in the dissociation of calcium carbonate by heat, the carbon dioxide is produced only at the boundary between the calcium carbonate and the calcium oxide phases.

Dr. H. S. Taylor recently described experiments on the preparation of copper and copper oxide catalysts[12] in which he found that there was a long "period of induction" in the reduction of heated cupric oxide by hydrogen. All the phenomena that he observed in connection with this reaction are in accord with the view that this is another case in which the reaction occurs only at the junction between phases. In conventional nomenclature we may say that we have here an example of autocatalysis, the metallic copper accelerating the reaction. It seems much more profitable, however, to analyse the phenomena in terms of the probable mechanism.

The oxygen atoms in copper oxide are thoroughly saturated chemically, which means in this case that they have taken up two electrons from the copper atoms and have thus completed their octets, and leave the copper in the form of ions. There is thus no reason for expecting a strong tendency to react with hydrogen at moderate temperatures. In view of Taylor's experiments, we conclude that the oxygen ions in cupric oxide are in fact very inert toward molecular hydrogen. Let us assume that, owing to some local imperfection in the space lattice of the atoms of the copper oxide, an ion of copper has taken up electrons and has formed a neutral atom. It is to be expected that such an atom should behave towards hydrogen molecules like metallic copper or other metallic substances. We have already seen that hydrogen molecules are adsorbed by platinum and by tungsten (and therefore probably by other metals) in the form of atoms. This action is presumably caused by the attraction of the "free" electrons of the metal upon the hydrogen nuclei. The hydrogen adsorbed by the copper in atomic condition can then react with the oxygen ions merely by the shifting of the hydrogen nuclei from the copper atoms to the oxygen ions, the electrons being transferred to another copper atom. Each hydrogen molecule thus supplies two electrons and is capable of converting an adjacent copper ion into a neutral atom. By such a mechanism it is clear that the reaction could proceed only at the junction between the phases.

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[10] "Experimental Researches," Everyman's Library Edition, p. 109.
[11] Langmuir, Jour. Amer. Chem. Soc., 38, 2263-2267 (1916).
[12] Rochester Meeting, Amer. Chem. Soc., April, 1921.

A New "Power-factor" Slide Rule

By P. L. Alger
Induction Motor Engineering Department, General Electric Company

and

H. W. Samson
Data Section, General Electric Company

While the ordinary slide rule is practically universal in its application, and can be credited with saving its users an amount of time equivalent to millions of dollars annually, there are special types of calculation that may be facilitated to a still greater extent by the use of a variation of the common style of rule. Such a situation and slide rule are described in the following article which deals with the solution of right-triangle problems.—Editor.

The familiar ten-inch polyphase slide rule has become an almost indispensable element in engineering calculations, and many newer, more complicated varieties of slide rule have become very popular. However, none of the extant commercial forms of rule are adapted for the convenient solution of numerical problems involving the third side of a right triangle of which two sides are already known. Ordinarily the third side is found by squaring the other two sides, adding or subtracting, and extracting the square root. This process requires either pencil and paper, or at least some mental gymnastics; and frequently requires a search for the decimal point.

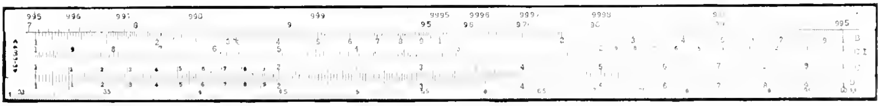

Fig. 1. Normal View of "Power-factor" Slide Rule

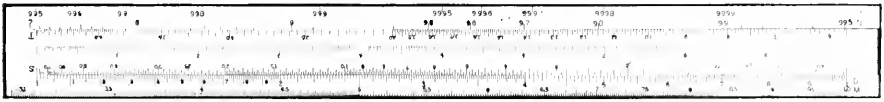

Fig. 2. Setting of Slide Rule to Read Cosines and Cotangents of Given Angles Below 45 Deg.

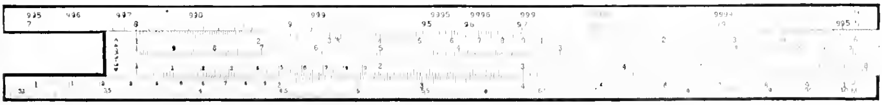

Fig. 3. Setting of Rule to Obtain Power-factor (0.80 on *N* Scale When *R* Equals 3.6 and *X* Equals 2.7)

A new "power-factor" slide rule for the more convenient solution of such problems has recently been devised by Miss Edith Clarke, its name being derived from its use in determining the power-factor in an alternating-current circuit. This new rule as shown in Fig. 1, was metamorphosed from a standard ten-inch polyphase slide rule by the substitution of a power-factor scale, *N*, for the ordinary scale of squares, *A*; and the addition of a new scale of square roots, *M*, on the lower edge of the face. The central slider was left unchanged.

The *N* scale gives the cosine of the angle whose cotangent appears immediately below on the *D* scale, or in other words, the sine corresponding to the tangent which appears on the *D* scale. Only the range from 45 deg. to 84 deg. 20 min., corresponding to values of the tangent from 1 to 10, is covered by the *N* scale. The N^1 scale covers an additional range from $\tan^{-1} 10$ to $\tan^{-1} 100$, but this scale is superfluous for ordinary work as the sines of these angles differ by less than one-half of one per cent from unity. Thus the X and D scales in conjunction serve the same purposes as the parallel sine and tangent columns in a trigonometric table, enabling either function to be found when the other is known. A 45-deg. range only has been covered by the X and X^1 scales for the reason that all operations with a triangle may be performed by means of functions of but one of the acute angles. By inserting the slider reversed and upside down, as in Fig. 2, it will be seen that if an angle, say 30 deg., is selected on the T scale, the X scale will give the cosine, 0.866, and the D scale the cotangent, 1.732.

As an illustration of its use in the solution of triangles, let us assume, referring to Fig. 4, that we have given values of R and X and require Z. First, if R is greater than X, as for example $R=3.6$ and $X=2.7$, divide R by X to obtain cot θ, which in this particular example is 1.333, as shown in Fig. 3. The value of cos θ, read on the X scale, corresponding to this value of cot θ, is 0.800, and hence $Z=\frac{R}{\cos\theta}=\frac{3.6}{0.8}=4.50$. Second, if X is greater than R, divide X by R to obtain cot ϕ and cos ϕ. Then Z is equal to $\frac{X}{\cos\phi}$. In other words, the triangle is always solved by use of the angle opposite the shortest side.

Obviously, if the hypotenuse and long side are given, the short side is found by simply reversing the process. In case the hypotenuse and short side are given the power-factor slide rule is not of the same convenience in the solution as when the long side is given, because the X and X^1 scales only give values of sines above 45 deg. and cosines below 45 deg. To satisfy this condition, were it often encountered, the X^1 scale could be replaced by a scale that would give values of sines from 5 deg. 44 min. to 45 deg.

The prime objective in the development of this slide rule was to simplify the process of calculating induction-motor characteristics from the constants of the equivalent circuit. This process is simply the calculation of the total impedance for a circuit containing two known impedances in parallel, the whole being in series with a third known impedance. Consequently, the numerical work consists in the conversion of impedances into admittances, their addition, and the conversion of the resulting admittance back into impedance. The only way to simplify this work without loss of accuracy seemed to be to shorten the elemental process of conversion of an impedance into the equivalent admittance. But the heart of this problem is just that of finding the third side of a right triangle when the other two are given.

Referring again to the right triangle in Fig. 4, let R and X be known values of resistance and reactance comprised in an impedance Z. The equivalent values of conductance, G, and susceptance, B, are then equal to $\frac{R}{Z^2}$ and $\frac{X}{Z^2}$, respectively. Assuming R to be greater than X, cos θ is found as previously explained. Then, by setting the value of cos θ on the M scale (that is, $\cos^2\theta$ on the D scale) and dividing by R on the C scale, we obtain the conductance G, since $G=\frac{R}{Z^2}=\frac{\cos^2\theta}{R}$. Finally the susceptance, B, is obtained by dividing G by cot θ. If the reactive power-factor, cos ϕ, is found instead of the active power-factor, cos θ, as is the case when X is greater than R, B is first found by dividing $\cos^2\phi$ by X, and then B divided by cot ϕ gives G.

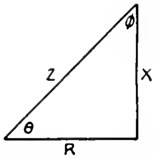

Fig. 4. Vectorial Representation of Simple Alternating-current Circuit

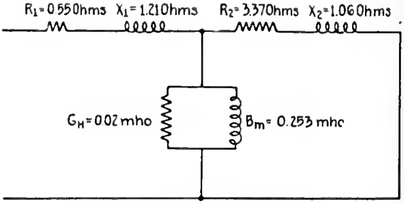

Fig. 5. Representative Equivalent Circuit of Induction Motor or Transformer

Of course the inverse process of finding R and X when G and B are known is exactly the same as described above if R is read for G, X for B, G for R, and B for X. For the sake of additional clarity the calculations for a representative equivalent circuit, Fig. 5, are shown in Table I in a convenient form that might be used in actual practice. It will be noted that active and reactive power-factors are taken account of by their positions in the columns.

TABLE I

	Active	Reactive
$Z_2 = r_2 + j\,x_2$	3.37	$+j$ 1.06
.... $\cot\theta_2$	3.18	
$P.F._2$ .. $\cos\theta_2$ .... $Q.F._2$	0.953	
$\left\{ Y_2 = g_2 - j\,b_2 \right.$	0.269	$-j$ 0.0847
$\left. Y_m = g_h - j\,b_m \right\}$	0.020	$-j$ 0.253
$Y = g - j\,b$	0.289	$-j$ 0.3377
..... $\cot\theta$		1.168
$P.F.$ .. $\cos\theta$ .... $Q.F.$		0.759
...... Z	2.245	
$\left\{ Z = r + j\,x \right.$	1.46	$+j$ 1.703
$\left. Z_1 = r_1 + j\,x_1 \right\}$	0.55	$+j$ 1.21
$Z_0 = r + j\,x_0$	2.01	$+j$ 2.91
$P.F._0$ ... $\cos\theta_0$ ... $Q.F._0$	0.567	0.822
...... Z_s	3.54	

Since this power-factor slide rule affords a mechanical means of solving any right triangle with the same facility and the same accuracy as ordinary operations of multiplication are performed, it will be useful in a great many kinds of engineering calculation. Surveying and bridge design in civil engineering, stress determination and steam flow calculation in mechanical engineering, and all kinds of alternating-current calculations in electrical engineering are some fields of application. In general, wherever the algebra of complex quantities involving the use of the symbol j for $\sqrt{-1}$ has proved useful in the representation of physical phenomena, the new slide rule will also prove useful in the performance of the corresponding numerical calculations.

Most problems have more than one solution, and this problem of calculations based on a right triangle is no exception to the rule. There are at least three other fairly convenient methods of finding Z when R and X are known. They are as follows:

By squaring R and X separately, using the B and C scales of an ordinary slide rule, adding the squares mentally, and extracting the square root, Z may be found. Time trials of this method have shown that it takes about $1\frac{1}{2}$ times as long to find both Z and the power-factor by it as by the new slide rule method; also it is a little less accurate on account of the increase in the number of operations.

By use of the relation, $1+\tan^2\theta = \sec^2\theta$, it is possible to find the power-factor on a polyphase slide rule with very fair speed and accuracy. Dividing R on the D scale by X on the C scale gives $\tan\theta$ on the C scale (opposite the 1 on the D scale) and also $\tan^2\theta$ on the B scale. By mentally adding 1 to $\tan^2\theta$, and setting this value of $\sec^2\theta$ on the B scale, there is found directly below the value of $\cos\theta$ on the CI scale. This process was found by time trials to require about $1\frac{1}{3}$ times as long as the new slide rule method, and also to be somewhat less accurate due to the use of two settings instead of one.

By referring to an actual table of corresponding values of $\cot\theta$ and $\cos\theta$, it is possible to find Z for known values of R and X with the same number of operations as with the new slide rule. But this substitution of a printed table of figures for slide rule scales has the disadvantages of requiring two devices instead of one and of requiring laborious interpolations between the tabulated values. While very good accuracy is thus obtainable, the time required is at least twice as long as by the new slide rule method.

Thus the new power-factor slide rule offers distinctive advantages over all the foregoing methods of calculation; and it is accordingly probable that it will in time be recognized as a very useful addition to the mathematician's tool chest.

American Street Cars in Finland

By J. A. H. Torry

International General Electric Company

During the latter part of 1920, twenty American built street cars, the first ever shipped to any country in Northern Europe, were put into service in Helsingfors, Finland. This city is the capital and the chief commercial center, also the principal seaport, being situated on the Gulf of Finland. Its population was 150,000 according to the last census, 1910, but is now much greater as the city is progressive and has grown rapidly since. The National University is located there, as well as many other educational and scientific institutions. The city is beautifully laid out, with wide streets, boulevards and parks, and in addition there are many historic monuments.

At the time the installation of these new cars was in contemplation, a number of special features had to be considered in view of the somewhat different class of service and more severe conditions than would be encountered by the average street car system in this country. Sharp curves in the track necessitated single-truck four-wheel cars, with a maximum wheel-base of seven feet; and the cars had to be of sufficient power and weight to haul one trailer under normal conditions, and two trailers during rush hours. In the total length of eleven miles of track there is approximately one mile of 3 per cent grade, 2500 ft. of 5 per cent, 1200 ft. of 6 per cent, 150 ft. of 7 per cent, and 35 ft. of 9 per cent. These grades, together with the service schedule, were the main factors in deciding whether a standard type of motor equipment would be suitable or whether motors of a more or less special design would be necessary.

After a careful study of the general conditions to be met, it was decided that a standard equipment of two 600-volt GE 249 motors per car with a gear ratio of 83/15 would be satisfactory. The car completely equipped, but without passenger load, weighs approximately 24,000 lb. With a total passenger load of about 6300 lb. the motor car weighs 30,300 lb. and will haul one trailer on all grades under continuous service and two trailers intermittently on the fairly level portion of the track during rush service hours. In order to protect the motors from excessive overload due to a heavy trailing load the rate of acceleration, based on level track, does not exceed one mile per hour per second when hauling two trailers and 1½ miles per hour per second when hauling one trailer.

These new motor cars are equipped with two-motor double-end control equipments and are arranged for hand, air, and rheostatic braking for emergency purposes. Connections are made for lighting the trailers and for operating their solenoid track brakes.

The standard Brill single trucks, on which these motor cars are mounted, are constructed for 3 ft. 3⅛ in. track gauge and have 7 ft. wheel-base and 31½ in. diameter wheels. A substantial wooden wheel-guard which extends completely around the truck is shown in Figs. 3 and 4. The interior of the cars is handsomely finished in cherry. Fig. 2 shows the seating arrangement, consisting of seven transverse cherry-slat reversible-back seats for two passengers on one side and seven single seats on the other, giving a total seating capacity of 21 passengers.

These cars are particularly noteworthy on account of the 6 ft. 3 in. platform at each end, where a total of 24 standing passengers can be accommodated, thus making the total carrying capacity 45 passengers. As in all Scandinavian countries, no passengers are permitted to stand in the car body aisle, this space being left clear for those moving to and from their seats.

The cars are operated by girl conductors; in fact, much of the operation is done by women, who have proved very proficient in the handling of the system.

These American built cars have proved satisfactory in every way, and the past severe winters experienced in Helsingfors have been more than a test of their capabilities. The successful operation of this equipment which was furnished by the International General Electric Company, Inc., through its local representative, the Finnish Electric O/Y, is expected to lead to further purchase of American built cars, not only in Finland but also in Norway, Sweden, Denmark, and other countries of Northern Europe.

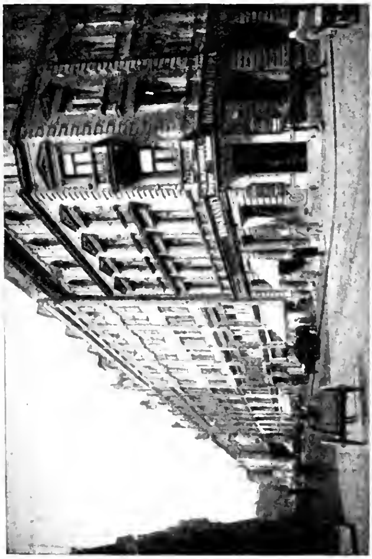

Fig. 1. A Section of the Main Street in Helsingfors, Finland

Fig. 2. Interior View of One of the American Built Cars of the Helsingfors Tramways Company

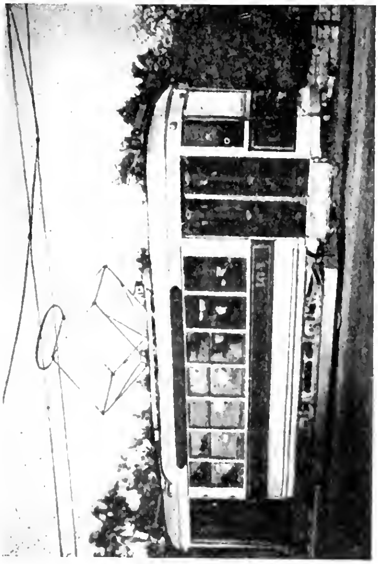

Fig 3. One of the New Motor Cars in Operation on the Outskirts of Helsingfors

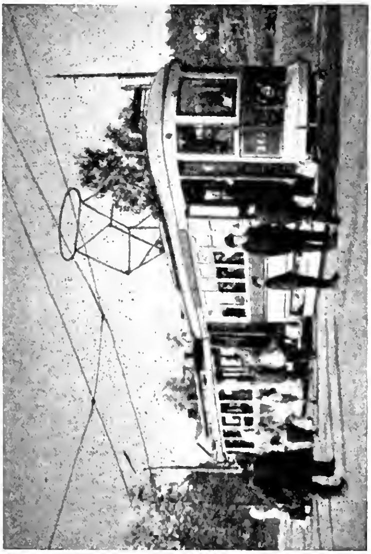

Fig. 4. One of the New Motor Cars with One Trailer

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.

Electric Drive—Steel Mills

The Application of Electric Power in the Iron and Steel Industry. Hall, W. S.
W. Soc. Engrs. Jour., May, 1922; v. 27, pp. 145-157.
(General consideration.)

Electric Wave Form

Triple Harmonics in Transformers. Faccioli, G.
A. I. E. E. Jour., May, 1922; v. 41, pp. 351-359.
(Reviews the salient points in a fairly simple style.)

Electrical Machinery—Rating

Method of Determining Resultant Input from Individual Duty Cycles and of Determining Temperature Rating. Jones, Bassett.
A. I. E. E. Jour., May, 1922; v. 41, pp. 329-341.
(Applies the theory of probabilities to the problems of duty cycles and ratings of motors. Introduces two new terms: "Operating Factor" and "Duty Cycle Factor.")

Heat Insulation

Heat Losses from Steam Line Pipes. Heilman, R. H.
Blast Fur. & Steel Pl., May, 1922; v. 10, pp. 261-265.
(Gives results of tests on bare and covered wrought iron pipe up to 800 deg. F.)

Power Factor

Analysis of Economic Loss Due to Power Factor—Basic Meterable Factors. Doran, J. E. and others.
N. E. L. A. Bul., May, 1922; v. 9, pp. 311-320.
(Discusses methods of measuring and charging for electric energy when power factor is taken into consideration.)

Protective Apparatus

Protective Apparatus for Turbo-Generators. Kuyser, J. A.
Elec. Rev. (Lond.), May 12, 1922; v. 90, pp. 678-681.
(Abstract of paper before the I. E. E.)

Ship Propulsion, Electric

U. S. S. Tennessee. Description and Official Trials. Jones, C. A.
Am. Soc. Nav. Engrs. Jour., May, 1922; v. 34, pp. 171-258.
(Given over almost entirely to illustrations and descriptions of electrical equipment and turbines.)

Steam Plants

Boiler-Room Performance and Practice of the Colfax Station, Duquesne Light Company. Clarke, C. W. E.
Mech. Engng., May, 1922; v. 44, pp. 295-300.
(Describes, in some detail, the operating features.)

Higher Steam Pressures or Pulverized Coal? Scheffler, Frederick A.
A. I. E. E. Jour., May, 1922; v. 41, pp. 346-350.
(Presents estimates intended to prove that lower steam pressures with pulverized coal are more economical than higher steam pressures, stoker fired.)

Steam Turbines

Steam Turbine Reliability and Design.
Engr. (Lond.), May 5, 1922; v. 133, pp. 486-487.
(Serial.)

Substations, Automatic

Economics of Direct Current Railway Distribution. Creecelius, Lawrence P. and Phillips, Victor B.
A. I. E. E. Jour., May, 1922; v. 41, pp. 363-378.
(Theoretical discussion.)

Switches and Switchgear

High Voltage Switchgear Design. Coates, W. A.
Elec'n (Lond.), May 5, 1922; v. 88, pp. 526-530.
(Outlines the general principles involved. Serial.)

Vibrations

Investigation, by Means of the "Vibrograph," of the Vibrations of Turbo-Generators. Geiger, Jos. (In German.)
Zeit. des. Ver. Deut. Ing., May 6, 1922; v. 66, pp. 437-440.
(Explains the "vibrograph" and describes a special case of vibration in a 10,000-kw. turbo-generator which was successfully investigated by its use after other methods had failed.)

NEW BOOKS

Burning Liquid Fuel. Rev. ed. Best, William Newton. 341 pp., 1922, N. Y., U. P. C. Book Co., Inc.

Course in Electrical Engineering. v. 2: Alternating Currents. Dawes, Chester L. 526 pp., 1922, N. Y., McGraw-Hill Book Co., Inc.

Dynamic and Static Balancing. Hammond, Edward K. 58 pp., 1921, N. Y., Industrial Press.

Economics of Electrical Distribution. Reyneau, P. O. and Seelye, H. P. 209 pp., 1922, N. Y., McGraw-Hill Book Co., Inc.

Electric Arc Welding. Wanamaker, E. and Pennington, H. R. 254 pp., 1921, N. Y., Simmons-Boardman Pub. Co.

Electric Ship Propulsion. Robinson, S. M. 274 pp., 1922, N. Y., Simmons-Boardman Pub. Co.

Operating Engineer's Catechism of Steam Engineering. Gornston, Michael H. 428 pp., 1922, N. Y., D. Van Nostrand Co.

Principles of Alternating Currents. Lawrence, Ralph R. 432 pp., 1922, N. Y., McGraw-Hill Book Co., Inc.

Questions and Answers Relating to Diesel, Semi-Diesel and Other Internal-Combustion Engines, Air Compressors, etc. Lamb, John. 209 pp., 1922, Phila., J. B. Lippincott Co.

GENERAL ELECTRIC REVIEW

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Editor, JOHN R. HEWETT
Associate Editor, E. C. SANDERS

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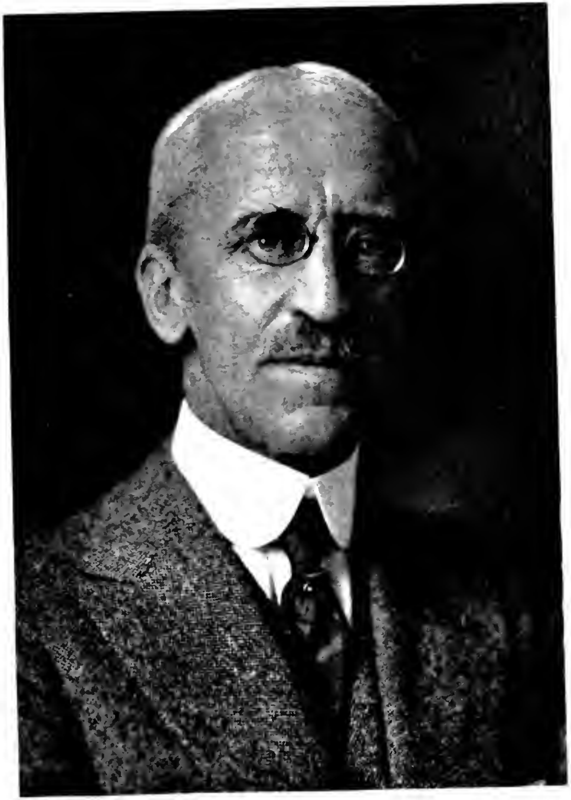


A. H. JACKSON

Both Mr. Barry and Mr. Jackson, who have been in the service of the General Electric Company for many years, were recently elected Vice-Presidents

GENERAL ELECTRIC
REVIEW

THE PURPOSE OF EDUCATION

At the recent commencement exercises at Union College, Schenectady, N. Y., many notable addresses were made, but the one that appealed to us particularly as engineers was that delivered by Mr. E. W. Rice, Jr., Honorary Chairman of the Board of Directors of the General Electric Company. Mr. Rice has had a life-long experience in the electrical industry and knows what an important bearing college education must play in preparing young men to carry on this and other industries as well as the professions.

Many of Mr. Rice's remarks had special reference to Union College, so rather than print his address as a whole we take the privilege of using those parts of the address that we feel will especially appeal to a larger audience as our editorial for this issue of the REVIEW.

"While the number of students in Engineering has increased rapidly in recent years, it is not our intention to unduly specialize in Science and Engineering, but rather to send into the world men who have obtained the foundation of a good education, men who because of their training will be better fitted to deal with the practical problems of life and who think less of asserting their rights than of performing their full duty and who regard it a duty as well as a privilege to give the world more than they receive."

"Even if that divinity which 'shapes our ends and controls our destinies' leads us more into the training of engineers, it will be our ambition to turn out an engineer who is not only well grounded in his subjects but who will have absorbed enough of good literature and sound science to love both and, to desire to learn more, who will have studied enough of the history of man and his relation to other men to secure a just perspective of life, who realizes that there is a scientific as well as a religious basis for good morals. We also regard it as especially important that all our graduates should be thoroughly trained to speak and to write our language correctly and clearly, if not with fluency and brilliancy."

"All science and industry have, as is well known, made wonderful progress during the past half century and quite naturally great emphasis has been placed upon intellectual and material achievements. We are rejoiced when we contemplate the contributions to the increased wealth, comfort, and power of millions of men which have been realized, a greater advance than has ever been made in the same time in all the world's history."

"Now we realize that all progress in scientific knowledge and its application results in an increase in man's control over nature. But it is of utmost importance that we should also realize that such increase of power does not change the nature of man. It increases his power for good, but it also increases his ability to do evil."

"The power of destruction is always present and it is easier to pull down than to build up. Therefore, man's responsibility to use wisely any increase of power becomes more serious as his control over nature increases. Great power cannot be safely or wisely used unless intelligently directed. But that is not all, not only must such power be directed with intelligence, but it must be directed and used in complete harmony with the great fundamental principles of morality. Wherever so directed and used, scientific discoveries are a blessing, but if not so used, they become a curse, and instead of adding to human happiness, merely increase human misery."

"In the stress of war, men made great sacrifices and were roused to great enthusiasm and devotion and industry. The reaction which followed the military victory is natural. But the problems of peace are even more difficult to solve and make greater demands upon the spirit of self-sacrifice and call for the greatest courage and the highest ideals. The need for men of vision, sound education and high character to lead in the work of recovering from the shock of war is insistent and the problems awaiting solution are serious and impressive."

"It has been stated that a large percentage of the adult males in the United States have been found to have a brain development corresponding to boys of fourteen. If this is true, admitting the women are superior, then the balance of political power in our country will be determined by those who can most successfully appeal to such childish intellects. The imperative necessity for wise leadership by educated men of high character is clearly indicated."

"I think that we will agree that we cannot hope to reap the full benefits of the marvelous advances in science and industry or expect to realize the higher standards of living which all desire, unless we learn to co-operate."

"The very advance in science and its practical application has increased the complexity of our community life and of our dependence upon each other. Because of such complexity, civilization cannot continue, much less progress, unless means are found to settle industrial difficulties by the rule of reason instead of by brute force. The economic waste of industrial warfare is greater than that of international war."

"The problem will not solve itself. It cannot be solved by passion or sentiment, and hasty legislation does more harm than good."

"The relation between economic causes and their final effect upon society is not clear. It is complicated by the number of links in the chain and is obscured by the long time required for the economic effect of a given cause to be realized in our daily lives."

"It is difficult for the most competent to follow such complex relations and therefore to agree upon what facts are fundamentally important."

"And yet there must be substantial agreement upon facts before even a beginning of a solution can be reached. Nothing but careful, patient, scientific investigation by competent and wise men of all the facts and influences at work can clear the way for satisfactory progress and a just solution."

"In such work the trained college man, who was found by experience to be the best leader in the complicated conditions created by modern war, should find that his training helps him in solving the more complex problems of peace."

"It would seem clear that not only the habit of mind induced by the study of science and engineering will help in the proper solution of such problems, but that the educated man with a good training in the fundamental laws and facts of science is peculiarly qualified to appreciate and guide the delicate and complicated scientific mechanism upon the proper functioning of which our comfort and happiness—even our very existence—become from year to year more dependent. But something more than knowledge is needed. We must develop new ideals, and above all, the highest possible sense of social obligation."

"For knowledge, no matter how great, is far from being the same as wisdom."

"Wisdom is knowledge plus the capacity to use it properly. It cannot be taught. It is a God-given quality, but ethics is the best substitute and a part of wisdom, and ethics, fortunately, may be taught by precept and example."

"In order that we may live together and properly enjoy the added material and intellectual blessings, we must all give more thought to improving our relations with each other. After all, true happiness is based upon human character and we cannot make permanent progress unless we keep constantly in mind the vital fact that man is distinguished from the brute largely by qualities which can be best described as moral and spiritual. 'Am I my brother's keeper?' must receive our affirmative answer and the definition of 'my brother' must continue to expand until the Golden Rule becomes our practical rule of daily conduct."

Highway Lighting

By H. E. Butler

Illuminating Engineering Laboratory, General Electric Company

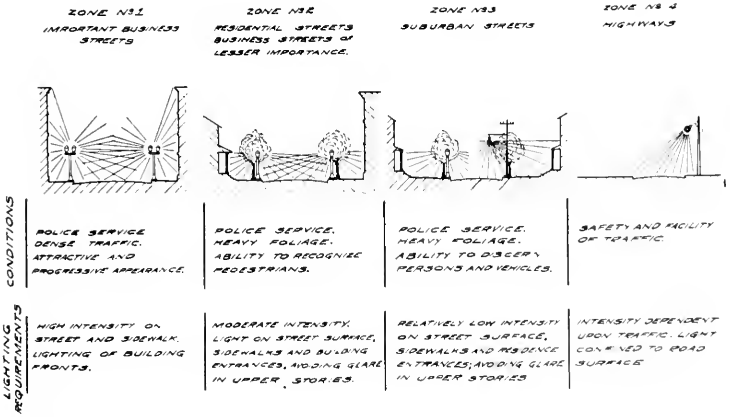
A great many years have passed since the discarding of the idea that the pedestrian who had occasion to travel the streets after dark should provide the light he needed. The manifold benefits of modern street lighting are too obvious to mention. Yet, the automobile of to-day is expected to furnish *all* the illumination it requires for night travel on our highways. While headlights will never be discarded from automobile equipment, it is equally true that the safety of travel on highways by night will never approach that by day until the character of the road illumination more closely resembles that of good street lighting. How to accomplish this, at an investment and maintenance cost sufficiently low to make highway lighting installations possible, presents a problem that has recently been solved by the development of the highway lighting unit described in the following article.—Editor.

The number and condition of the highways within a county, state, or country is a measure of its development. Even backward China is at last realizing the benefits which result from good roads well maintained. In the United States, millions of dollars are being spent annually on the construction of new highways and the repair of others.

In New York State alone there are about 9000 miles of highways on which have been expended $130,000,000. H. Elting Breed, Consulting Engineer, New York City, formerly first Deputy Commissioner of Highways, New York State, submitted the following statement to *The Engineering News Record* of September, 1919.

"The total expenditure of $130,000,000 that New York State has already expended is only a drop in the bucket of moneys that will be poured forth throughout the country upon highways in the next ten years. From its last bond issue plus the share to be contributed by towns and counties, New York State has still available for new roads $524,800,000; add to this $490,000,000 of appropriations or pending appropriations by various other states; $200,000,000 of Federal aid to be doubled by the states using it and further contributions by counties and towns, then the total is almost $1,000,000,000 for good roads."

While highways will always be in greater demand by day than by night, as are the railroads, the full return from the vast sums of money spent in roadbed and road surfaces will not be realized until night travel has been made safe. To bring about this condition untold endeavor has been made to develop a fully satisfactory automobile headlight, but the results obtained have not been commensurate with the effort expended. The obvious conclusion is that the real solution to the problem lies in illuminating the road surface



	ZONE Nº 1 IMPORTANT BUSINESS STREETS	ZONE Nº 2 RESIDENTIAL STREETS BUSINESS STREETS OF LESSER IMPORTANCE.	ZONE Nº 3 SUBURBAN STREETS	ZONE Nº 4 HIGHWAYS
CONDITIONS	POLICE SERVICE DENSE TRAFFIC. ATTRACTIVE AND PROGRESSIVE APPEARANCE.	POLICE SERVICE. HEAVY FOLIAGE. ABILITY TO RECOGNIZE PEDESTRIANS.	POLICE SERVICE. HEAVY FOLIAGE. ABILITY TO DISCERN PERSONS AND VEHICLES.	SAFETY AND FACILITY OF TRAFFIC.
LIGHTING REQUIREMENTS	HIGH INTENSITY ON STREET AND SIDEWALK. LIGHTING OF BUILDING FRONTS.	MODERATE INTENSITY. LIGHT ON STREET SURFACE, SIDEWALKS AND BUILDING ENTRANCES, AVOIDING GLARE IN UPPER STORIES.	RELATIVELY LOW INTENSITY ON STREET SURFACE, SIDEWALKS AND RESIDENCE ENTRANCES; AVOIDING GLARE IN UPPER STORIES	INTENSITY DEPENDENT UPON TRAFFIC. LIGHT CONFINED TO ROAD SURFACE

Fig. 1. Graphic Illustration of the Conditions and Lighting Requirements for Important Business Streets, Residential Streets, Suburban Streets and Highways

to a moderate intensity by stationary light sources that are to be considered as part of the highway equipment, thus relieving the automobile from the necessity of furnishing all the needed illumination which apparently it cannot do without producing an objectionable degree of glare.

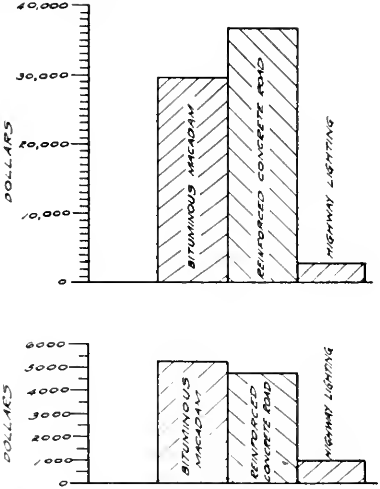


Fig. 2. Relative Investment and Maintenance Cost Per Mile of Highways and Lighting

Investment Cost of Lighting Equipment Based on 300-ft. Spacing. Novalux Highway Unit with 2500-Lumen (250-c-p.) Mazda C Series Lamps Suspended 30 ft. Above Roadway.
Maintenance Includes Interest at 6 Per Cent and Depreciation on the Investment. Depreciation of 10 Per Cent on Macadam, 5 Per Cent on Reinforced Concrete, and 20 Per Cent on Lighting Equipment. Highways 16 ft. Wide.

This method of lighting highways possesses the following advantages:

I Prevents accidents
(1) By showing up dangerous curves
(2) By reducing headlight glare
(3) By illuminating signs, sides of roads, and obstacles.

II Adds to comfort of night driving
(1) By relieving eye strain
(2) By assisting in making repairs
(3) By discouraging holdups.

III Increases night traffic and thereby relieves day congestion.

IV Decreases running time and increases road capacity.

V Helps to bring electricity to the farm by providing a pole line.

VI Increases real estate values
(1) By tending to extend the city along highways
(2) By bringing electrical conveniences.

Before discussing the several types of units applied to highway lighting, it may be well to refer to Fig. 1 which shows the distribution of light desirable for various classes of streets. It will be observed that the units recommended for business, residential, and suburban sections distribute the light symmetrically. If these units were used for highway lighting considerable light would be wasted as the type of unit most economically suitable for highway lighting should direct its light along the roadway as illustrated at the right-hand side of Fig. 1. This type of distribution is obtained from the Novalux highway unit.

Previous attempts to obtain satisfactory highway lighting met with little success until the development of the highway unit mentioned. A contributing cause of former failures has been the high investment and maintenance cost per mile due to the large number of units required. The Novalux unit brings down the cost of highway lighting to a relatively small item compared with the cost of building and maintaining the roads. The relative magnitude of these costs may be visualized from the chart in Fig. 2.

The radial wave reflector was the first type of lighting unit used for highways. This unit although efficient for certain classes of street lighting does not meet the requirements of trunk highways. It is particularly adapted for small lamps and correspondingly short spacing. The cost of such an installation is obviously too high to meet average conditions and therefore its sphere of usefulness is limited.

The next unit developed for the purpose contained refractor equipment. This combination delivers its maximum candle-power near the horizontal and may therefore be used with liberal spacings. The symmetrical distribution of its light, however, causes a large part to be ineffective because thrown outside the road confines. Unlike city and suburban streets, where it is desirable to illuminate bordering buildings and houses, light delivered outside the highway zones is practically lost.

The unit shown in Fig. 3 is the latest development and has made highway lighting practicable. This unit has the characteristics of light distribution required for the effective and efficient lighting of highways. It consists of a number of nested parabolic reflectors.

It will be seen that the light is reflected from six individual parabolic reflectors, three on each side, similar to those used for automobile headlights. The reflectors are cut off in such a manner as to make it possible for one lamp to be in the focus of the six reflectors. As shown in Fig. 4, this unit distributes the light along the road without the waste associated with units having symmetrical distributions.

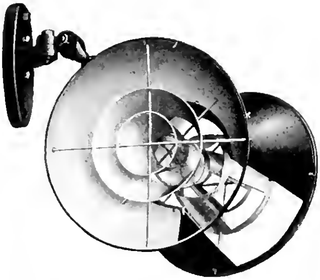


Fig. 3. Novalux Highway Lighting Unit, Showing the Nests of Parabolic Reflectors and the Flexible Method of Mounting the Unit

Several installations of these lighting units have been made at Colonie, N. Y.; Miami and Miami Beach, Fla.; Detroit, Mich.; Williamstown, Pa.; Amherst, N. Y.; Brigham, Utah; Spanish Fork, Utah; and Swampscott, Mass. Fig. 5 shows a day view of an installation and Figs. 6 and 7 show night views. These are good illustrations of adequate highway lighting. This was accomplished with 250-c-p. units spaced approximately 300 ft. apart and suspended 30 ft. above the roadway.

Fig. 5. Day View of Highway Lighting Installation, Miami Beach, Florida

Careful consideration should be given to the reflecting qualities of the pavements as they have a marked effect on the illumination of the highway. Dark colored surfaces require higher illumination than light colored surfaces in order to appear equally lighted. Therefore on highways having dark surfaces more lighting units per mile are required than on highways with higher reflecting surfaces. The present practice of spacing recommended by Illuminating Engineers is 300 ft. for the former and 400 ft. for the latter type of highways.

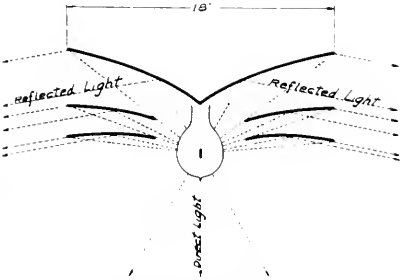


Fig. 4. Diagram Showing the Paths of the Reflected Light and Direct Light from Novalux Highway Lighting Unit

How well this unit is adapted to this class of lighting, as compared with other lighting units, is shown by the candle-power and illumination curves in Figs. 8 and 9. Fig. 8 shows the candle-power distribution and illumination obtained from the radial wave reflector compared with the Novalux highway unit; Fig. 9 compares the highway unit with the refractor equipment. All units are spaced 300 ft. apart, suspended 30 ft. from the roadway, and equipped with 2500-lumen (250-c-p.) lamps. It will be observed that the Novalux highway unit delivers several times the minimum illumination obtained from the other equipments and its distribution is much more uniform. If it is desired to compare these equipments on the basis of equal power, spacing, or height, attention is called to the illumination curves in Fig. 10. If it is found necessary to compare these units on the basis of prevailing methods of suspension, spacing, and size of lamps generally used with these equipments, refer to the illumination curves in Fig. 11. Illumination data comparisons usually are given in the form of curves which are practically self-explanatory and need no lengthy description in order to indicate their usefulness in solving highway lighting problems. The assumption upon which the calculations are based and the range of the calculated values were made to conform as nearly as possible with what was formerly considered good average practice. If other values are required, it will be possible to interpolate sufficiently close for all practical purposes. The illumination curves show initial values of illumination, and where necessary some allowance should be made for depreciation in service. The following are a few of the many questions that can readily be answered by referring to the data given in the various illumination curves:

Fig. 6. A Section of the Albany-Schenectady Highway Lighted by Novalux Highway Lighting Units Equipped With 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamps

What average intensity or illumination will result from a specified spacing?

Taking equal average illumination as a basis, what will be the spacing required for various units with their different equipments?

Taking equal minimum illumination as a basis, what will be the spacing required for various units with their different equipments?

From this and the wattage, what is the power consumption per linear foot?

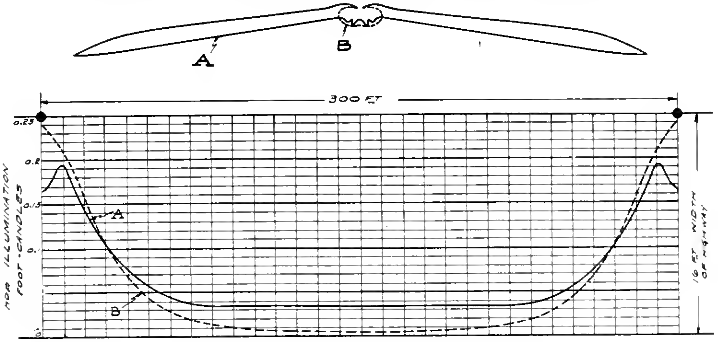
Taking equal uniformity of illumination as the basis, what will be the spacing required?

What will be the average and the minimum illumination, and the uniformity of illumination?

Fig. 12 shows the relative illumination value of the Novalux highway unit when suspended 30 and 35 ft. and for various spacings. By studying these curves it will be found that units suspended 30 ft. give the most satisfactory results and that the gain in uniformity from units suspended 35 ft. does not warrant the expense of a 35-ft. pole or a pole extension.

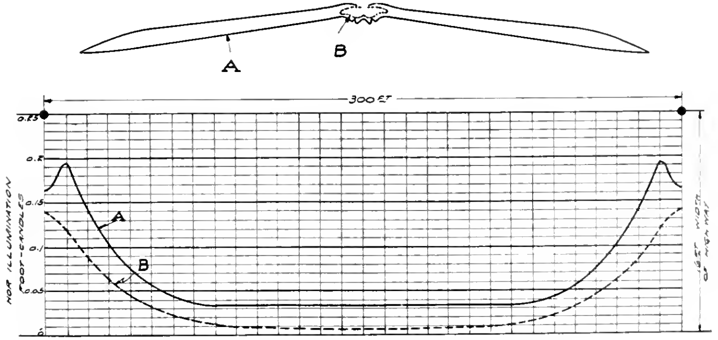
Fig. 7. Night View of Paradise Road, Swampscott, Mass., Illuminated by Novalux Highway Units Equipped with 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamps

Along some highways the poles on which the telegraph, telephone, or power circuits are installed are oftentimes found too short to suspend the highway unit 30 ft. This is the lowest suspension that can be used in order to obtain satisfactory illumination. Under such conditions the expense of installing longer poles is eliminated by using the pole extension shown in Fig. 13. This pole extension makes it possible to install the highway unit at the most effective height. When installing these units it is important to line up the reflector with the highway in order to obtain the best results: i.e., the reflector should be directed on the surface of the highway and not on the outside of the road.



A: Novalux Highway Unit, Parabolic Nest Reflector. Height of Unit 30 ft.
B: 20-in. Dome Radial-Wave Reflector, Street Hood (Steel Reflector). Height of Unit 30 Ft.

Fig. 8. Chart Showing the Relative Candle-power and Horizontal Illumination on a Road by the Novalux Highway Unit and the Radial-Wave Reflector, Both Equipped with 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamps. Illumination Calculated on Surface of Highway Along the Center Line



A: Novalux Highway Unit, Parabolic Nest Reflector. Height of Unit 30 Ft.
B: Novalux Pendent Unit, Dome Refractor, Clear Rippled Glass Globe. Height of Unit 30 Ft.

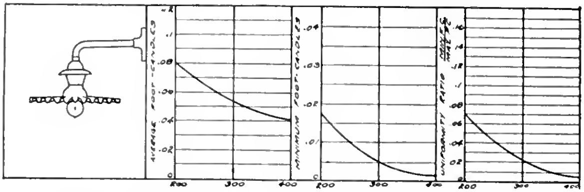
Fig. 9. Chart Showing the Relative Candle-power and Horizontal Illumination on a Road by the Novalux Highway Unit and the Dome Refractor and Clear Rippled Glass Highway Unit, Both Equipped with 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamps. Illumination Calculated on Surface of Highway Along the Center Line

To obtain such an adjustment a universal bracket, illustrated in Fig. 14, is provided with each highway unit. These pole extension and bracket devices make it possible to utilize small poles and yet at the same time adjust the unit so that the light will be directed along the roadway.

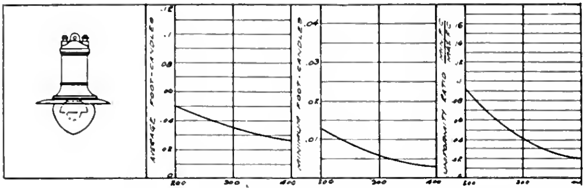
The simplicity, flexibility, and efficiency of the incandescent system of highway lighting is not confined to the lighting unit but extends to the transformer circuit and its auxiliaries where the apparatus is suited to meet all possible conditions for highway service.

Series Lighting Circuit

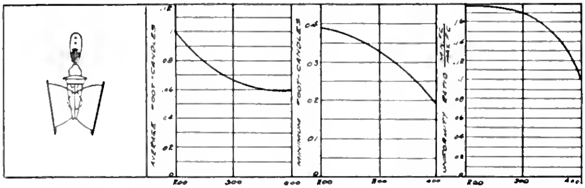
The problem of selecting the conductor size for this type of circuit is exceptional in that the current density can be neglected. This condition results from the fact that the mechanical stresses caused by suspension overhead or pulling into conduit underground are so great that a wire, large enough 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.



A: 20-in. Radial-Wave Reflector, Dome Type; Street Hood, Steel Reflector. Height of Unit 30 Ft.



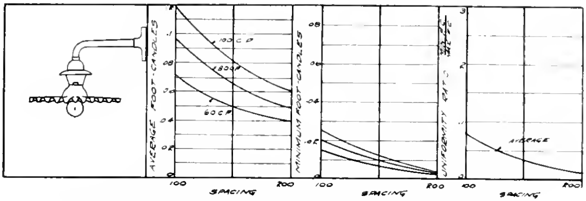
B: Novalux Pendent Unit, Dome Refractor, Clear Rippled Glass Globe. Height of Unit 30 Ft.



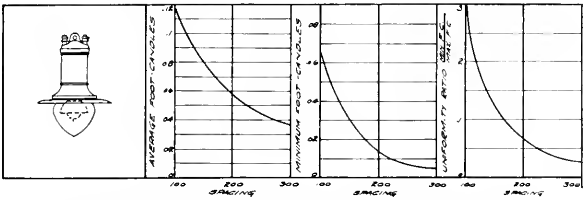
C: Novalux Highway Unit, Parabolic Nest Reflector. Height of Unit 30 Ft.

Fig. 10. Comparison of Other Types of Units with the Novalux Highway Unit on the Basis of Equal Power, Spacing, Height, and Size of Lamp (2500-Lumen [250-c-p.] 6.6-amp. Mazda C Series). Illumination Calculated on Surface of Highway Along the Center Line

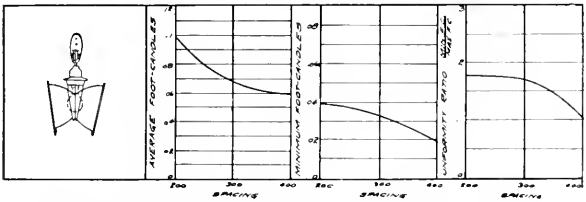
Following the introduction of the series system, constant-current transformers ranging in current rating from 1.75 to 10 amp. secondary have been installed. This wide range, however, necessitated carrying in stock such a variety of lamps, transformers, and accessories as to limit the commercial efficiency 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 5.5 amp., but the number of either of these is considerably exceeded by the 6.6-amp. circuits, and the tendency is to standardize the latter rating. Fig. 15 gives 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 enable one to determine the advantage of one size of conductor over the other, but the prevailing cost of copper should be taken into consideration; i.e., whether the interest and depreciation on the additional investment 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 as these two sizes of cable are used in underground work.



A: 20-in. Radial-Wave Reflector, Dome Type, Street Hood, Steel Reflector with 600-, 800-, 1000-Lumen (60-, 80-, 100-c-p.) 6.6-amp. Mazda C Series Lamp. Height of Unit 15 Ft.



B: Novalux Pendent Unit, Dome Refractor, Clear Rippled Glass Globe with 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamp. Height of Unit 25 Ft.

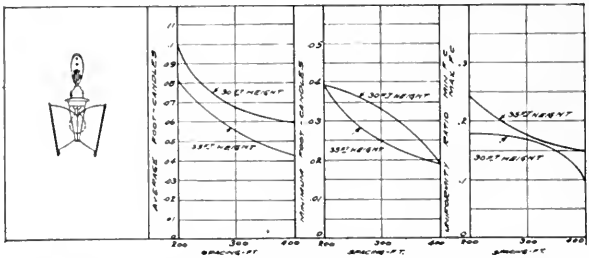


C: Novalux Highway Unit, Parabolic Nest Reflector with 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamp. Height of Unit 30 Ft.

Fig. 11. Comparison of Other Types of Units with the Novalux Highway Unit on the Basis of Present Practice. Illumination Calculated on Surface of Highway Along the Center Line

Since the introduction of highway lighting, it has been found that the underground system of distribution is practicable. With this in mind, data giving the relative losses due to inductance and I^2R losses will be found in Fig. 16 which shows these 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 loss of No. 6 copper is practically in proportion to its I^2R losses while that of No. 8 copper is about $^2/_3$ of its I^2R losses. This is true when the current does not exceed 20 amp. which is the case with these circuits.

Fig. 17 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 circuit 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.



Highway Unit, Parabolic Nest Reflector with 2500-Lumen (250-c-p.) 6.6-amp. Mazda C Series Lamp

Fig. 12. Chart Illustrating the Relative Illumination from the Novalux Highway Unit Suspended 30 and 35 ft. above the Highway. Illumination Calculated on Surface of Highway Along the Center Line

Types of Constant-current Transformers and Auxiliaries Suitable for Highway Service

There are two types of constant-current transformers suitable for highway lighting: the station or substation type and the pole type. The former, shown in Fig. 18, is designed for localities economically close to the station or substation. This type consists of air-cooled transformers, available in sizes from 3 to 80 kw. standard for 2300 volts, 60 cycles primary, 6.6 amp. secondary and for one or two circuits. They can, however, be designed for any circuit. Such equipment embodies the following features:

(1) Constant current within one per cent of normal from full load to short circuit, regardless of fluctuations in primary voltage, lamp failures, grounds, or short circuits.
(2) Automatic regulation; no change in taps for variations in load; no adjustments necessary.
(3) Instantaneous regulation; balancing mechanism supported on ball bearings.
(4) Maximum insulation between all parts.
(5) High efficiency and power-factor.
(6) Ventilated, air-cooled, impregnated windings.

The pole-type constant-current transformer is designed for places not economically close to a station; and consequently this type is well suited for most highway installations. Fig. 19

Fig. 13. Application of the Pole Extension for Highway Lighting

illustrates the application of this type of transformer which adds another important link to the chain of constant-current transforming devices. Since its introduction it has aided in making highway lighting economically possible, and there is a wide field and a great demand for this service.

Series street lighting systems require constant current, and constant-current transformers have always required a substation with control panels and an attendant; therefore, it has been difficult to provide street lighting for smaller towns and villages where the revenue derived would not be sufficient to warrant the installation of a substation and attendant.

Large cities also have experienced difficulty in solving the demand for higher intensities and more units in their suburbs. The growth of these outlying districts has been so rapid that it has been almost impossible to keep pace. When it becomes impracticable to run circuits from the control station because of the distance and the copper required, it is not always advisable to erect a substation; but if it is, the growth is usually so rapid that there is an interval before the substation can be erected when the lighting service is likely to be inefficient or ineffectual.

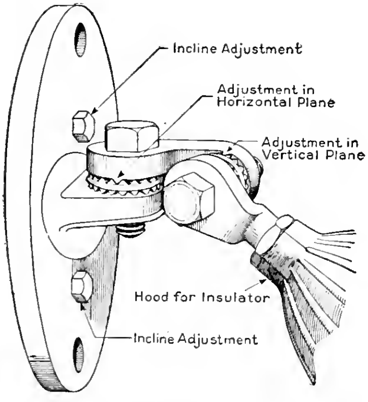


Fig. 14. Sketch of the Universal Adjustable Bracket for Novalux Highway Units

The type of transformer shown in Fig. 19 has been designed for such service. It is entirely automatic and positive in action. It does not require a substation or an attendant, and it can be controlled by an oil time-switch. These features are combined with as close current regulation through as wide a range as offered by the best station type constant-current transformer. The current from full load to no load is maintained within one per cent of normal. This feature alone practically guarantees the life of the Mazda lamps operating on a circuit controlled by such a transformer. The efficiency is the same as for the station type transformer and the power-factor is 20 per cent higher than for any previous design of pole-type regulating transformer.

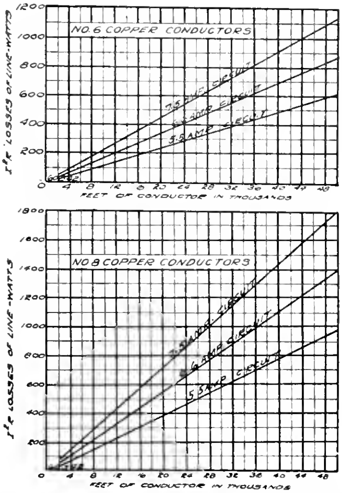


Fig. 15. Line Loss of No. 6 and No. 8 Conductor for 5.5-, 6.6-, and 7.5-amp. Circuits of Various Lengths

For the operation of Novalux highway lighting units with Mazda C lamps this transformer is ideal. The high internal reactance serves to protect the lamps at starting and acts instantaneously to check surges on the line which would tend to shorten the life of the lamps. The moving secondary coil with its high repulsion gives almost perfect regulation from full load to dead short circuit. It protects the lamps not only from changes in current due to changes in secondary load, but also from fluctuations in primary voltage.

The construction of this transformer contains no untried features, but simply combines various features incorporated in several different types of transformers which have been in production for a long time. The core is of the standard three-legged construction with coils surrounding the center leg. The primary coil is fixed at the bottom of the core, and above is the floating secondary coil. The balancing mechanism, however, has been modified so that an exact line-up of the coils is not necessary for satisfactory regulation.

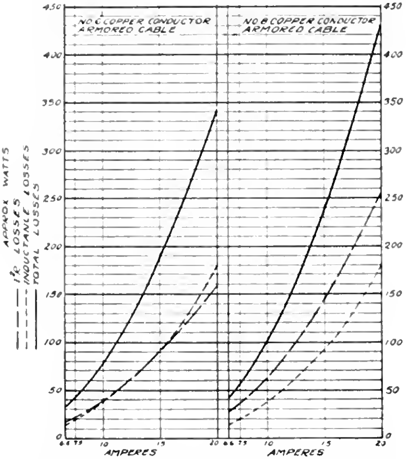


Fig. 16. The Relative I·R and Inductance Losses in the Line for No. 6 and No. 8 Copper Conductor, Based on 1000 ft. Single-conductor Cable, $\frac{5}{32}$-in. Overall, Insulation of Lead and Steel Grounded Armor

In order to give protection to the lamps at starting, the minimum reactance of the transformer is made fairly high. This results in a motion of the coil of only a few inches, while at the same time the repulsion of the coils is high, thus giving excellent regulation. This transformer may be tipped 10 deg. from the vertical in any direction without affecting the regulation. This is much more than the transformer would be called upon to stand in actual service. The coils are liberally designed so that their temperatures come within A. I. E. E. requirements. A single adjusting lever permits adjustment of the secondary current to the desired value. The final current adjustment is made in the factory and no further change in adjustment should be necessary.

After being installed this transformer requires no more attention than one of the constant-potential type. It is used in sizes from 1 to 20 kw., 6.6 amp. secondary, and for any commercial frequency.

The lamp capacity of the station and of the pole-type constant-current series transformers for different sizes is shown in Table I. This table also shows the lumen and wattage rating of the various sizes of lamps used for this class of lighting.

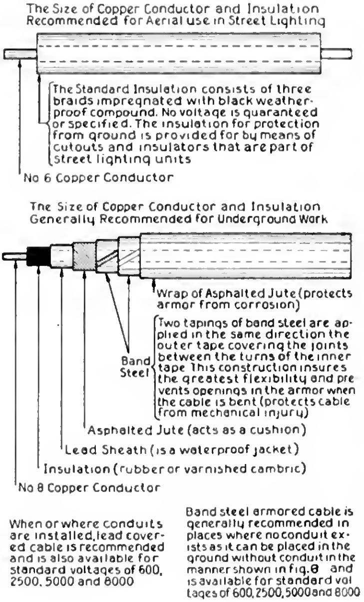


Fig. 17. Standard Insulations for No. 6 Aerial and No. 8 Underground Alternating-current Series Street Lighting Cables

Auxiliary Series Transformers

The two types of series transformers suitable for highway constant-current series circuits are illustrated in Figs. 20 and 21: the former may be used for a floodlighting unit; the latter for a group of lamps where it is necessary to eliminate high voltage or where a small number of lamps are required and a multiple circuit is not available. The secondary windings of these transformers are highly insulated from the primary; this prevents the possibility of the operator coming in contact with the main circuit when he is focusing the light on billboards or signs along the highways, or when making other adjustments on the floodlighting unit. The group lighting transformers are available in various sizes and for any rating of current or frequency, and have a 1:1 ratio of primary to secondary current. The floodlighting unit transformers have 110- to 125-volt secondaries and are available for any standard constant-current secondary series circuit.

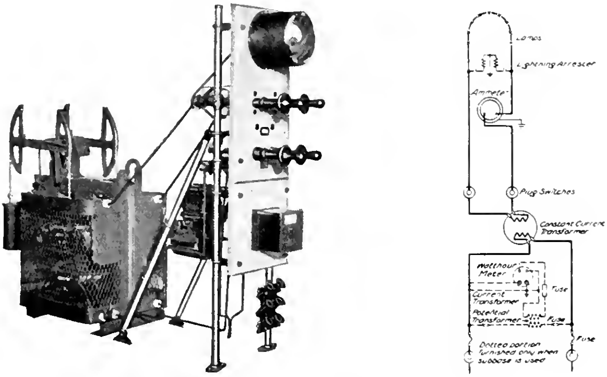


Fig. 18. Station Type Constant-current Transformer Equipment and Its Application

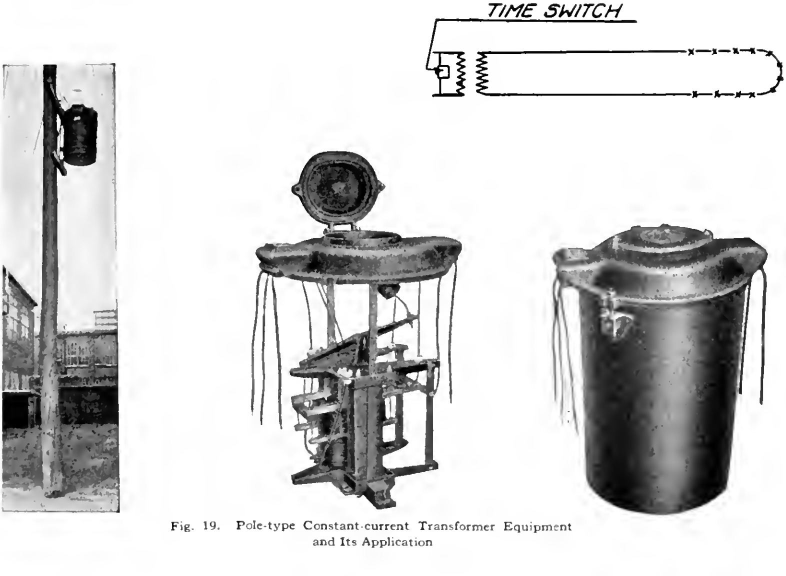


Fig. 19. Pole-type Constant-current Transformer Equipment and Its Application

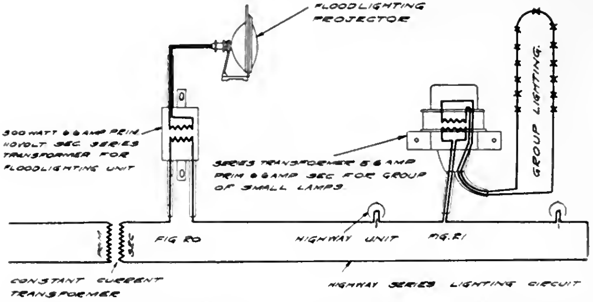


Fig. 20. (At the Left) Application of the Single-lamp Transformer on Highway Series Circuits for Floodlighting Units

Fig. 21. (At the Right) Application of the Group Lighting Series Transformer on Highway Series Circuits for Bridge Lighting or Places Where High Voltage is Prohibited

TABLE I

LAMP CAPACITY FOR POLE TYPE AND STATION TYPE CONSTANT-CURRENT TRANSFORMERS, 60 CYCLES, 6.6-AMPERE SECONDARY

Lumen rating	600	800	1000	2500
Nominal c-p.	60	80	100	250
Line amperes	6.6	6.6	6.6	6.6
Lamp amperes	6.6	6.6	6.6	6.6
Lamp wattage	45.5	56	66.2	153

STRAIGHT SERIES LAMPS

Transformer				
* 1	20	16	14	
* 2	41	33	29	12
3	62	50	43	18
5	104	84	71	31
* 7.5	156	127	108	46
10	208	169	143	62
15	313	254	215	93
20	417	340	287	124
†25	521	423	358	154
†30	626	509	430	186
†40	835	679	574	248
†50	1041	849	717	310
†60	1250	1018	861	372
†70	1460	1187	1001	435
†80	1670	1357	1146	496

* Not available in Station Type.
† Not available in Pole Type.
5 per cent line loss and 95 per cent efficiency for transformer considered.

Duplex Radio Telephone Transmitter

WITH SPECIAL REFERENCE TO TESTS ON THE S. S. *AMERICA*

By W. R. G. Baker and I. F. Byrnes
Radio Engineering Department, General Electric Company

Within a comparatively few years radio developments have progressed from the more or less erratic transmission of signals to regular commercial telegraphy, to one-way telephony, to simplex telephony, to duplex telephony. The authors of the following article point out that while simplex radio telephony is serviceable when messages are transmitted by radio operators, the necessity of continually manipulating the equipment for alternate sending and receiving makes the system unsuitable to the general public for the purpose of carrying on a conversation. The initial incentive for the development of a satisfactory duplex system lay in the desire of steamship passengers to converse by telephone with persons on land. The following article describes tests which were recently conducted for this purpose. Their successful results are highly gratifying to the participants; the Radio Corporation of America, the American Telephone and Telegraph Co., the Western Electric Co., and the General Electric Company.—Editor.

During the early development of wire telephony, the device now known as a telephone receiver was also used as a transmitter. Hence it was necessary for the telephone user to place the instrument to his ear to listen and then hold it to his lips to talk. This arrangement was quite similar to the familiar speaking-tube method of communication. If the present wire telephone system required the user to perform some operation to change from the talking condition to the receiving condition, it would be termed simplex telephony, the same as the two preceding methods.

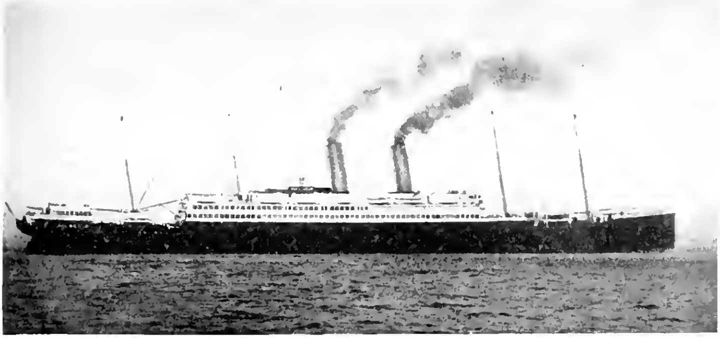


Fig. 1. The S. S. *America* of the United States Lines

Radio telephony has passed through a period of development quite similar to that of wire telephony. The majority of radio telephone equipments require the user to operate a push button to change from the transmit to the receive condition. So long as only radio operators, or persons more or less familiar with radio equipment, operate the apparatus, this switching feature is not so objectionable. However, it would not be reasonable to expect the general public always to operate the switch at the proper time.

True, duplex radio telephony permits the operator to send and receive simultaneously as with the ordinary telephone. Interchange of thought is far more rapid between the two participants if one conversant can at any moment interrupt the other. Otherwise a conversation may lose coherence and the transmission of a long message may often entail irksome repetition.

Evidently the greatest need for duplex radio telephony is in those installations where the equipment is used by the general public. This condition arises in providing communication between ships and shore stations.

Ship to shore telephone communication, in order to render the maximum amount of service, must be capable of being linked up with the regular wire telephone system. With such an arrangement a passenger on board a ship may converse with parties on shore so long as the latter have access to a telephone. Thus a business man located anywhere in the United States might use his ordinary desk telephone to converse with one of his associates who may be on an ocean liner several hundred miles at sea.

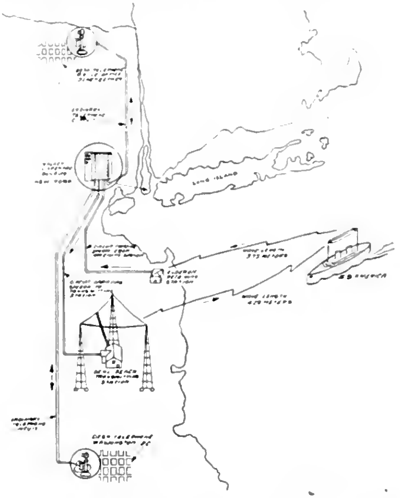


Fig. 2. Schematic Diagram Illustrating the Connections Used in the Tests for Duplex Radio Telephony between Ship and Shore Lines

During the months of February and March a number of tests were made on the S. S. *America* (Fig. 1) with General Electric Duplex Radio Telephone equipment. The *America* is operated by the United States Lines and sails from New York to Plymouth, Cherbourg, and Bremen. The results of the tests are indicative of the future possibilities of radio telephony.

At the present writing two transatlantic trips have been made with the equipment on the *America*. Transmission was carried on under the ship's call letters K D O W. The shore station, where the radio and land lines were linked together, is located at Deal Beach, N. J. The call letters are 2 X J. This station is operated by the Western Electric Company and is connected by a toll line to a telephone switchboard in New York City. By means of this arrangement communication could be carried on from the ship to any point reached by the regular wire telephone system.

The input to the antenna on the *America* was approximately 750 watts. The Deal Beach station uses an antenna input of about 1500 watts. Duplex telephony was carried on over a maximum distance of 1600 miles. This was night range under good atmospheric conditions. During the daytime reliable conversations were held at distances between 400 and 500 miles.

When it is desired to place a call for a party on shore, the standard practice used for a toll call in wire telephony is followed. A regular desk telephone was installed in Capt. Rind's quarters on the *America*. When he desired to talk to some one on shore he called the ship's radio operator by pressing a push button mounted on his desk. The operator answered and after ascertaining the telephone number, or the name of the party desired on shore, established communication with Deal Beach. The operator at Deal Beach transferred the call to the New York toll line, thus completing the circuit between the *America* and the switchboard operator at New York so that both operators could exchange information regarding the call. When New York had the party at that end, the ship's operator called Capt. Rind and he con-

Fig. 3. Installation of Duplex Radio Apparatus on Board the S. S. *America*

versed from his extension in the same manner as over any telephone system. Fig. 2.

The equipment is of course not limited to a single extension on board the ship as an extension may be installed in every stateroom if desired.

A general layout of the installation on the *America* is shown in Figs. 3 and 4. The transmitting apparatus comprised five main units, namely: motor-generator, kenotron panel, radio panel, operator's control panel, and the extension station. For reception a highly selective receiver was used in conjunction with an anti-resonant circuit. Before describing these units in detail the general operating characteristics of the equipment will be explained.

Fig. 4. Another View of the Installation on Board the S. S. *America*

Under ordinary conditions a radio receiver is rendered inoperative if a radio transmitter is in use on, or near, the antenna to which the receiver is connected. This is due to the fact that the current in the transmitting antenna is thousands of times greater than the currents detected by the radio receiver. This difficulty has been met in transatlantic telegraphy by locating the transmitting and receiving stations a number of miles apart and employing directive antennas, balancing devices, etc., to eliminate the transmitted signals from the receiving apparatus. Such methods obviously cannot be applied on shipboard, especially when it is desirable to use the same antenna for both transmitting and receiving. In general, the methods of duplexing can be divided into two classes: those in which the receiver is protected by

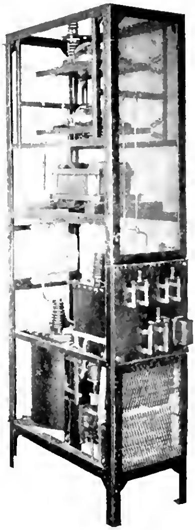


Fig. 5. Kenotron and Power Control Unit Used in the Duplex Radio Telephone Tests

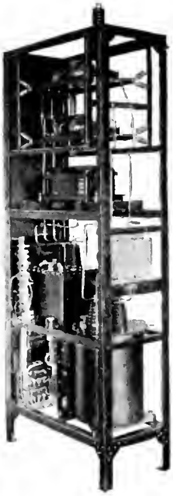


Fig. 6. Another View of the Kenotron and Power Control Unit

directive balancing or difference in wavelength, and those whose operation is based on permitting the transmitter to radiate only during those moments of actual speech.

The method of duplexing employed on the *America* might be classified in the first group. In this particular installation the radio transmitter was adjusted for transmission on a frequency of 800,000 cycles (375 meters). Modulation, or speech control, of the transmitter output took place either at the operator's control unit or at the extension station. While conversations were being carried on, the transmitter oscillated continuously into the antenna system.

In considering the equipment on the *America*, attention will first be given to the power supply. The duplex transmitter requires a direct-current supply at 10,000 volts for the plate circuit of the tubes. This supply is obtained by means of the full-wave single-phase 500-cycle kenotron rectifier unit illustrated in Figs. 5 and 6. The plate and filament energy for the kenotrons is obtained from a 500-cycle generator operating on the 125-volt direct-current ship mains.

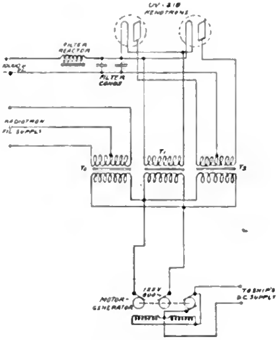


Fig. 7. Circuit Diagram of Kenotron Panel

The kenotron panel has mounted within it the necessary units for the control and rectification of the 500-cycle generator output. The plate transformer, automatic motor starter, and radiotron filament transformer are located in the base of this unit. Above these are mounted the kenotron filament transformer, filter condensers, and a filter reactor. Two kenotrons (UV-218) are provided with a spring suspension and

Fig. 8. Radio Panel Used in the Duplex Radio Telephone Tests

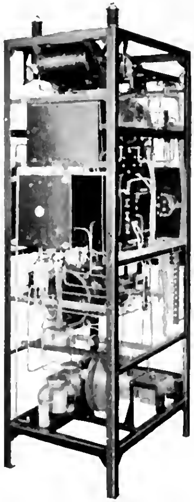


Fig. 9. Another View of the Radio Panel

are mounted, one above the other, near the top of the panel.

A schematic circuit diagram of the kenotron panel is shown in Fig. 7. The motor-generator is started by a push button in the operator's control unit. The transformers T_1, T_2 and T_3 have their primaries connected to the 120-volt 500-cycle supply. The kenotron (UV-218) filaments are heated by transformer T_1 at a potential of 11 volts. In like manner, transformer T_2 delivers a secondary voltage of 11 volts for the radiotron tube filaments mounted in the radio unit. The plate transformer T_3 delivers a secondary voltage of approximately 25,000 between outside terminals. It will be observed that these terminals connect to the plates of the kenotrons (UV-218). This results in full-wave rectification of the transformer output, producing a pulsating direct current which is smoothed out by the filter condensers and filter reactor. Three rheostats are mounted externally to the kenotron panel and control the motor speed, alternator voltage, and filament voltage. An external filament voltmeter is provided and is the only meter that requires supervision on the part of the radio operator.

Figs. 8 and 9 give a general idea of the construction of the radio panel. This panel provides for the generation and speech control of high-frequency energy over a frequency band from 1,000,000 to 375,000 cycles. This corresponds to a wave-length range from 300 to 800 meters. A six-position wave-change switch is mounted on the front of the panel. A signal switch is also mounted on the front of the panel to the left of the wave changer, so that telephony and continuous wave or interrupted continuous wave telegraphy may be used if desired. The anti-resonant circuit is tuned by the small knob on the lower section of the panel. The motor-driven chopper gives a 1000-cycle note when interrupted continuous wave telegraphy is being used. Two radiotrons (UV-206) are mounted near the top of the panel. One of these tubes operates as an oscillator and the other as a modulator. A radiotron (UV-203) is also used as a speech amplifier. The current flowing in the antenna system is indicated by the radiation ammeter mounted in the center of the panel.

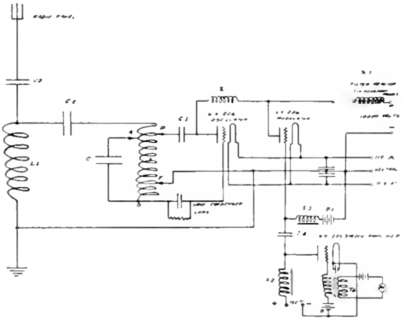


Fig. 10. Circuit Diagram of the Radio Panel

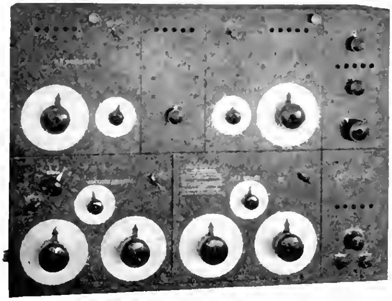


Fig. 11. Duplex Radio Telephone Receiver Used in the Tests

The fundamental circuit arrangement of the radio panel is shown in Fig. 10. The oscillator tube draws its plate supply through a radio choke coil X. A shunt circuit for coupling the plate radio frequency to the antenna circuit consists of the condenser C_1 and the turns in use on the inductance L between points P and F. The radio choke is used in order to prevent the plate radio frequency from flowing back into the 10,000-volt direct-current supply. Excitation for the oscillator grid circuit is furnished by the voltage built up between turns F and G. The frequency of the oscillations is determined by the condenser C and the inductance between turns A and G. This oscillating circuit is loosely coupled to the antenna circuit through the condenser C_2. Sufficient turns are used on the loading inductance L_1 to bring the antenna circuit into resonance with the intermediate circuit. One of the major requirements of this system of duplex transmission is that the frequency of the radio output of the transmitter shall not change, due to the swaying of the antenna. This is accomplished by using such a low value of capacitance in the coupling condenser C_2 that variations in antenna constants cause only a detuning effect and do not greatly react on the frequency setting circuit L C.

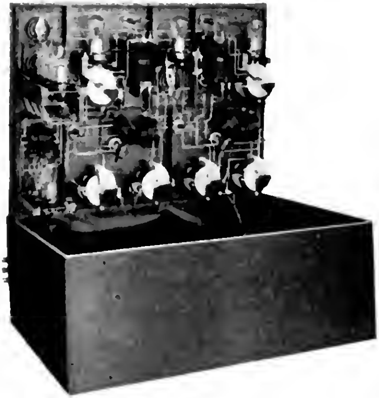


Fig. 12. Another View of the Duplex Radio Telephone Receiver

The method of modulating the high-frequency output of the transmitter, in accordance with the voice vibrations, is accomplished by means of the "constant-current" system. It will be observed in Fig. 10 that the plate of the modulator tube is connected to the transmitter side of the filter reactor. Upon speaking into the microphone M, variations take place in the primary current of the transformer T_4. This transformer has a step-up ratio and therefore increased variations are applied between the grid and filament of the speech-amplifier tube. A biasing battery B is used in the grid circuit of this tube in order to provide a linear operating characteristic. The plate circuit of the speech amplifier tube contains a reactor X_2. Due to the audio-frequency changes in grid voltage, amplified variations are built up across X_2 and are transferred to the grid circuit of the modulator tube through the condenser C_4. The grid of the modulator tube is biased by means of a battery B_1 and is also provided with a choke X_3 to prevent the input to the grid from flowing to the filament through the battery instead of through the tube. The plate current now flowing into the modulator tube must pass through the main reactor X_1 and in doing so it builds up an electromotive-force around this reactor of the same wave form as that originating in the microphone circuit. This potential is applied directly to the plate of the oscillator tube. Since the current in the antenna circuit varies almost directly with the oscillator plate potential, it is evident that the antenna output will be modulated in accordance with the voice vibrations applied to the microphone.

The radio receiver is shown in Figs. 11 and 12. All of the units are mounted on the rear of a metal panel and are available for inspection by swinging this panel outward. The cabinet is built with seven shielded compartments so that when closed the various circuits are shielded one from another. A total of eight radiotrons (UV-201) are used.

Filament supply for the radiotrons is furnished by a 6-volt 120-ampere-hour storage battery. Three 22-volt dry batteries are used for plate potential. In order to minimize the effects of vibration that are often encountered on shipboard, the tube sockets are cushioned with felt. The variable condensers are also provided with counterweights for the same reason. The antenna circuit is tuned by means of a variable condenser and a tapped inductor. Provision is made for accurate variation of coupling between the antenna and secondary circuits. All tuning in the latter circuit is accomplished with a variable condenser. Three filament rheostats controlled from the front of the panel are used to adjust the detector and amplifier tubes. A small wave-change switch is used to control the range of the radio-frequency amplifiers. One position of this switch gives a wavelength range from 250 to 500 meters, while the second position gives a range from 500 to 4000 meters. Two variable condensers are utilized for tuning the primary and secondary of the intermediate-frequency circuit. Variable coupling is also provided in this circuit. The output of the receiver connects to two telephone plugs mounted in the lower right-hand section of the panel. This arrangement enables the audio-frequency amplifier to be connected or disconnected when desired.

The log of the tests made from ship to shore indicates that approximately 125 people talked over the system. The majority of these people had never before used a radio phone but no difficulty was experienced in carrying on conversation as easily as over a land phone. The longest land line connection was made from New York to Washington, D. C. On this occasion Captain Rind, while 200 miles at sea, conversed with Chairman Lasker of the Shipping Board. Mr. Lasker used the regular desk phone in his office. When the *America* was 2586 miles out from New York a call was received from the S. S. *Westland* asking doctor's advice for a sick man. The telephone was turned over to the doctor who advised treatment for the patient. An idea may be gained of the extreme sensitivity of the receiving equipment on the *America* from the fact that two amateur stations were heard when the *America* was 2000 miles out. When 1100 miles out the 8:30 p.m. concert of WGY Schenectady Broadcasting Station was received very loud and clear. One afternoon the telephone bell rang in an office of the Radio Department of the Schenectady Works of the General Electric Company and the telephone operator announced a call from the *America*, then approximately 300 miles out from New York. Several men in the office carried on conversation with the men on board. The newspaper men also profited by the duplex transmitter on the *America* when a reporter from the New York *Tribune*, while still 400 miles out, talked to other reporters in New York and gave them his press notices direct. When 400 miles from New York the engineers on board the *America* talked to Mr. Carty, Chief Engineer of the American Telegraph and Telephone Company, who was located in the Board of Trade building, at Harrisburg, Pa. A large audience was assembled in the Board of Trade building and loud speakers were used so that everyone present could hear both sides of the conversation. At the end of this demonstration the applause of the Harrisburg audience could be very plainly heard by those on the *America*.

Among the prominent men who talked from their offices in New York to men on the *America* were:

Capt. Yungen, Manager of the Southern Pacific
Mr. Reeves, Vice-President of the Red "D" Line
Mr. Wm. Gibbs, Chief of Construction of the Mercantile Marine
Mr. Brennen, Chief of Electrical Division, N. Y. Police Dept.
Mr. Alexanderson, Chief Engineer of the Radio Corp.
Mr. Batchellor, Radio Inspector of New York
Mr. Bates, Vice-President of the Grace Line
Mr. Rossbottom, of the United States Steamship Lines
Mr. Munson, of the Munson Steamship Lines
Mr. Sheedy, London representative of the United States Lines
Mr. Smith, of the United States Lines.

A considerable amount of radio traffic is handled by the operators on large transatlantic liners. This may eventually require simultaneous telegraphy and telephony and tests are now being made on the *America* with this object in view. It is therefore not improbable that in the future a passenger may be telephoning from a liner while at the same time the radio operator will be transmitting radiograms with the telegraph equipment.

The Electric Range

By F. H. McCormick

Edison Electric Appliance Company, Inc.

The electric range has been brought to a high state of development; a low cooking rate is available in fully half of our electrified communities; experience shows it to be popular with the user. These facts justify enthusiastic and aggressive endeavor on the part of the salesman to demonstrate the superiority of this modern type of cooking apparatus. Until the number of electric ranges in use becomes sufficient to assure knowledge of their practicability passing from neighbor to neighbor, the central station must intensively encourage their installation in order to build up this attractive revenue load. The following article clearly outlines the advantages of the electric range to the cook and to the power supply company, and describes the range which is manually controlled only, the range which is automatic with respect to temperature control and that which is super-automatic with respect to both time and temperature control. An article of an allied nature appeared in our March, 1922, issue under the title: "Heavy Duty Electrically Heated Apparatus for Hotels, Restaurants, Bakeries, Etc."—Editor.

The extensive use of electrical energy as a source of heat for domestic cooking operations is a development of the last ten years. In spite of the apparent simplicity of using electricity to develop heat, its widespread use has trailed far behind the incandescent lamp and the industrial motor. This slow development may be accounted for by the fact that prior to 1912 such domestic heating appliances as were available were slow, rather inefficient, and comparatively short-lived, principally because a satisfactory resistance material was not yet in use. Furthermore, central stations have only recently found it profitable to furnish electrical energy at a cost sufficiently low to enable it to compete successfully with other fuels.

The present broad-spread use of electrical heat in the modern home demonstrates that these retarding influences have been eliminated. The electric flatiron is universally used; the grill, percolator, curling iron, waffle iron, and toaster are finding wider and wider favor. No modern home is complete without plenty of "convenience outlets" to facilitate the use of these appliances.

Quite in keeping with the growing appreciation of the advantage of electrical heat, via the lamp socket, we find a similar growth in the use of heavier electrically heated apparatus, such as ranges, water heaters, air heaters, bread baking ovens, and hotel kitchen cooking equipment. Those who are interested in the trends of the electrical industry should particularly watch the development of the electric range for the indications are that the coming decade will see as great an expansion in the use of electrical heat as did the last decade in the application of the industrial motor. At least the way is clear, now that the pioneering has been done.

To establish electrical energy successfully as an economical source of heat for domestic cooking, a rate of not more than five cents per kilowatt-hour has been found to be advisable. The larger central stations which have thousands of ranges connected to their lines usually have a rate which averages slightly more than three cents per kilowatt-hour.

The Society for Electrical Development is authority for the statement that a cooking rate is now offered in 6500 out of a total of 13,733 communities having electric service available in 1921. This society has also recently published data collected from 100 representative central stations that have encouraged the connection of ranges to their lines. These companies report 52,476 ranges in use having an aggregate connected load of 259,189 kilowatts. An inspection of these data shows that, contrary to the general opinion, the extensive use of ranges is not confined to the West and Canada where comparatively cheap hydro-electric power is available. Typical central stations, each with more than 2000 ranges connected, are found in as widely scattered states as Texas and Massachusetts, Minnesota and Missouri, Utah and Wisconsin, Idaho and Ohio. It may be safely estimated that there are 100,000 ranges in use in the United States.

The electric range has passed the experimental stage. In many thousands of homes in this country the food is being regularly prepared better and easier than ever before because of this new servant in the kitchen. The electric range is making headway not because it is simply "another cookstove" and new, hence interesting, but rather by the demonstration of results which with other fuels are impossible, or obtained only with the greatest skill and manipulation.

It is proposed to discuss the electric range: first, from the viewpoint of the housekeeper who is interested in it as a superior means of accomplishing a desired result, quite aside from the source of the heat; and, second, that of the central station management which views it solely as a present or prospective load on its distribution lines, with accompanying profit.

THE MODERN HOUSEKEEPER AND THE ELECTRIC RANGE

At the present time a remarkable growth in the use of labor-saving appliances in the modern home is taking place. The home without a washing machine, electric iron, and vacuum cleaner is the exception rather than the rule, while percolators, toasters, ironing machines, and electrically driven sewing machines are being sold at an ever increasing rate. To quite an extent this development is due to the high wages demanded by servants and the unsatisfactory service given. This is resulting in smaller homes completely maintained by the housewife with the aid of these electrical labor-savers. The electric range possesses greater possibilities in labor-saving for the progressive housewife than any of the other appliances, inasmuch as cooking is an every-day three-times-a-day operation, as compared to ironing for instance or cleaning which is usually done but once a week.

As to labor-saving—the cleanliness of the electric range eliminates scouring pots and kettles and cleaning soot covered walls, for when electricity is used to produce heat there are no fumes, no gases, no smoke, consequently walls are unaffected, and when the cooking utensil is lifted directly from the hotplate, the bottom is spotless.

The ease and accuracy with which the temperature in an electric oven can be controlled is a big point in its favor. Domestic science specialists have many times pointed out the importance of accurate, uniform temperatures in producing dependable high-grade results. The usual statement in a cook book, "Bake in a moderate oven until brown," is being replaced by the more accurate statement, "Bake at 375 deg. F. for 40 minutes." A short experience with the electric oven gives the operator the pleasant satisfaction of being able to prepare the food, set the oven switches as required, place the food in the oven, leave it the required length of time without once opening the door to see if it "looks right," and when ready open the door with the assurance of finding a perfect dish.

Fig. 1. Open Coil Hotplate. Capacity 1000 Watts

Fig. 2. Parts of Hotplate shown in Fig. 1

The heating elements in the oven are placed inside the lining and are arranged to give any desired heat distribution. As no ventilation is required to carry off the waste products of the fuel the oven walls can be very effectively insulated to conserve the heat, and with a properly regulated vent the air in the oven can be maintained with just the right amount of moisture to accomplish the desired result. For instance, in roasting beef it is desirable first to sear the surface to seal the juices and then maintain a lower temperature until the meat has become heated through, the time depending upon whether a rare, medium, or well done roast is wanted. In the electric oven the full radiant heat from the elements in both top and bottom of the oven may be used to sear the surface of the meat quickly after which the unit in the bottom will maintain the roasting temperature (350 deg. F.) for the desired time. Meanwhile the moisture from the meat is largely retained in the oven, thus preventing the surface of the roast from becoming hard and dry before the center is cooked. In the usual fuel oven a considerable circulation of air through the oven is required to carry off the waste products of the fuel. This results in a relatively hard and dry surface on the roast except when a covered roasting pan is used and much care given to basting. In the electric oven an open pan is used, no basting is necessary, and the shrinkage is very much less than with other fuels.

Vegetables cooked on the electric range disclose a flavor and tenderness not often realized with the usual cooking methods. But a fraction of the usual amount of water is used and the vegetables are steamed rather than boiled. This is possible as the low concentrated heat of the surface units may be adjusted to prevent evaporation or scorching. The flavor is retained rather than boiled away. It is possible to place vegetables in the oven with roasts and puddings. The oven dinner is a popular habit with electric range users.

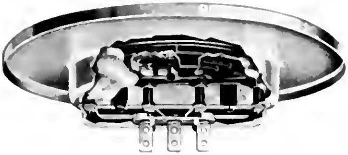


Fig. 3 Sectional View of Sheath-wire Hotplate

Only when an electric range is used are broiled steaks at home comparable with those served at high-grade restaurants. The intense radiant heat from a heating unit in the top of the oven can be applied directly to the surface of the steak with a truly remarkable result.

The electric range is safe. Heat is available instantly at the turn of a switch. No matches or flames are necessary and all possibility of fire, explosion, or asphyxiation is eliminated. Heat is applied to its task in the electric range more efficiently than in any other type of cook stove. As the result almost no waste heat is dissipated into the kitchen to cause discomfort, particularly in the summer time.

It is relatively easy to convince the modern housekeeper of the advantages of electric cookery, and in the future the intelligent housewife will demand an electric range in her kitchen.

Having created a demand on the part of the housewife, the remaining factors that are essential in establishing a tremendous future for electrical cookery are: first, ranges which will merit confidence by high-grade results, sanitary construction, and reliable service, at a first cost consistent with their merits; and, second, a cooking rate by the central station which enables electrical energy to compete on an economical basis with other cooking fuels. However, on the part of the central stations a low rate alone is not sufficient. They must also furnish continuous reliable service, aggressively push the sale of ranges, and give prompt attention to range service calls.

Recent Improvements in Electric Ranges

Each year brings some advance in electric range design. Manufacturers are constantly striving to advance the progress of electrical cookery by applying features to ranges to improve results, eliminate attention, lengthen the life of all parts, improve appearance, and reduce cost.

The surface heating units must receive first attention in considering range design as they receive the hardest service and are the most used parts of the range. In general two types of construction are used. The first, commonly known as the open-coil type, utilizes coils of nickel-chromium resistance wire laid in moulded porcelain of special composition to resist sudden temperature changes; and second, the enclosed type, in which the resistors are enclosed within a cast-iron plate. In the particular ranges under consideration either type can be used, the construction of the cooking surfaces being such that all units of both types are interchangeable thus permitting the individual wishes of the purchaser to govern type, size, and location of the surface units.

The open-coil unit, as illustrated in Fig. 1 and shown disassembled in Fig. 2, is unique in that the heating coil with terminal connections attached is simply laid in a double spiral groove in the surface of the porcelain block. This construction permits the heating coil to be easily replaced if damaged. A drawn steel pan adapted to the openings in the cooking surface and an insulating block to prevent the loss of heat downward complete the assembly.

Fig. 4. Combined Three-heat Double-pole Snap Switch and Single Plug Fuse

The enclosed units utilize the improved form of "sheath wire." A sectional view of one is shown in Fig. 3. The resistor in these units is prepared by inserting a coil of nickel-chromium wire in a straight seamless steel tube after which the insulation of especially prepared magnesium oxide is inserted. The tube is then swaged to compact the insulation. This element is then formed into a spiral shape, placed in a mould and molten iron poured around it. The result is a simple heating unit, the element having become an integral part of the casting. It will be readily appreciated that an insulation which will withstand the extreme temperature of molten iron without deterioration will hardly be affected at the operating temperature of the unit even though this may be a dull red heat. This unit is particularly adapted for the heavy service required in boarding houses and small restaurants.

An innovation in wiring details is shown in the combined three-heat double-pole snap switch and single plug fuse with porcelain indicating handle in Fig. 4. Ranges are almost universally connected to 110-220 volt, three-wire secondary circuits. This makes it allowable and advisable to omit any fuses in the neutral or grounded wire, thus considerably simplifying the location of trouble in case of a blown fuse. The fuses are made accessible by withdrawing the cleanout pan a few inches. The porcelain switch handle indicates at a considerable distance the position of the switch as "High," "Medium" or "Low."

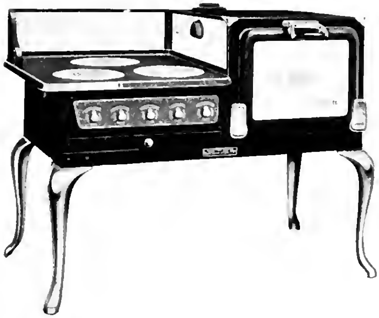


Fig. 5. **An Up-to-Date Electric Range**

Appearance is particularly important in the up-to-date kitchen with its white enameled walls and fixtures. The contrast in appearance between the latest development, Fig. 5 and Fig. 6, one of the earliest ranges, is pertinent.

To find a place in the modern kitchen an electric range must be more than a combination of hotplates, switches, wires, and an oven, supported on legs. It must be sanitary and easily cleaned, and the appearance of the whole must be pleasing. Style and appearance have as important a place in a range as in an automobile, both of which are purchased by women. Black japan, polished nickel, and white vitreous enamel are combined to give a pleasing whole. In one range, illustrated in Fig. 5, the sanitary features have been carried out to a much higher degree than ever before. For instance, all edges and corners of the cooking surface are rounded and fit closely with the vitreous enameled splashers. All corners of the oven lining are rounded to facilitate cleaning. This lining is made up from four pieces of sheet steel with all joints double-seamed on a special machine to make them moisture-tight, and thus prevent moisture escaping into the insulation.

Fig. 6. **One of the Earliest Range Models**

The importance of temperature in oven baking and the usual uncertain methods of measuring it led to the development of the thermostatic metal thermometer shown in Fig. 7. To measure the air temperature in the oven correctly it was found necessary to have the measuring instrument project into the space. The indications of a thermometer flush with the door lining, as is the usual practice, were found to vary too much to be reliable. A thermometer located in the door has the additional objection that the jar of opening and closing disturbs the calibration. To eliminate these difficulties the thermostatic metal thermometer is located in the oven wall at a point where it will very closely measure the true oven temperature and at the same time be convenient to observe. This sensitive thermometer is a great aid to the housewife in duplicating results and eliminating guess-work.

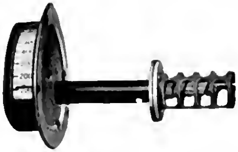


Fig. 7. Thermostatic Metal Thermometer for Range Oven

In this connection it is interesting to quote the following extract from a Bulletin by May B. Van Arsdale of Teachers' College, Columbia University:

"Several expert instructors as well as housekeepers were asked the question: 'How do you test your oven for bread?'

"The following are typical of the answers received:

"'By the feeling of the heat on my face.'

"'By the way the heat strikes my face when the oven door is opened.'

"'By holding my hand in while I count fifteen.'

"'By holding my hand in while I count ten.'

"'By a piece of manila paper—when it becomes the *proper* shade of brown.'

"'By the coloring of tissue paper.'

"'To test the oven without a thermometer put a little flour on the bottom of the oven, and if it chars *quickly*, it is too hot; if it browns *slowly*, while you count 10 seconds, it is just hot enough for bread.'

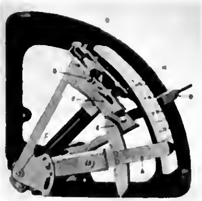


Fig 8 Temperature Control Mechanism for Automatic Range (Open View)

"'By leaving the gas on ten minutes.'"

Using the "feeling" method it was found that the members of a cooking class estimated an oven to be at "medium" heat when the actual temperatures varied from 145 to 428 deg. F.

Automatic Range

Not content to have developed the electric oven to the point of superiority over all other cooking compartments, electric range manufacturers have directed their efforts to the development of automatic control systems to reduce attention and thus meet, to a still greater extent, the desire on the part of the housewife for less hours in the kitchen.

A most important advance is the addition of thermostatic control to maintain the oven temperature automatically at any desired point. This relieves the operator of the necessity of watching the thermometer and manipulating the switches to secure the proper temperature. She readily learns to interpret recipes in terms of temperatures and simply sets the automatic regulator to maintain the required temperature. She finds the control is helpful practically every time the oven is used.

Fig. 9. Super-Automatic Range

An exposed view of the thermostat is shown in Fig. 8. It is shown in position on the side splasher of the range in Fig. 9. A helix of thermostatic metal located in the oven is the actuating element. A notable advance is recorded in the recent development of a thermostatic metal capable of being used at temperatures as high as 600 deg. F., without changing in calibration or taking a permanent set.

The operation of the thermostat is as follows: The motion of the helix is transmitted to the shaft *C* on which the cam *E* is mounted. This cam operates against the roller *F* which transmits the movement of the helix to a sensitive quick-make-and-break switch *D*. This switch controls the current in the operating coil of a 30-amp. relay shown in Fig. 10. This relay, or contactor, is located just back of the switchboard and controls the current to both oven heaters. The control lever *B* is set at the desired temperature and the oven switches turned on. As the oven heats the cam *E* moves until it lifts the roller and opens the switch. Then in cooling the roller is released and the circuit is again restored. The wave spring utilized to secure the quick make and break of the thermostat contacts has proved very reliable in service and is an essential factor in eliminating contact trouble and chattering of the contactor.

Fig. 10. Contactor for Heat Control

The temperature is maintained so closely as to eliminate the effect of any variation on baking. It is possible to absolutely duplicate results in so far as the oven is concerned.

Super-Automatic Range

A further advance has been made by combining a time control with the temperature control on the range shown in Fig. 9. The time control enables the oven to be started at any predetermined time, even though the operator be absent, and be shut off at any later time, the temperature control meanwhile functioning. For instance, an oven dinner may be prepared in the morning and placed in the oven. The time control may then be set to turn on at 4 p.m. and off one hour later with temperature control lever set at 350 deg. F. The housewife can return at 6 o'clock to find a hot, perfectly cooked dinner waiting.

The time control also finds many uses in simply limiting the time of the cooking period to that desired by the operator, thus eliminating attention even though she may be in the kitchen all the time. With this complete range, baking and in fact all oven cookery becomes truly automatic and capable of being indefinitely repeated with the assurance of uniform high-grade results.

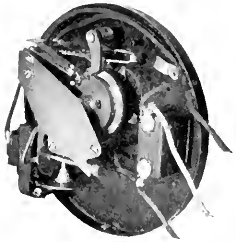


Fig. 11. Elapsed Time Switch (Open View)

An essential feature of the time control mechanism is the use of a small motor as the driving element, thus eliminating any winding. An exposed view is shown in Fig. 11. The motor drives the central shaft through worm gears. This shaft carries the cams which control the contacts in the relay circuit. Fig. 12 is a wiring diagram of the complete range. A front view of the time control is shown in Fig. 13. In operation the hour dial is set with the hour of the day at the time of setting under the arrow at the top; the *on* hand is then set to turn the current on

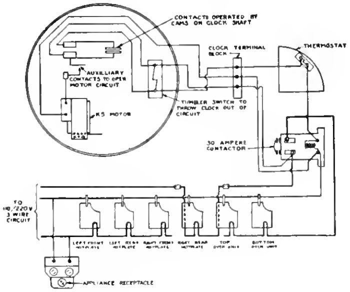


Fig. 12. Wiring Diagram of Complete Range

as desired and the *off* hand to open the circuit as much later as is required to cook the food, bearing in mind that the stored heat in the oven is utilized to complete the operation.

Fig. 14 illustrates in curve form the operation of the combined time and temperature control of the oven.

Fig. 13. Elapsed Time Switch (Front View)

THE RANGE AS A CENTRAL STATION LOAD

The energy consumption per range per month as reported by the various central stations to the Society for Electrical Development is remarkably uniform, the average being 128 kw-hr. This is equivalent to practically $4.00 per range per month, at the average rate reported. This average operating cost to the user is of particular interest in establishing the fact that the field for the electric range is not restricted to the wealthier classes, for at this rate it can be operated on an economical basis by the majority of central station customers.

The revenue from the average lighting customer varies from $18.00 to $24.00 per year; the average range customers pay $18.00 per year. In considering the cooking load it is important to remember that when the existing lighting customer becomes a cooking and lighting customer, the gross income from this customer is trebled.

The additional investment involved naturally has an important bearing upon the profitableness of the range load. The central stations having the longest experience with ranges report that the load characteristics have a real influence on the investment and must be carefully considered. The connected load of a range is comparatively large, for to be successful the heating elements must perform their work rapidly and the range must have sufficient capacity to prepare the heaviest meal required without delay. The range illustrated in Fig. 5 has a maximum connected load of 6500 watts. The average connected load per range reported by 100 central stations in 1921 was 5560 watts. In actual service the total connected load of the range is practically never required, for not all of the heaters are on at the same time, as most of the cooking is done with the switches turned to the "Low" or "Medium" rather than the "High" heat, on which the connected load is based. The average maximum demand of a single range as reported by the same central stations giving the above data is 2400 watts or 42 per cent of the connected load. This low demand-factor has a real bearing on the cost of transformers, service-wires, and meters for serving range customers. Three-wire services using number 6 B & S wire and 15-amp. three-wire meters have become standard for serving 5- or 6-kw. ranges.

In addition to the low demand of a single range, the diversity in the habits of a group of cooking customers connected to one transformer results in a greater diversity of demand for a group of ranges than for any other large class of electric load. Many companies make it a practice of supplying three cooking customers from a single 5-kw. transformer and as many as 18 from a 20-kw. transformer. The effect of this large diversity is illustrated in Fig. 15, which shows the variation in maximum demand for one year for a typical apartment house with a range in every apartment.

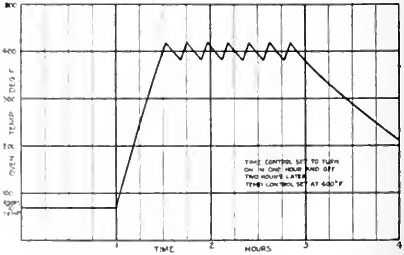


Fig. 14. Graphic Chart Showing Automatic Time and Temperature Control of Super-Automatic Range Oven

The curves in Fig. 16 were recently taken in a middle western city in an effort to secure a close comparison of lighting and range loads. Five combined lighting and cooking customers served from one transformer and five customers served with lighting only in the same neighborhood and presumably similar in habits were selected and graphic load curves were taken for one week. The curves shown are the average for the week. In an endeavor to secure a typical load curve for ranges alone, curve (B) was subtracted from curve (A), with the result shown in curve (C). It is evident that the addition of a range load very considerably smoothes out the residence district load curve and makes use of distribution facilities otherwise practically idle during the day. During the winter the range and lighting peaks overlap somewhat; during the summer there is almost no overlap. A number of central stations have made tests to determine the relation of connected load to station capacity for ranges. It has been generally agreed that this ratio is approximately ten to one, that is, but 600 watts of station capacity is required to service a 6000-watt range.

A further subject for consideration in connection with the profitableness of the range load to the central station is that of maintenance. The importance of the preparation of the meals in the home necessitates a high degree of continuity in the electric service. Prompt and trained attention must be given to all trouble calls, whether due to the distribution system or the range itself. The range with everlasting heating units is yet to be built. Tremendous advances have, however, been made in recent years towards producing longer lived heating units and reducing the cost of making repairs and replacements by simplifying the construction. The cost of supplying prompt service to ranges has been carefully determined during recent years. In the 1920 report of the N.E.L.A. Range Committee the summary of the cost of maintenance by eight companies serving 10,802 ranges showed a total average cost, including both material and labor, of $4.50 per range per annum. Generally, any charges for material, except that replaced free under the manufacturer's guarantee, is billed to the consumer.

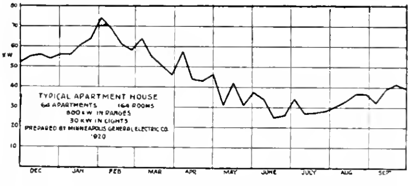


Fig. 15. Curve Covering a One Year Period Showing Variation of Fifteen-Minute Maximum Demand on Combined Range and Light Load

CONCLUSIONS

It has been demonstrated that, because of the superior results and greater convenience, the electric appeals to the modern housekeeper as being nearer the ideal than any other fuel range.

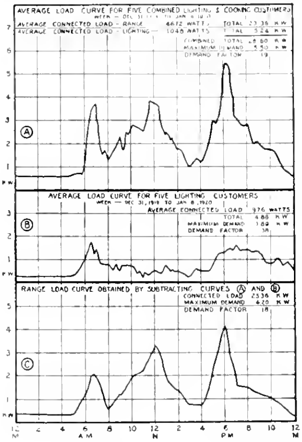


Fig. 16. Curves Showing Comparison of Lighting and Range Loads

Most central stations are finding it possible to offer profitable cooking rates sufficiently low to allow electric ranges to be operated at a cost strictly comparable with other fuels.

A low rate for energy is not alone sufficient to build up a range load. Aggressive merchandising, dependable and adequate service, and prompt attention to repair calls are also essential.

The range load offers to the central station an opportunity to build up the density of the load in the residential and suburban districts with but small additional investment, thus greatly increasing the revenue per dollar invested in the distribution system feeding those districts.

Central stations, in planning a new generating and distribution system, should not neglect the probable tremendous increase in load and revenue from residential and particularly suburban districts which will result from the extensive use of electric ranges.

The Advantages and Disadvantages of Electric Drive in a Beet Sugar Factory

By A. J. Forbess

Electrical Engineer, Amalgamated Sugar Company, Ogden, Utah

In this article the advantages and disadvantages of electric drives are compared with steam-engine drive from the standpoint of the operator and manager. A beet sugar factory operates but one-third of the year and the operating power is in the nature of a by-product so that the higher power efficiency claimed for electric drive is not a deciding factor. It is shown, however, that properly applied electric motors give greater continuity of service, lower cost of operation, etc., than the steam engine. The peculiar fitness of steam turbines is also shown.—Editor.

Possibly the most striking phase of this subject is the lack of definite comparative data, which could give some idea of the relative desirability of electric and other forms of power for a sugar mill. Even manufacturers of electric apparatus seem to have little to offer in the way of definite figures as to comparative costs of purchase, operation, and maintenance of electric or steam-engine drives.

Railroads are tending to electrify; roads already electric are expanding; and other forms of industry all over the country are putting in electric equipment. Though they do this to the accompaniment of a constant wail that their power bills are bankrupting them, they do not only continue to electrify but they increase their electric equipment when they have changes or additions to make in their plants. Since these people are in business to make money, it is fair to assume that this widespread tendency toward motor drive must have some sound economic foundation. Either its cost must be low, or it must possess some advantages important enough to take precedence over cost.

In view of these facts it seems odd that in sugar mill operation electric drive has been so little used. If it pays other industries to buy electric current through meters to run their machinery, it should be profitable for us to find out whether we can to advantage use our engines for running generators instead of line shafts. As a matter of fact, motor drive is being gradually introduced into sugar mills at different stations and under varying conditions. There are many old mills where other equipment has to a certain extent been replaced by motors; and new factories are being electrically driven throughout. The claim is made that electrified mills show a reduction in operating expenses of 15 to 20 per cent

The most obvious disadvantages of electric drive from our point of view is the cost of the change-over of an existing plant from steam engine drive to motor drive. Besides the outlay for apparatus involved in the change, a plant built to be operated by a line shaft cannot always be converted to direct motor drive without considerable expense. For instance, the centrifugal pumps, unless they had been designed for this drive, would probably not be of suitable speeds. In that event the change would mean either a new pump, which would be expensive, or a belt-driven pump. The latter is practical but the use of a belt with a motor sacrifices part of the possible advantage of motor drive. The belt gives lower efficiency than a direct-connected motor and causes greater wear on the bearings, also increases the danger to the operator, and the maintenance expense. Another example of this is the centrifugal machines. In our Ogden factory the countershafts from which these machines are run were originally belted to the main line shaft. When the change was made to electric drive these countershafts were directly connected to motors through reduction gears. When this factory was built, these machines were arranged to be run by belt; owing to their arrangement the changes necessary to convert each of them to direct motor drive would have involved a great deal of tearing out and rebuilding. The expense of making these changes would not have been justified by the advantage to be gained by the direct motor drive. If it were a case of adding new equipment in an old mill, however, particularly in such a case as our Ogden mill, where the line shaft is already full, it would probably prove less expensive as well as simpler to buy a motor to drive it. Aside from the matter of the expense of making the change-over in an existing mill from engine to electric drive, there are but few difficulties to be encountered. These are of such minor importance and are so easily overcome that it is unnecessary to devote a great deal of time to them. Some of the most apparent of these problems are: securing a desirable power-factor, adapting the motor speeds to the speeds of the machine, altering the speed of a machine to directly connect to a motor, the low starting torque of the electric motor and the seemingly low transmission efficiency of the electric drive.

In the matter of the power-factor, a great deal can be done to avoid trouble by using care to install motors of correct sizes and high speed. In other words, at a station requiring 20 horse power for its drive, use a 20-h.p. motor, not a 40 or 50 as seems to be the practice in some cases. The higher the speed of the motor the higher the power-factor and the lower the first cost. This lowers the investment required, as well as raising the power-factor to standards compatible with good engineering. During the 1920 campaign we took graphic meter readings of our motor installations in Ogden in order to determine whether the motor sizes were correct. We found some places where changes were desirable, and during the summer of 1921 we made the indicated corrections. For instance, we were running the crystallizers with a 25-h.p. motor, and the granulator, granulator fan, and sugar elevators with a 40-h.p. motor. Wattmeter records showed that a 10-h.p. motor would handle the former and a 25-h.p. the latter. Accordingly, we moved the 25-h.p. motor from the crystallizer to the granulator, and brought in a 10-h.p. field motor for the crystallizers. Because the beet-end engine was heavily overloaded, it seemed advisable to relieve it of part of its load, so we set up the 40-h.p. motor from the granulator to run the beet wheel, beet washer, and picking table. These changes brought up the power-factor. This case is typical of the ease with which a favorable power-factor can be secured. In all our mills where we generate power, with the possible exception of Twin Falls, the power-factor is well above 85. In most of them it holds very close to 90 nearly all the time. Our Ogden mill drives all the sugar end electrically and part of the beet end, and also the beet sheds, etc. The reports show that the power-factor there runs between 85 and 90. Thus it is clear that a low power-factor need not accompany electric drive.

The drive of conveyors and special machinery requires some means of reducing the high speed of the motor to the low speed of the machine. The lower the speed of the induction motor the higher the cost and the lower the power-factor, so it is desirable to select as high a speed as will give quiet running and long life. This means that a much greater speed reduction is required in driving with motors than from a line shaft. This reduction can be accomplished by a belt, a countershaft and belt, or a reduction gear. The first two means mentioned give low efficiency and have high maintenance costs. The reduction gear is rather expensive in first cost, but its maintenance and operating costs are low. Since an induction motor is built to operate at a fixed speed, when it is desired to change the speed of a piece of direct-connected motor-driven machinery, instead of simply changing the size of a pulley as with engine drive, it becomes necessary to use new apparatus designed to meet the new conditions, or to install some equipment to effect the desired change such as a belt or a reduction gear.

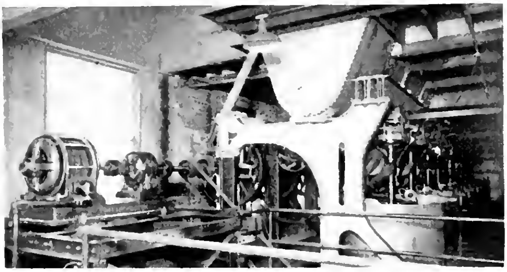


Fig. 1. Centrifugals Driven by a 50-h.p. Induction Motor Through a Reduction Gear

At some stations the low starting torque of the motor as compared with the high starting torque of the clutch on a line shaft presents a difficulty which has to be overcome. This is easily done by the use of a clutch with an ordinary squirrel-cage motor; or the same results can be secured by the use of a slip-ring motor. The latter, designed to act automatically as the speed increases, is probably more satisfactory in the hands of unskilled operators. Voltage regulators take care of any tendency to disturbance in voltage when the motors are started.

At first observation, the transmission efficiency of the electric drive may appear to be lower than that of the steam-engine drive. Where a machine can be belt driven from the main line shaft, as the pumps in the Ogden factory, the transmission efficiency is higher than if it were electrically driven. Assuming a loss of about three per cent in the drive belt to the line shaft, about six per cent in shaft bearing friction and pulley windage, and another three per cent in the belt to the machine, we get an estimated efficiency of 88 per cent from the engine to the machine. With electric transmission we expect a loss of about eight per cent in the generator when direct connected to an engine, of four or five per cent when turbine driven, of about two per cent in the wiring, and of from eight to fifteen per cent in the motor, leaving an overall efficiency for this form of transmission of 78 to 84 per cent. When a countershaft is used with the line shaft the transmission will be about the same in efficiency as by electricity. Take for example our cutters, run from a countershaft. If these were motor driven through a reduction gear, the efficiency would be about the same as at present. In some of our factories we have steam pumps for the main water pumps. By substituting centrifugal pumps direct motor connected, the same amount of water can be pumped for just about half the cost in steam consumption.

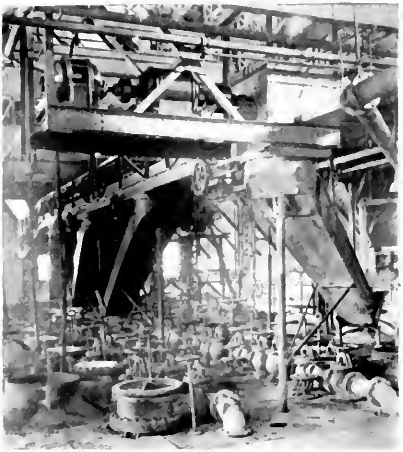


Fig. 2. A Cossette Conveyor Driven by a 10-h.p. Induction Motor Through a Reduction Gear

It, therefore, appears that whereas in some instances the transmission efficiency by electric drive is lower than by steam drive, in other places it is higher. So long as the amount of power consumed in driving the machinery does not increase the amount of fuel burned under the boilers, a slightly lower transmission efficiency, if it does exist, is not of vital concern.

Thus it appears that the only serious disadvantage of electric drive is the high cost of changing from steam engine to electric power in an existing mill The advantages may be roughly grouped under three heads:

(1) The economy of electric drive.
(2) The ease of transmitting power electrically.
(3) The popularity of electric drive with superintendents and operators.

(1) Undoubtedly, the most important of these is economy. As compared to steam drive, electric drive shows a saving in money in three ways; lower operating cost, lower maintenance expense, and the saving made possible by using the turbine instead of the engine. In a sugar mill continuity of operation is imperative. A shut-down of but a few hours causes not only loss of production and labor, but also a loss due to fermentation of juices which sometimes amounts to thousands of dollars. For this reason, anything which tends to secure greater reliability in operation makes for greater economy; and electric drive, through its marked flexibility, is peculiarly adapted to this end. The entire plant will seldom if ever be tied up by failure of its motive power. Especially is this true where central station power can be had. In the Twin Falls factory, one of the generator engines was wrecked during this campaign. It was found necessary to bring new parts from the factory. If this engine had run a line shaft upon which a number of machines depended for power, these would all have been compelled to stand idle until the new parts were received and installed; in other words, a complete shut-down of several days. But, because it runs a generator which supplies current for lights and motors, we simply

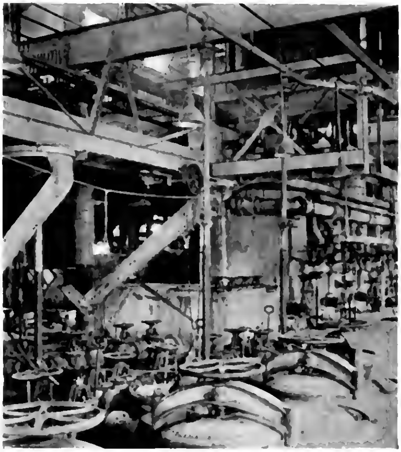


Fig. 3. Another View of the Cossette Conveyor Driven by a 10-h.p. Induction Motor Through a Reduction Gear

threw a switch onto the incoming power line and continued to operate the mill on the electric company's power while we waited for the engine to be put back into service.

Also, our main engine at Twin Falls was crippled during this campaign, due to leaky piston rings. While we were waiting to get the parts to make the required repairs, we had to keep this engine running as best we could, installing temporary motors to relieve it as much as possible. During the three or four weeks' time this trouble lasted, it is estimated we burned $10,000 more coal than normal for that period; besides this the entire factory was slowed down, with resulting lowered output during this time. Now if this engine had been used to run a generator instead of a line shaft, we could have used the incoming electric power for a sufficient number of machines to have enabled the engine to keep the remaining number up to normal speed, while we waited for the new parts.

In an electrically driven factory in Southern Utah the pulp pumps gave considerable trouble during this last campaign. They ran for about 24 hours, then had to be shut down and repaired. Owing to their being motor driven, no time was lost because of the repairs. One pump started and the other stopped without in any way interfering with the operation of the mill. If we had had similar trouble at any of our other plants, it would have meant a complete shut-down of the beet end long enough to shift the belts. This always means a loss of time; also, some time is required to readjust the factory after each shut-down. In 1920 the main water pump in our Ogden factory was belted to the line shaft. Consequently, every time the beet-end engine was shut down for any cause, this important pump stopped, with considerable resulting trouble. During the summer of 1921 we connected it directly to a motor. As a result, it was hardly shut down during the 1921 campaign, because when it was necessary for any reason to shut down the generator engine the pump was switched to the electric company's power.

The adoption of individual motor drive makes it possible to operate any part of the apparatus in the mill without the necessity of running or of shutting down the whole mill, as with steam-engine drive. Thus a breakdown in any machine is less serious in an electrically driven mill as only the operations directly dependent upon the disabled machine are affected. Also, individual drive makes it possible to shut down a machine when it is not in use instead of continuing to run it as long as the line shaft runs. This not only avoids wear and tear on the machine with possible resultant shut-downs for repairs, but makes a saving in power by elimination of friction losses. Idle machines take no power.

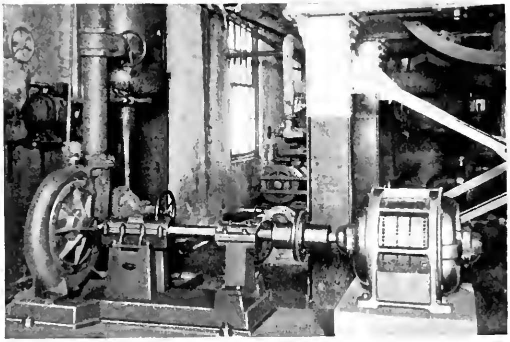


Fig. 4. Main Water Pump Driven by a 40-h.p. Induction Motor

Furthermore, the flexibility of individual drive facilitates overhauling the machinery during the inter-campaign. Adjustments can be made and the apparatus operated by means of a small generating unit, or from an electric power system, without the necessity of running practically the whole mill as with steam-engine drive.

The first cost and maintenance of belts are large items; and when the direct electric drive can be used, belt expense can be entirely eliminated. The costly construction for safeguarding the oiler and even the attendant himself are thereby not required. The simplicity of electric drive, and its dependability without constant attention, reduce labor cost. A large amount of trouble is avoided which has its origin in heating of bearings, breaking, wear and adjustment of clutches, belting and shafting break-downs. In the case of installing a new pump, the high-speed pumps adapted for use directly connected to motors can be used at a saving in first cost.

Motor operated machines can be tested for power consumed and defects in the mechanical condition of the apparatus detected. For instance, when we first started the white centrifugal machines at Ogden, the overload relay stopped the motor when it had run but a short time. All the belts, bearings, clutches, etc., had been examined, and were supposed to be in good condition. However, after a short period of running, we had another examination made. This revealed two or three bearings too tight, and some clutches out of adjustment. When these had been corrected the machines gave no further trouble. If this station had been engine driven, it is probable the defects would have gone undetected. A motor can have its overload relay set at any desired point; then in case of a sustained overload it automatically stops. If care has been used to install motors of correct horse power for the work, the continuous overload demand of any station will not exceed the rated horse power of the motor; while an abnormal overload will be at once detected. This provides protection against the burning out of bearings or else the excessive consumption of steam, involving loss in power and wearing out a costly machine.

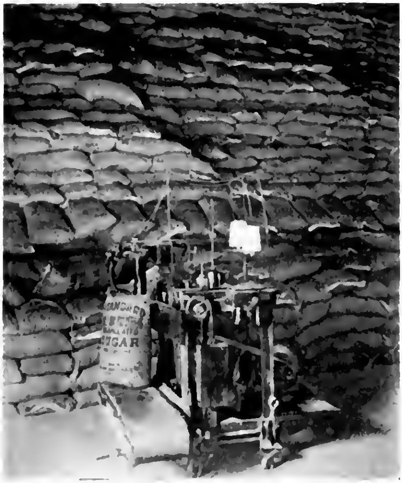


Fig. 5. Portable Motor-driven Bag Sewing Machine at Work in a Sugar Warehouse

The labor and material expense for cleaning the power equipment and putting it in condition for the inter-campaign is much lower than in a steam engine-driven factory, due to a material decrease in the amount of shafting, bearings, hangers, belting and gearing. All belting in a beet sugar factory must be taken off at the end of the campaign, cleaned, dressed, and then put on at the beginning of the campaign. Belts are comparatively short-lived and expensive to replace. Wiring in conduit requires practically no maintenance. The motors ordinarily require only coverings to protect them from being splashed with water, and from dust. Those which operate in damp or dirty places should be cleaned and the windings given a coat of insulating varnish. Before the start of the campaign the bearings should be drained of old oil and refilled with new.

By standardizing the speed of motors, it is possible to secure a high degree of interchangeability. This decreases the amount of money tied up in spare equipment. Furthermore, owing to the smaller floor space taken up by motors than by shafting and belts, increased manufacturing area becomes available in the same size buildings. The smaller weight of the motor and wiring compared to the heavy line shaft, with its vibrations when running, makes a lighter building construction admissible.

A further economy in first cost, as well as operation and maintenance, which is available by the adoption of electric drive is the possibility of substituting the steam turbine for the reciprocating engine. The cost of the turbine unit installed is roughly 65 to 70 per cent of the cost of an engine type unit of the same generating capacity. The only advantage of a good Corliss engine over a turbine is that under the usual steam conditions the engine consumes less steam. This, however, does not signify that the engine is more efficient. Since the only non-recoverable losses in either case are external friction and radiation and these are less for the turbine than for the engine, the turbine will, in fact, be found more efficient. Also the turbine-generator is more efficient than the engine-driven generator, showing an efficiency of 95 to 96 per cent, as compared with 90 to 92 per cent for the engine-driven generator.

The entire absence of oil in the steam from the turbine is an important feature. The steam sides of all heaters and evaporators remain clean throughout the campaign, and tend to maintain their capacities. Furthermore, the efficiency of a turbine over a period of years will be more nearly constant than that of the steam engine. Owing to its simplicity of construction the maintenance cost of a turbine is estimated to be about one-fifth that of a steam engine. Since the turbine has so many advantages but delivers a greater amount of exhaust steam, a careful study should be made of this steam at normal power load and its use for heating and evaporating. Turbine units under 1,000 kw. are apt to yield an excess of exhaust steam.

(2) The ease of transmitting power electrically is in marked contrast to the complicated system of belts, main shafts and countershafts required with steam engine drive. The location of the equipment of a steam-engine driven plant is decided by the line shaft; around this the factory is built. Accessibility to the source of power becomes of greater importance than other items, such as efficient use of floor space, etc. With electric drive, this condition vanishes. Each machine can be located in the most advantageous position regardless of line shafts or belt arrangements. Machines are easily installed or moved, giving greater opportunity for efficient use of space and machines. The first cost of wiring will be found lower than the first cost of shafts and belts.

Electric drive in place of steam-engine drive results in lower maintenance cost, lower operating cost because of the smaller amount of labor required, fewer repairs, less time lost, greater output, and less juice soured on account of shut-downs.

Distant motors operating pumps or beet dumps present no more difficult power problem than stations located under the roof of the main factory building, and less expense of transmission, when compared to a long steam line or power shaft, or even a separate power plant.

(3) A further advantage of the electric drive is its popularity with superintendents and operators. It is simple and quiet. Comparatively, it is safe, it reduces the danger to workmen from shafts and belts. The ceilings and walls are left freer from belts, there is less interference with light, less vibration, less dust. These advantages are somewhat intangible and cannot be accurately estimated in money. Nevertheless, studies of factory management have shown that everything that makes for pleasanter, less tiresome working conditions, make for higher efficiency in the working force.

Our experience has shown that in every plant where we have installed a generator, the advantages of motor drive, from the point of view of the operator, are quickly apparent. Superintendents never have to be urged to use motors; rather they seem to think that we cannot put in too many motors to please them. The dependability of motors is reflected in the superintendents' feeling that if they can get a motor put in to run a machine, their troubles with that machine are over. Keeping in mind that trouble with a machine means lost time, loss in production, and loss in sugar due to fermentation, the significance of this attitude on the part of the men who operate the plant is evident.

Thus it appears from the evidence available that the only serious disadvantage of electric drive in a sugar mill is the first cost of making the change from steam engine to motor power in a mill already equipped for engine drive. Other disadvantages are either of so little importance or so easily overcome as to carry little weight.

The most striking advantages are three in number: saving in money; ease of transmitting power electrically; and the preference shown for it by superintendents who have used both engine and electric drive. When carefully analyzed the latter two of these three items will probably owe most of their importance to economy.

Our practice in the sugar company's mills is to put in motors where the engine drive is proving unsatisfactory, or where the load has become too heavy for the engine, or where the addition of new equipment calls for extension of the present drive. In this way electrification is brought about gradually without the heavy expense of complete changeover at any one time and avoids the necessity of retiring from service engine equipment which is still in good condition. Thus we feel that we are taking a middle course; avoiding a sudden heavy purchase of expensive equipment and at the same time gradually availing ourselves of the opportunity to save money in our operations which the electric drive affords.

Thermocouples and the Measurement of Searchlight Mirror Temperatures

By Frank A. Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

The object of the investigation described in the following article was to study the operating temperatures and their distribution over the surface of a searchlight mirror. While the thermocouple is the logical device with which to make such measurements, the adaptation of it for this particular purpose required the display of considerable ingenuity to secure the high degree of accuracy desired. Anyone interested in searchlights or thermocouples will find the information contained in this article to be of exceptional value.—Editor.

There has recently been occasion to conduct a series of temperature measurements on the back surface of the mirror of a 36-in. high-intensity searchlight. This type of projector takes 150 amp. and there is 12 kw. of energy radiated from the arc. A large part of this is received and absorbed by the mirror, and unless some means of forced cooling is employed it will soon overheat and be destroyed either by the glass fracturing or by the silver and paint peeling off. A fan attached to the searchlight forces currents of cooling air down both the front and back surfaces. It is the presence of this strong flow of air that makes the determination of the mirror temperatures somewhat of a problem, and the answer to this problem was found in the technic herein described.

The back surface of a searchlight mirror has, in addition to a film of silver, a coat of copper deposited on the silver and on top of this several layers of waterproof paint. This paint is like a black enamel in appearance and it was one of the conditions of the test that the paint should not be injured. Another obvious condition was that the ventilation should not be disturbed either by the presence of bulky testing equipment or by leaks or false openings that would allow the cooling air to escape. The construction of the searchlight lent itself admirably to the fulfillment of the latter condition as the "dome" or metal protection for the glass mirror has the general curvature of the mirror itself and is separated from it by $^3/_4$ in. at the edge and $1^1/_2$ in. at the center. This dome served as a mounting for the thermocouples as illustrated in Fig. 1.

The thermocouples, 42 in number, are shown held in place by short brass tubes soldered to the dome, and beside each couple is a square paper patch that covers a $1^1/_2$-in. "handhole" that was used in setting and inspecting the thermocouple. A short piece of string tied to each tube passed through the hole and served as a "life line" for a part of the mounting that might accidentally fall down between the dome and mirror and obstruct one of the small air passages at the bottom. The thermocouple wires are shown leading to transfer boxes that enabled the operator to connect any couple quickly to the potentiometer and note the indicated temperature on a direct reading scale.

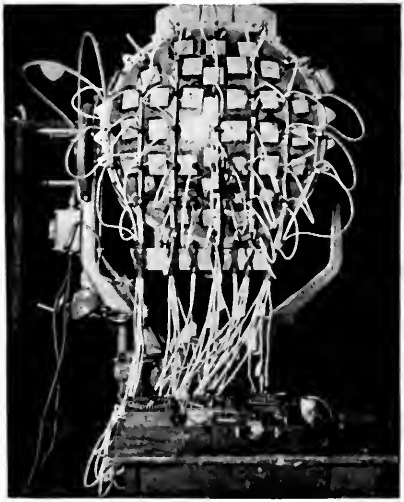


Fig. 1. Forty-two Thermocouples Mounted on the Back of a 36-inch Searchlight Mirror

A better idea of the component parts of the thermocouple and mounting will be gained from Fig. 2. On the left, the various parts are shown; and on the right, a thermocouple mounted against a piece of glass. The junction, or hot end, of the thermocouple was encased in a cast metal cylinder and close to the junction were two spiral springs fitting closely to the insulation and fastened to it by several turns of tape. The short tube lying opposite the end of the thermocouple was composed of a central fiber tube over which rubber tubing was forced and the end that touched the mirror was then ground slightly concave to conform better to the shape of the optical surface and to guarantee an air tight contact between the mirror and the rubber.

A washer glued to the rear of this tube served to center the thermocouple and keep it from making contact with the sides and at the same time prevented the entrance of air to the end of the thermocouple. It also served as a seat for the spring.

The longer tube in the middle was made up of the brass tube that was soldered to the dome, a fiber lining that does not show plainly in the illustration, and a section of rubber tube slipped over the slightly extending fiber. This rubber tube served to hold the keeper or short section of fiber tube that pressed the thermocouple and protecting tube against the mirror when it was forced against the rear spring. By the use of two springs it was found easy to adjust their length so that separate pressure was exerted against the thermocouple and the protecting tube. This insured contact by both, which of course was very essential.

Fig. 2. Parts of the Protected Thermocouple and an Assembled Thermocouple Clamped on a Glass Plate

As ordinarily made and used the junction of the two wires of a thermocouple is a sphere possibly a sixteenth of an inch in diameter which forms when the wires are welded together. It is obvious that if used in this form the area of contact between the thermocouple and test surface will be extremely small, while the remainder of the junction and exposed wires will be very large in comparison. If the thermocouple is protected and held against the test surface by a clay or asbestos pad, such as is often used, the indicated temperature will be determined almost entirely by the temperature of the pad, while the test surface will play a minor part. Under these conditions accurate work seems impossible and it has been almost a hopeless task to secure consistent results, or results free from sudden and more or less inexplicable variations. These variations seem to occur when the pad dries out and loosens from the test surface. There is possibly a little warping of the pad and this lifts a section of it away from the test surface and allows the cooling air to enter. A sudden drop of 20 deg. in the reading was not unusual with the former method and under such conditions the results are not dependable and the incentive for careful work is gone.

The electromotive force difference generated by heating the junction of two dissimilar metals is not a surface phenomenon but is maintained throughout the body of the metals. So long as the two metals are at the same temperature the junction may have any shape or size and a third metal may be used to bridge between them without altering the electromotive force or constituting a short circuit. It is thus permissible to surround the junction with a metal casing, preferably cast on in order to secure good contact, and this was done in the present case.

Lead, or soft solder, has been found suitable on account of the low temperature at which it melts and the ease of finishing it or altering its shape. A lead cylinder $\frac{1}{4}$ in. in diameter and about $\frac{3}{8}$ in. long was cast around the junction of each thermocouple. The end of the cylinder covered the junction by about $\frac{1}{16}$ in. after the end had been carefully filed flat. This form of end was, when applied to the convex surface of the mirror, but little better than the original bare wires; and some additional means was required for getting good surface contact over the entire end of the cylinder.

It was found that the silver amalgam used by dentists for filling teeth served the purpose admirably. A small lump of rather plastic silver amalgam was placed on the end of each thermocouple before it was mounted on the mirror, and by applying pressure the amalgam was caused to flatten out and fit the curvature of the mirror. Lead readily amalgamates and any excess mercury in the silver was quickly absorbed. Both lead amalgam and silver amalgam have low softening temperatures and when working with temperatures around 100 deg. C. the cylinders kept in a plastic condition that was very favorable for good surface contact.

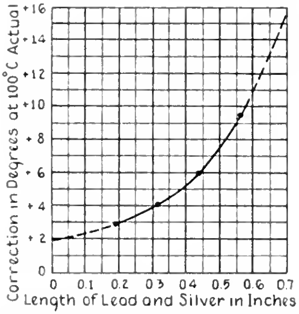


Fig. 3. Characteristic Calibration Curve of Thermocouples on a Thin Vessel Painted with Black Marine Paint and Containing Boiling Water

The thermocouples were checked by mounting several of them against a thin metal vessel filled with boiling water. The vessel was first painted with a black paint so as to avoid metallic contact, which of course could not occur when testing a mirror. The calibration curve of the thermocouples with various lengths of lead cylinders is given in Fig. 3. The mounting was in all particulars like that used on the mirror, so that, except for the interference of the cooling air the correction for length of cylinder can be found from the curve for readings around 100 deg. C.

Some figures that were obtained when experimenting with various methods are as follows; the actual temperature of the test surface was 100 deg. C.:

Junction protected by roll of asbestos	76.5° C.
Junction in soldering silver (without amalgam) protected by roll of asbestos	86.0° C.
Junction in lead (without amalgam) protected by roll of asbestos	90.5° C.
Junction in lead with amalgam tip protected by roll of asbestos	94.5° C.
Junction in lead with amalgam tip protected by fiber and rubber tube	96.0° C.
Junction in lead with amalgam tip making metallic contact with vessel and protected by asbestos roll	98.2° C.

The last couple, if placed in the protecting tube used in the mirror tests, would probably have come within a single degree of reading the exact temperature.

The temperature indications of the thermocouples lagged several minutes behind a couple placed in the water. The reason for this is obvious, and while the sluggishness of the thermocouples in following quick variations might for some purposes be a disadvantage, in other cases it was of positive benefit in the mirror tests because it smoothed out the small variations due to changes in the arc and gave better averages. By decreasing the length of lead cylinder the sensitivity of the thermocouples to change of temperature can be increased but some lag will always remain.

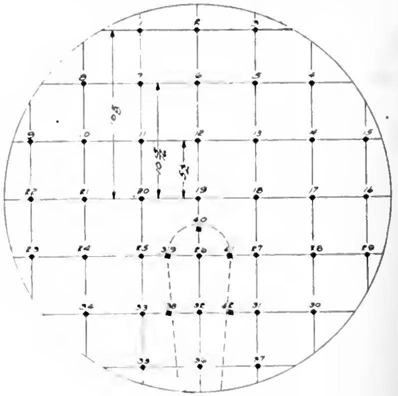


Fig. 4. "Checkerboard" Location of Thermocouple Stations on Back of Searchlight Mirror under Test

A few preliminary tests were made with cold air blowing on the couples mounted on the metal vessel and as a result of these tests further corrections of 2, 3 and 4 deg. were made to readings at different parts of the mirror.

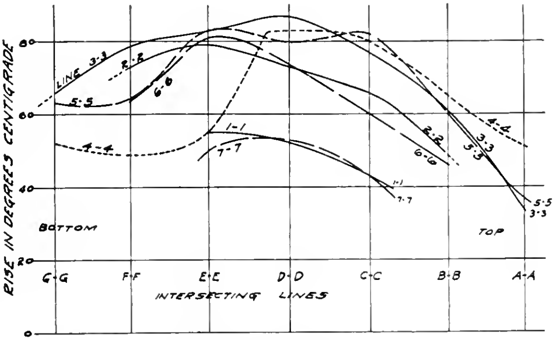


Fig. 5a. Curves showing Rise of Temperature Plotted for Vertical Lines through Test Stations of Fig. 4

During previous temperature explorations several arrangements of testing stations were used, but the checkerboard arrangement shown by the rectangular web in Fig. 4 has proved the most satisfactory. The reason for this is that curves of temperatures may be plotted for both horizontal and vertical lines through all the stations and double the points are available for plotting isotherms. In Fig. 5a the curves are temperatures along the vertical lines and the curves of Fig. 5b are along the horizontal lines. In plotting the isothermal lines of Fig. 6 it was found best to plot first an intermedia temperature, such as 70 deg., and the short and broken curves last. The 70 deg. isotherm has 20 crossing points or data stations from the curves of Figs. 5a and 5b and it was a simple matter to obtain a smooth curve with the greatest accuracy possible to get from the given test data. The matter of horizontal and vertical lines is gone into in some detail because the first impulse of anyone starting to investigate temperatures of a circular body, such as a mirror, is to arrange the test stations in concentric circles. As a result, only a few points can be used twice and long spaces between points can be filled in only by a generous use of the imagination.

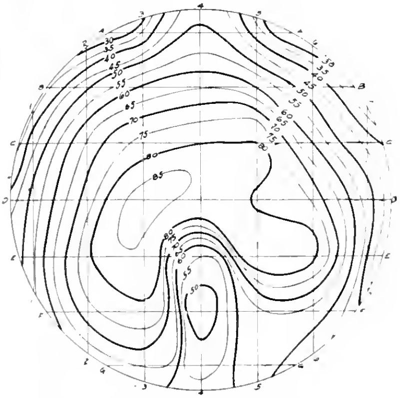


Fig. 6. Isotherms after 1 hr. 4 min. showing Rise of the Mirror Temperature above that of the Room. The test station locations are as shown in Fig. 4

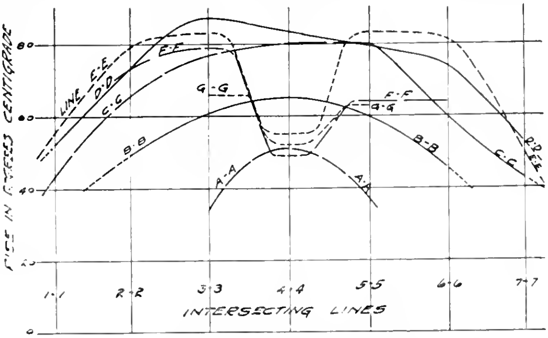


Fig. 5b. Curves showing Rise of Temperature Plotted for Horizontal Lines through Test Stations of Fig. 4

The isotherms of Fig. 6 show the temperature conditions encountered when using an experimental lamp head. The head influenced the temperatures chiefly through the shadow cast upon the lower part of the mirror. The sudden drop of temperatures along the lower half of the vertical axis shows the location and the influence of this shadow. As a result of these tests, of which there were about twenty, the temperature differences due to the shadow were reduced to less than half and the strains in the glass arising from these temperature differences were lessened accordingly. The temperatures on the right and left sides were at first unsymmetrical but this was soon corrected by a better balancing of the air passages; and further, by comparing the first and last tests, information was gained that has an important bearing on the useful life of a mirror.

At temperatures of 100 deg. C. and over, the rubber on the protecting tube showed a tendency to stick to the paint and care had to be exercised in removing the couples. It was found that if the couple was given a twist while it was pressed on the hot paint, damage could be done to the paint and the silver reflecting surface. With due attention given to these two points a mirror can be tested without damage.

Several people connected with the tests have been brought up, so to speak, on clay pads and bare thermocouple junctions and to them the consistent and accurate operation of the thermocouples was extremely gratifying.

The Repair of Railroad Equipment and Reclaiming of Scrap Material with the Electric Arc in Railroad Shops

By J. J. Liles

Baltimore Office, General Electric Company

All devices for saving money in the maintenance of railroad equipment should be of interest to the American railroad official today. The newer applications of the electric arc to repair work and its use in scrapping and salvaging material, as described by the author, should attract considerable attention in the railroad world and will, we hope, lead to an extension of the electric arc's usefulness in railroad service.—**Editor.**

Labor saving machinery of all descriptions is to be found in the modernized railroad shop. Lifting magnets, motor-driven trucks and conveyors are now considered necessities to meet the changed economic conditions in American railroading.

The electric arc welding outfit has won its permanent place in the railroad shop for repairing all manners of locomotives and car parts and for renovating arch bars, frogs, and other forms of railroad material.

With these uses of the electric arc we have been familiar for many years but railroad engineers will be keenly interested in the application of the electric arc to the dismantling, for the purpose of repairs, of steel cars, tenders, locomotives, etc. and in its further application to the reclaiming of scrap material in general.

The C. & O. Railway Company, one of the Chicago-Atlantic Coast routes, has installed a large amount of equipment primarily for the above purpose. The equipment is distributed over the System, and installed at its principal shops. The machines vary in size, depending upon the amount of work to be done at the different points. The capacities of the motor generator arc welding sets range from 500 to 2000 amp. at 75 volts.

The big saving in the above mentioned work with the electric arc is secured by the ease with which they burn off rivet heads. In this connection, the following data may be of interest:

Cost of burning off rivet head with the arc and backing the rivet with air	$.0158 ea.
Cost of cutting off rivet head and backing the rivet with air	.035 ea.

These costs include labor only as no costs covering interest and depreciation have been compiled. Current, however, has been estimated very closely at 60 kw-hr. per 1000 rivets and at a cost of 1 cent per kw-hr. It is the opinion of the Motive Power Department that the necessary machinery for burning, including the air equipment necessary for backing and for use on horizontal burning, would cost less than a complete pneumatic equipment.

With the pneumatic method of removing rivets, two car men and one helper can cut and back out an average of only 640 rivets in one day of 8 hours. With the arc, data which have been gathered show that two burners and one backer can remove an average of 1700 rivets per day of 8 hours; and this average can be maintained over a long period. However, the writer saw several weekly records which showed an average for six days of 8 hours each, of 2400 rivets per day. The greatest number burned in one day by one man was 1486 rivets in 8 hours. Data also show that an average of 579 rivets can be burned

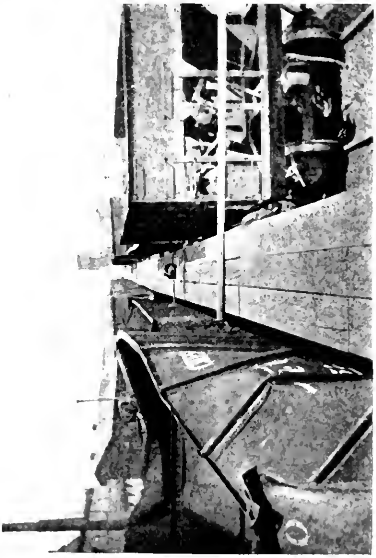


Fig 1. The center one of three platforms, 400 ft, long with line up of cars ready for the burners

Fig 2. Rivet Heads burned flush with surface of car

Fig. 3. Sample of Floor Work These eight rivets were burned at the rate of 400 per hour

Fig. 4. After the Rivets are Backed. The rivet holes are not damaged by the arc

with each 1-in. by 10-in. graphite electrode. Two burners and one backer can remove damaged parts of cars ahead of 60 repair men.

A current of 400 to 500 amperes and graphite electrodes 1 in. in diameter were used to obtain the above results. Larger currents could be used, but the advantage gained, in number of rivets burned, would be offset by the difficulty in handling the heavy arc, the danger of burning adjacent metal, the cost of very heavy cable and the difficulty in handling the cable. After careful experiments, it was decided that 400 to 500 amperes was the most economical and that an arc of ½ in. to ¾ in. was most effective.

Fig. 5. Motor-generator Set and Control (225-h.p. induction motor; 150-kw., 75-volt generator) for supplying energy to five operators per shift

Fig. 1 shows the way the equipment is lined up when it is to be scrapped or repaired. A number of cars can be assembled and the burning and backing operations concluded without having to move the cars at all, plug-in stations being installed at frequent intervals. Platforms, several hundred feet long and about 6 ft. high, are built between the tracks. When the operator has worked out of reach from the ground, he finishes by sitting or standing on the platform. Supported under this platform is the negative cable with frequent plug-in stations and ballast resistance;—500 amp., .04 ohms at each station. The tracks completing the circuit are well bonded. Sometimes the necessary supply of current cannot be obtained on account of poor contact between the track and the body of the car. In such cases, a simple jumper is provided for clamping to the rail and body of the car.

The motor-generator sets are located in close proximity to the work in order to avoid excessive drop in voltage. The operators become very proficient in handling the arc. The heads of the rivets are burned off flush with the surface of the car. Fig. 2 shows rivets after the heads have been burnt off flush with the car. This illustration also shows that the molten metal on the vertical work falls away by gravity. Note the metal lodged on bumper beneath the rivet.

At several shops, the location of the work is more or less prominent and employees on other work are continually passing and are prone to look at the arc. On this account, it is necessary at times to do the rivet burning at night, the equipment being utilized during the day on general welding work.

Face shields of the double window type are used. The inner window is of clear glass and the outer window of colored glass and hinged at the bottom and held in place by coil springs. This arrangement enables the operator to get a clear vision of his work by pulling down the colored glass and without removing his shield.

In some cases where the air hammer is used for cutting off the rivet heads, a man is required to guard the work with a board or broom to prevent the head of the rivet hitting anyone who may be passing or at work nearby. Accidents from this cause were common before air was discarded.

The electrode holders are mostly made in the railroad shops. The operators' hands are protected by circular shields about 12 in. from the electrode holder. The operators dress in ordinary workmen's overalls with no special hand or foot protection. All rivets after burning are dislodged with air punches. One backer only is necessary for two burners.

Floor rivets are burned as fast as those on vertical surfaces. A very ingenious device was developed by one of the company's employees for removing the molten metal by air; in this device a small air hose is brought to within 5 in. of the arc and when the operator is ready to blow away the molten metal, the arc is momentarily broken and a slight thumb pressure on the air valve cleans the horizontal surface for backing the rivets. See Fig. 3.

A difficulty frequently experienced with the air hammer is the removing of rivet heads on springy surfaces. One can readily see the extra time required with air when the metal gives with each blow; with the electric arc this difficulty does not occur.

When patching is to be done, the foremen will chalk mark the locations of holes, and the operator with a single contact burns a hole of sufficient diameter to take the rivets required for the repairs.

A close inspection after burning and after the work has cooled will show that the rivet is not welded to the car, the circular line of the rivet being clearly seen. The experienced operator confines his arc to the rivet head and does not burn the car or damage the rivet hole. Fig. 4 shows an example of the work after heads have been burned and the rivets backed out. Note the clean finish of the work and that the holes show no indication of the rivet being welded to the car during the process of burning.

Occasionally a car is brought in which seems beyond repair, but the damaged parts are removed so fast with the arc that repairs can be made speedily and at a minimum expense. The repair yards are nearby and very little time is consumed in removing cars from the track where the burning is done. The car department has planned its work for convenience and there is no duplication in handling of any material.

There is under consideration the installation of a small traveling crane to follow the backers so that loose pieces can be removed quickly and at little cost.

All of this work is directly under the Superintendent of Motive Power and everyone is very enthusiastic over the results being obtained.

The Thomson Wagonette of 1897

By Hermann Lemp
Works Engineer, General Electric Company, Erie, Pa.

The history of traction is always full of surprises. It will certainly be news to many of our readers that the sturdy little electric wagonette described and illustrated in this article was "doing the job" and doing it well a quarter of a century ago. We are all apt to forget how comprehensive the work of the pioneer was in some of our early developments. It is often the change in economic conditions rather than engineering skill that turns the financial failures of earlier years into modern successes. All honor to those pioneers who had the courage, skill and imagination to do such fundamental work 25 years ago.—Editor.

In the history of General Electric Company activities, it is recorded that the year 1897 witnessed, as a major undertaking, the initial development of interurban trolley lines. That various other ways of solving the many sided transportation problem were actively engaging the minds of the General Electric Company's engineers is also evidenced by the fact that in the early part of the year mentioned, the suggestion was made by Professor Elihu Thomson and E. W. Rice, Jr., that an electric carriage be designed and built. They specified that this electric carriage should combine the most advanced principles of construction then recognized, with the addition of certain novel but promising features, which it was believed would materially advance the "Electric" as a sound commercial proposition.

Actual work was begun on an electric wagonette on March 24, 1897; and on the day before "the Fourth" of that year, the conveyance made its first run through the streets of Lynn, Mass. For a period of four or five years this electric wagonette did yeoman service as a station wagon, and in other ways fully demonstrated that its designers had not erred in building a vehicle which, in a number of essentials, would be a close prototype of its successors a quarter of a century later.

A glance at the specifications which follow will convince the reader that the G-E wagonette of 1897 quite truly established what physiologists term "a type survivor" for the "species" in certain major features as well as in many minor details. Many features of the modern electric vehicle will be found in this sturdy little "horseless" of the nineties.

Capacity, Speed, Mileage

The maximum seating capacity was eight persons. The normal full load speed on level ground was 14 miles per hour when consuming 36½ amperes at 80 volts. The maximum attainable speed was 18 miles per hour. The operating radius of the wagonette, fully loaded, was roughly 20 miles, or a round trip of 10 miles.

Chassis

The chassis was of steel tubing, strongly trussed to carry its principal weights of underslung battery, motor and live or passenger load. The wheel base was 72 in.

Fig. 1. The Thomson Wagonette of 1897

Battery

The battery was of the underslung type. This method of carrying the battery was decidedly unconventional at the time and aroused considerable criticism. Experience, however, has proven the underslung battery support to constitute the best construction for commercial electric vehicles. Forty 60-ampere cells of the Electric Storage Battery Company were arranged in four compartments of ten cells each. These compartments were supported on rollers, the terminals of the battery making automatic contact with the motor circuit when in place. The batteries could be removed for charging or that function could be performed without such removal. With the battery in place, charging connections were made by opening a trap door under the right-hand forward seat, a cable being then connected to the charging terminals. The charging current was carried through a differential registering wattmeter involving approximately a period 35 per cent longer to bring the meter back to the zero point during charging than for discharging under similar current conditions. The battery also provided current for two electric lamps and a signal bell.

Wheels

The wagonette was successively equipped with both wire wheels carrying pneumatic tires and with wooden artillery wheels carrying solid tires. At the time the latter equipment gave a more favorable ton-mile wattage and less trouble on the road.

Motor

The motor was totally enclosed; its normal rating was 3 horse power at 75 volts and 30 amperes with an overload capacity of 100 per cent. The temperature rise did not exceed 60 deg. C. The fields were of the 4-pole construction. The armature had a double winding, the two parts being superimposed in single slots, each winding being correspondingly connected to a commutator placed one at either end of the shaft.

Drive

The drive consisted of an enclosed and well lubricated single reduction herring-bone gear connected to a differential on the rear axle. One side of the motor frame was swung concentrically to the rear axle, the opposite side being supported from the spring supported body; following established railway practice.

Control

Control was arranged for the following positions:

1st position forward. Battery in two sections connected in multiple with motor field and armature windings in series. (This connection was only used for starting so that for all practical purposes the battery connections always remained in series.)

Fig. 2. Thomson Wagonette Showing the Electric Motor

2nd position forward. Battery, field and armature all in series.

3rd position forward. Battery in series. Field and armature windings in multiple.

4th position forward. Battery in series. Half of field short-circuited.

1st position backward. (With carriage moving in a forward direction for electric braking.) Motor short-circuited. Armature reversed.

2nd position backward. (Single running position.) Two halves of battery in multiple. Motor armature and fields in series.

Safety Stop

In order to proceed from any forward position to the backward position, it was necessary to spring the controller handle outward and around a safety stop—this measure preventing accidental reversal. The position immediately beyond the stop acted as an electric brake when going forward, and the position of rest ahead of the stop acted automatically as an electric brake should the carriage move backwards.

Foot Brake and Locking Device

The controller was so constructed that when the foot brake was applied it automatically opened a break switch in series with the controller. Current could not be re-applied until the controller handle had been brought back to the zero, or rest position, when the break switch was automatically closed. The controller was also provided with a key for allowing the battery circuit to be permanently opened to avoid meddling or theft in the absence of the operator.

Steering

The steering was by a tiller provided with the Lemp hydraulic steering check, installed between front wheel knuckles and the steering post and handle. This hydraulic checking device performed a double function, i.e., it protected the operator from road shocks transmitted from the steering wheels and also held the latter irreversible, although at all times free to respond to any movement of the steering handle.

Although the General Electric Company never manufactured pleasure or commercial vehicles in quantities, its research and experimental work with the wagonette and self-propelled vehicles of other types indicates, nevertheless, that the company had no small part in influencing "the great revival for the electric" which Mr. Edison has so emphatically emphasized; and that it has lent material aid in the development of this important factor in our social and economic life.

New Conceptions of Matter

By G. M. J. Mackay

Research Laboratory, General Electric Company

The work of the Cavendish Laboratory at Cambridge, England, under the able guidance of Sir Ernest Rutherford, has made such profound changes in our conceptions of the ultimate structure of matter that every one is anxious to learn something about it. Recently Dr. F. W. Aston of the Cavendish Laboratory was in America and gave lectures concerning this work. Our present author gives an account of this work in as simple language as is possible, and we believe that his description will be appreciated by a large number of our readers.—Editor.

Since the time of the early Greek philosophers there has always been much speculation regarding the ultimate nature of matter, but it is only within the last hundred years that any real knowledge of this subject has been obtained. Progress was only made when careful observers began to correlate and interpret the results of quantitative experiments made in the laboratory.

Phenomena which could not be explained by the consideration of matter in bulk, as we ordinarily see it, fell into the following classes:

1. Chemical reactions;
2. Electrical conduction in metals, liquids, and gases;
3. Radiation of light, heat, and electrical energy; and
4. Radioactivity.

The quantitative study of chemical reactions led to the far reaching generalization of John Dalton—the Atomic Theory—first stated in 1803. Supplemented by the hypothesis of Avogadro in 1811, and by the correlation of the chemical properties of the elements with a periodic arrangement according to their atomic weights by Mendeléeff in 1869, the science of Chemistry firmly established the idea that each of the 87 elements was composed of extremely small particles, or atoms, of fixed weight which combined with atoms of other elements according to definite and known laws.

Investigation of the conduction of electricity in liquids and gases, however, showed that the atom of the chemist could be still further divided into particles which were negatively and positively charged. The negatively charged particle, or the electron, was found to possess a mass of 1/1850 of that of the hydrogen atom, and is considered to be the "atom" of negative electricity. The positively charged residue of the atom, or positive ion, is thus of practically the same mass as the original particle. The relative motions of these electrically charged particles under different conditions were carefully studied, chiefly by Sir. J. J. Thomson and his associates in the Cavendish Laboratory, and new light was thrown not only upon the mechanism of conduction, but also upon the phenomena of radiation.

The most radical advances in our knowledge of the structure of atoms have occurred during the last 30 years. Following an intense period of activity, due to the discovery of X-rays in 1895, which led Becquerel to the discovery of radioactivity and the Curies to the isolation of radium, the work of Sir Ernest Rutherford and his associates at Montreal, Manchester, and Cambridge, in the investigation of the disintegration of the radioactive elements, has led to most remarkable conclusions.

As a result, the atom is now pictured as consisting of two distinct, though related, systems, a positively charged nucleus, and a surrounding group of electrons arranged in shells somewhat analogous to a planetary system. The nucleus, though only about 1/5000 of the diameter of the whole structure, has practically all of the mass of the atom. It is itself complex, being built up from the nuclei of hydrogen and of helium atoms and from electrons. Though not yet definitely shown, it is probable that the helium nucleus is composed of four hydrogen nuclei and two electrons, so that the nucleus of the hydrogen atom is probably the real unit of mass, and is the real "atom" of positive electricity, which is now being called the "Proton."

From experiments on the scattering of X-rays by the electrons of the atom, and on the lines of X-ray spectra,[1] Barkla and Moseley[2] showed that the nuclear charge of an atom varied by unity in passing from one element to the one of next higher atomic weight. Thus, if the charge on the hydrogen nucleus is 1, that on the helium atom is 2, lithium 3, beryllium 4, boron 5, carbon 6, and so on up to the heaviest element, uranium, which has a nuclear charge of 92. This expression of the nuclear charge is called the

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[1] Phil. Mag. *21*, p. 648 (1911).

[2] Phil Mag. *26*, p. 1024 (1913); *27*, p. 703 (1914).

atomic number. As a further result of Moseley's work, it is possible to fix definitely the number of possible elements and their position in the Periodic Table. The missing elements are those of atomic numbers 43, 61, 75, 85, and 87.

The number of electrons in each atom external to the nucleus must be equal to the atomic number of the element in order to make the atom electrically neutral. This number is of much more fundamental importance than the atomic weight, as will be seen from the consideration of isotopes. The chemical properties of the elements are determined by the arrangement of these electrons,[3] the radiation of energy by changes in their orbital motion,[4] and the phenomena of electrical conduction in gases and liquids by the gain or loss of one or more from the atom.

Radioactivity, on the other hand, is a function of the nucleus. The nucleus of the radioactive atom explodes with the production of alpha rays, beta rays, and gamma rays. The γ rays have been identified as X-rays of very short wavelength produced by the disturbance caused among the outer electrons. The β rays are electrons which are shot out with a velocity of 62,000 miles a second. The α rays are particles of matter which are expelled with a velocity of 10,000 miles a second.

The atomic weight of the α particle has been determined by Rutherford by deflection in a magnetic field and found equal to 4. It carries two positive charges, and the spectrum has been found by Ramsay and Soddy to be identical with that of helium. The particle is therefore the nucleus of the helium atom.

Uranium and thorium are two elements which disintegrate in this way, each giving rise to a line of descendants of about 30 new elements of a very interesting type. Thus the uranium atom of atomic weight 238 and atomic number 92 explodes with the emission of an α particle yielding a new element uranium X_1, lower in atomic weight by 4 units, and in atomic number by 2 units. Uranium X_1 then loses a β particle with a consequent increase of nuclear charge to 91, but with no change in atomic weight. The changes occurring in the whole series are shown in Fig. 1.

The final product is an element identical in all its chemical properties with ordinary lead, but with a different atomic weight. The end product of the thorium series is also an element identical with lead, but with still another atomic weight. Ordinary lead has an atomic weight of 207.19 while that from uranium should have a weight of 238.2 less 8 α particles, or 206.2, and lead from thorium should have a weight of 232.12 less 6 α particles, or 208.12. During the war Soddy, Richards, Hönigschmid, and others carefully investigated samples of lead from different sources and found that the lead of lowest atomic weight from Joachimstal uranium minerals was 206.08, and the highest atomic weight of lead extracted from thorite was 207.9. Soddy has called elements of this type, which have the same nuclear charge or atomic number, but different atomic weights, "isotopes."

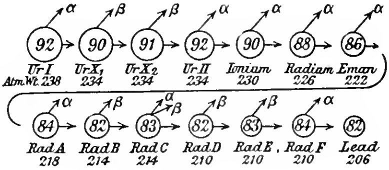

Fig. 1. Uranium Disintegration Series

The ratio of lead to uranium in certain minerals, since the life period of radioactive elements can be determined, gives a method for the calculation of the age of the earth. From such data this appears to be about 1,000,000,000 years.

A list of the isotopes of radioactive elements is given in Table I.

Of the five postulates stated by John Dalton when he gave the Atomic Theory to Chemistry, the only one which has been found to be in the least degree faulty as a result of over a century of active and unremitting investigation is the one which states that "atoms of the same element are similar to one another and equal in weight." Though the indirect evidence afforded by the discovery of radioactive isotopes indicated that this was not so, no direct method was available for testing this hypothesis until 1910. At that time Sir J. J. Thomson devised a method which, in the hands of Dr. F. W. Aston, has since become one of the most fruitful methods of applying chemical analysis to the individual atoms.

Thomson showed that sharply defined parabolic streaks were obtained on a photographic plate when beams of positively charged ions were deflected by means of

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[3] Langmuir, G. E. **Review**, *22*, p. 505 (1919); J. Am. Chem. Soc., *41*, p. 868 (1919).

[4] Bohr, Phil. Mag. *26*, pp. 1, 476, 857 (1913).

magnetic and electrostatic fields. This proved that the ratio of the charge of electricity to the mass of the particle was constant for all the ions forming the parabola, and since the charge was known to be a definite unit, that the masses of the individual atoms were approximately the same. But the apparatus was not sufficiently accurate to detect small differences in weight.

The first indication that the non-radioactive elements might also have isotopes was given when Thomson announced that when neon was analyzed by the positive ray method, two parabolas were obtained corresponding to the atomic weights 20 and 22, and none for a weight 20.2. In 1913, Aston succeeded in fractionating these two gases by diffusion through pipe clay and obtained two parts differing by 0.7 per cent in density. This result is in agreement with the separation theoretically possible in the light of the more recent and more accurate determinations.

After the war, Dr. Aston continued this investigation with the idea of making the method of analysis so accurate that the atomic weights of the gases in question would be definitely settled.

In order to do this he radically modified Thomson's positive ray apparatus, so that atomic masses can now be determined to an accuracy of one part in a thousand.

By the application of specially designed magnetic and electrostatic fields to positively charged ions emerging from a narrow slit in the cathode of an electrical discharge tube, he is able to deflect beams of ions which come to a focus on a photographic plate. Each line is produced only by charged atoms having exactly the same atomic weight, and the lines due to different atoms are separated by distances proportional to their masses. Thus a mixture of atoms can be separated into rays of particles having equal mass in an analogous way to the resolution of ordinary light by the spectrograph into its components of different wavelengths. On account of this similarity, the instrument has been called a positive ray spectrograph, and the spectrum produced, a mass spectrum.

TABLE 1—ISOTOPES OF RADIOACTIVE ELEMENTS

Substance	At. No.	Atomic Mass of Isotope	Group
Uranium	92	U_1 U_2 238 234	VI
Protoactinium	91	UX_2 Pa 234 230	V
Thorium	90	Th. UX_1 I & UY Ra. Th. Ra. Act. 234 232 230 228 226	IV
Actinium	89	Ms. Th_2 Ac. 228 226	III
Radium	88	Ms. Th_1 Ra. Th.X Act. X 228 226 224 222	II
Emanation	86	Ra. Em. Th. Em. Act. Em. 222 220 218	VIII
Polonium	84	Ra. A. Th. A. Ra. C. Th. C′ Ac. C′ 218 216 Ac. A. 212 Ra. F. 214 210	VI
Bismuth	83	Ra. C. Th. C. Ac. D. 214 212 Ra. E. 210	V
Lead	82	Ra. B. Th. B. Ra. D. Th. D. Ra. G. 214 212 Act. B. 208 Ac. D. 210 206	IV
Thallium	81	Ra. C.″ Th. C.″ Ac. C.″ 210 208 206	III

When neon was subjected to analysis in this way, it was found that lines corresponding to atomic weights of exactly 20 and 22 made their appearance. The latter line was much fainter than the former, as it should be, since only 10 per cent of the heavier isotope is required to make the mean atomic weight of ordinary neon 20.2.

Similar analyses were then made of as many of the elements as possible with the result that many of our supposedly simple elements have been resolved into two or more isotopes. Table II summarizes the results thus far obtained.[5]

The most significant result of these measurements is that, with the exception of hydrogen, the weights of all the elements measured

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Aston, Phil Mag. *38*, p.707 (1919); *39*, p.611 (1920); *40*, p.628 (1920); J. Chem. Soc. (Lond.), *119*, p.677 (1921).

"Isotopes," by F. W. Aston, Edward Arnold & Co., London, 1922.

Dempster's Phys. Rev., XI, p. 316 (1918), Science *52*, p. 559 (1920); *53*, p. 363 (1921), *54*, p. 516 (1921).

are whole numbers to an accuracy in most cases of one tenth of one per cent. Also the relative positions of potassium and argon, nickel and cobalt, are reconciled with the order of increasing mass in the periodic table.

This immediately revives the original hypothesis of Prout, suggested in 1815, that atoms were themselves built up from particles of Protyle which he endeavored to identify with hydrogen. The modern development of this idea is that the ultimate particles of matter are composed of atoms of positive electricity, or protons, and the atoms of negative electricity, electrons.

TABLE II—ISOTOPES OF NON-RADIOACTIVE ELEMENTS

Element	At. No.	At. Wt.	Minimum No. of Isotopes	Masses of Isotopes in Order of Their Intensity
H	1	1.008	1	1.008
He	2	4.00	1	4.0
Li	3	6.94	2	7, 6
Be	4	9.1	1	9
B	5	10.9	2	11, 10
C	6	12.00	1	12
N	7	14.01	1	14
O	8	16.00	1	16
F	9	19.00	1	19
Ne	10	20.20	2	20, 22, (21)
Na	11	23.00	1	23
Mg	12	24.32	3	24, 25, 26
Si	14	28.3	2	28, 29, (30)
P	15	31.04	1	31
S	16	32.06	1	32
Cl	17	35.46	2	35, 37, (39)
A	18	39.88	2	40, 36
K	19	39.1	2	39, 41
Ca	20	40.07	(2)	40, (44)
Ni	28	58.68	2	58, 60
Zn	30	65.37	(4)	(64, 66, 68, 70)
As	33	74.96	1	75
Br	35	79.92	2	79, 81
Kr	36	82.92	6	84, 86, 82, 83, 80, 78
Rb	37	85.45	2	85, 87
I	53	126.92	1	127
Xe	54	130.20	5 (7)	129, 132, 131, 134, 136, (128) (130?)
Cs	55	132.81	1	133
Hg	80	200.6	(6)	(197–200), 202, 204

Since isotopes are identical in their chemical behavior, physical methods only are available for their separation. Neon has been partially separated into its constituents by Aston,[6] chlorine by Harkins[7] and mercury by Brönsted and Hevesy.[8]

The latter by repeated condensations of mercury at very low pressures in a vacuum by liquid air have produced two fractions which differ in density from one another by 0.5 per cent. This means that it is possible to construct two barometers of chemically identical mercury but which will give readings differing by one half of a millimeter.

The isotopes of chlorine and mercury make possible the existence of 18 different mercuric chlorides, but since these can not be distinguished by any chemical test, there is no occasion for the chemist to be dismayed at the seeming increase in complexity of the compounds with which he deals; rather should he rejoice at the very great simplification which has been made in the ideas regarding the mass of the atoms of the elements.

Since hydrogen has an atomic weight greater than unity, one would naturally expect that when four atoms of hydrogen combine to form an atom of helium the resulting atomic weight would be 4.032 instead of exactly 4.00. When the positive and negative charges of the hydrogen, which are relatively very far apart, are compressed into the helium nucleus, from the electromagnetic theory of mass, a loss of mass due to "packing" should occur. But when mass is annihilated energy should appear, and, assuming the loss of mass as measured, it may be calculated that if the hydrogen in 9 cubic centimeters of water were transformed to helium 200,000 kilowatt-hours would be evolved. Dr. Eddington believes that this answers the riddle of why the sun keeps hot, since if 10 per cent of the hydrogen present in

[6] Brit. Assoc. 1913.

[7] J. Am. Chem. Soc., *43*, p. 1803 (1921).

[8] Zeit. f. Phys. Chem., *99*, p. 207 (1921).

the sun condenses to form helium, enough energy would be supplied to maintain the present temperature for 1,000,000,000 years.

The amount of energy liberated in radioactive change is tremendous when compared to the actual quantity of material involved. Thus the most efficient source of heat at present controllable is the combustion of hydrogen with oxygen to form water. The same volume of radium emanation, the heaviest gas known, by natural decay over a long period of time, yields ten million times this amount of energy. The α particle is shot out with 20,000 times the speed of a rifle bullet and 400,000,000 times the energy, mass for mass, and so provides a projectile for bombarding ordinary matter which can not even be approached by any artificial means. To speed up a positively charged helium atom to this velocity would require a potential of 4,000,000 volts, and to give an electron the velocity with which it leaves the nucleus 2 to 3,000,000 volts would be needed.

Rutherford has used this high speed helium nucleus as a tool to investigate the structure of ordinary matter, and has obtained most remarkable results. If an α particle from radium C which has a range in air of 7 centimeters hits a hydrogen nucleus in head on collision, the maximum speed given to the latter would be 1.6 times that of the α particle, and its range in air would be 28 centimeters. These ranges can be determined by observing with a microscope the splashes of light made by the impact of the particle on a zinc sulphide screen when placed at various distances from the active source.

By this method of searching for longer range particles than that of the helium projectile used, Rutherford has examined all the elements up to atomic weight 40 with the exception of helium, neon, and argon. Since hydrogen is an impurity difficult to get rid of, particles with a range greater than 32 centimeters in air only were looked for. The results are given in Table III.

In addition to these, the following elements of higher atomic weight were examined: chlorine as $MgCl_2$, potassium as KCl; calcium as CaO; titanium as Ti_2O_3, manganese as MnO_2; iron, copper, tin, silver, and gold in the form of metal foils. In no case were any particles observed of range greater than 32 cm. of air. The question whether any of these elements give particles of range less than 32 cm. has not been examined.

TABLE III—RANGES OF H PARTICLES EXPELLED BY ALPHA PARTICLES

Element	Material	Maximum Range of Particles in Cm. of Air
Lithium	Li_2O	None over 32
Beryllium	BeO	None over 32
Boron	B	ca. 45
Carbon	CO_2	None over 32
Nitrogen	Air	40
Oxygen	O_2	None over 32
Fluorine	CaF_2	over 40
Sodium	Na_2O	ca. 42
Magnesium	MgO	None over 32
Aluminum	Al, Al_2O_3	90
Silicon	Si	None over 32
Phosphorus	P (red)	ca. 65
Sulphur	S, SO_2	None over 32

These long range particles can be deflected by a magnetic field and the amount of deflection compared with that shown by the swift H particles produced when α particles pass through ordinary hydrogen. This was done, and the particles were found to behave just like swift H atoms carrying a positive charge. The results indicate, therefore, not only that hydrogen is a probable constituent of the nuclei of all atoms, but that in the cases of boron, nitrogen, fluorine, sodium, aluminum, and phosphorus, artificial radioactivity has been induced since the hydrogen atoms leave the nucleus with more energy than that possessed by the helium projectile which caused their emission.

McLennan has calculated[10] that these results indicate that by operating at six million volts one could, with the daily expenditure of 600,000 horse power, disintegrate the nuclei of three cubic feet of nitrogen and

[9] Phil. Mag., 37, pp. 538, 571 (1919); Proc. Roy. Soc., 97, p.374 (1920); J. Chem. Soc. (Lond.), *121*, p. 400 (1922).

[10] Science, 55, p. 229 (1922).

obtain thereby not only the recovery of the 600,000 horse power but also, approximately, 80,000 horse power in addition.

It must be remembered, however, that the results so far are on an excessively minute scale, since if all the α particles from one gram of radium, which amount to 163 cubic millimeters of helium in a year, were fired into aluminum, the amount of hydrogen liberated by the disintegration of the aluminum nuclei could not be more than 1/1000 of a cubic millimeter per year.

On the Scope of Spectroscopy. Some Problems and Results

By Enoch Karrer, Ph.D.

Applied Science Laboratory, National Lamp Works, General Electric Company

The author first outlines how the field of spectral analysis has increased in recent years and shows how most of the spectrum has now been "explored." Much valuable data are given in the tables accompanying this article. Formerly we used to consider the spectra of the elements as unaffected by external causes, but in the light of our modern knowledge we must now consider these spectra as being affected by such external causes as the magnetic field, the electrostatic field, and, if we believe in Einstein's theory, by gravitation.—Editor.

Spectroscopy has acquired a very broad interpretation in the last few decades and it is difficult to give a satisfactory definition except a very general one that spectroscopy has to do with spectra of electromagnetic waves.

In the early days spectroscopy largely meant spectral analysis; that is by spectral analysis the chemical composition of unknown substances was qualitatively determined by observing the spectrum emitted by the substance. Such spectral analysis was at first restricted to the visible portion of the spectrum. Substances were known to emit characteristically colored lines. To refresh one's memory on the relation between wavelength and color Fig. 1 is given.* Thus spectral analysis lent great assistance to chemistry. Substances could be qualitatively analyzed very quickly by means of the spectroscope. Further advantages offered by the method were:

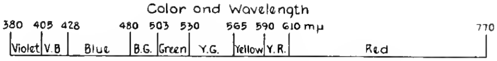

Fig. 1. Relation between Color and Wavelength

Small samples sufficed.

The qualitative chemical analysis easily obtained was a good guide to the quantitative chemical analysis.

The sample could be studied while subjected to any condition, and in confined spaces.

Another great advantage to astrophysics is that the substance may be anywhere in time and space. Thus have come about the wonderful revelations of the composition of the sun of our solar system, and of other suns of the gallactic, of stars and nebulas. The light which has left a distant star centuries ago reveals to us today what that star was made of then. Not only the composition but many other facts about the mass, size, motion and distance of the celestial bodies have been revealed.

Spectroscopy now covers the whole range of wavelengths from the shortest Hertz wave to the shortest Roentgen rays. The visible part of the spectrum is a small portion of this and still a smaller portion of the total electromagnetic wave spectrum as is shown in Fig. 2. If the portion of the spectrum of the shortest wavelengths (up to 10^{-9} cm.) were 1 cm. long and the whole of the electromagnetic wave spectrum placed upon a ribbon, the ribbon would reach from here to the sun several million times. Or hook the end of the ribbon on to the front of a light wave and let the ray of light go out into space for a century or more before the ribbon is unwound. If the visible portion is made 1 cm. long the light wave may proceed for about two hours to unwind the total spectrum to the longest wave indicated in the illustration. For the person interested only in the visible portion of the spectrum it is convenient to divide the whole spectrum into

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* These boundaries depend upon the individual eye and upon many other factors.

three parts: viz., the visible, the ultravisible (of higher frequency, shorter wavelengths) and the infravisible (of lower frequency, longer wavelengths). There are several units of length in which wavelengths are expressed. These units and their relations are indicated in Fig. 2.* (The logarithms of wavelength are plotted.) The chart also suggests how the whole of the spectrum might be divided roughly from the standpoint of general methods and apparatus.

The number of regions indicated in this chart is less than that usually given. This is particularly true in the ultravisible part where there has been a tendency to name every inch of new territory explored by the explorer's name. Certainly in the history of physics these explorers can be duly honored without so encumbering the nomenclature.

For the most part the whole spectrum has been explored in the sense that either wavelengths have been measured by direct isolation or otherwise using electrical and photoelectric relationship; or the properties of bodies have been studied with reference to the various wavelengths. There is a small region (0.40 mm. -2 mm.) between the infra-red and the Hertz waves where neither has been done. As is indicated in the illustration (by dotted arrows) this region will probably be shared by the infra-red and the Hertz regions. In the gamma region properties of bodies have been studied to some extent, but no measurements of wavelengths have yet been accomplished. Beyond the gamma region as it is now known other things may come to light to suggest a new region. It is only in the last year or so that the Roentgen and ultra-violet regions have been overlapped.†

Important as have been the practical results of spectral analysis they have only been qualitative up to very recent years. Spectroscopy can give quantitative results. To do this the brightness of the most sensitive lines of an element may be observed as the quantity of the element in a mixture is decreased. This method was first extensively used during the late war to analyze the aluminum alloys used in German airships. It has been used at the Bureau of Standards for the Treasury Department to analyze gold and silver. It was used, I believe, to establish the amount of zinc in the venom of snakes, and this fact has led to the establishment of the presence of zinc in all living cells.

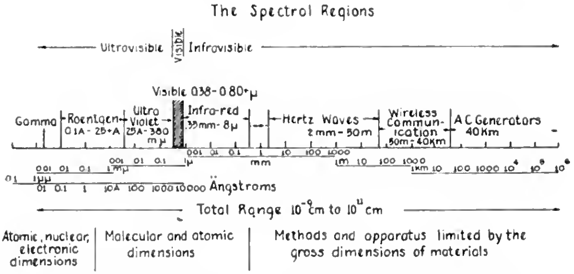

Fig. 2. The spectrum of electromagnetic waves showing the various regions and wavelengths (logarithm of wavelength is given rather than actual wavelength)

Some wavelengths which are useful in quantitative spectral analysis of the various elements are given in Table I.‡ This subject of quantitative spectral analysis is mentioned in some detail because it should be of use in the determination of molybdenum in tungsten, for instance.

After having believed for many years in unalterable spectra characterizing all elements it has been from time to time a shock of mild surprise to the spectroscopist and physicist to learn that the spectra of elements do depend upon the conditions. External magnetic fields (Zeeman effect) and electrostatic fields (Stark effect) influence spectral

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* There is some confusion in regard to the name or abbreviation of the millionth part of the millimeter. The thousandth part of the mm is generally designated by μ while more logically it is μm (i.e., the micrometer). There are good reasons for its present name (micron) and symbol (μ). The thousandth part of the micron (μ), however, should be the millimicron (mμ) and not (μμ) to avoid unclassified arbitrary abbreviations.

† For the recent pioneering in this field see Lyman, Sci., 1922, 15, 161. Millikan, Proc. Nat. Acad., 7, 289, 1921; McLennan, Proc. R. S., 1919 and 1920; Mohler and Foote, Sci. Pap. B. S. 425, 1922, or Bul. B. S. 17, p. 471, 1922; and other papers by these authors.

‡ This table is taken from Gramont C. R. 171, p. 1103, 1920.

lines, and now we believe (from Einstein's theory) that gravitational fields affect the lines. Furthermore there are the effects of pressure, temperature, chemical combination; and finally the electrical condition of the atom or molecule (ionized or un-ionized) and the effect of small amounts of foreign substances not in chemical combination.

Spectroscopy, as has already been indicated, deals with spectra whose longer wavelength limit is in the deepest infra-red and whose shorter wavelength limit lies beyond the shortest Roentgen ray. It is natural that with such extensive additions beyond the visible, new methods and new apparatus should be brought into being. At the same time new things are accomplished. For example, X-ray spectroscopy has demonstrated that it affords the best means of determining the coefficient of expansion of small samples of metals; and X-ray spectroscopy can show the differences in magnetic and non-magnetic nickel.

In general when an element is stimulated to give its characteristic spectrum (i.e., so as not to give a continuous spectrum) the spectrum consists of bright lines, whose inter-relationships have been fathomed in only a very few cases. The various chemical elements have different numbers of lines. Fig. 3* shows how the number of spectral lines varies with the atomic number of the elements. This curve is not up to date† and is perhaps more nearly accurate if we consider the lines counted to lie only in the visible and very near ultra-violet. It is interesting to note the positions where elements are still missing (indicated by heavy vertical dashes on atomic number axis). The element of atomic number 75 next to tungsten is of interest. The relationship between certain hydrogen lines, first observed by Balmer, is very simple $\frac{1}{\lambda} = N\left(\frac{1}{2^2} - \frac{1}{m^2}\right)$ where N is a constant (109678.2); λ is wavelength of any line whose position in the series is given by m representing integers 3, 4, etc. There are other simple series in hydrogen; the Lyman series $N\left(\frac{1}{1^2} - \frac{1}{m^2}\right)$ beginning at 1216 (i.e., $m = 2$); the Paschen series,

$$N\left(\frac{1}{3^2} - \frac{1}{m^2}\right)$$

the Pfund-Brackett Series,

$$N\left(\frac{1}{4^2} - \frac{1}{m^2}\right).\ddagger$$

These are expressible by

$$\frac{1}{\lambda} = N\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

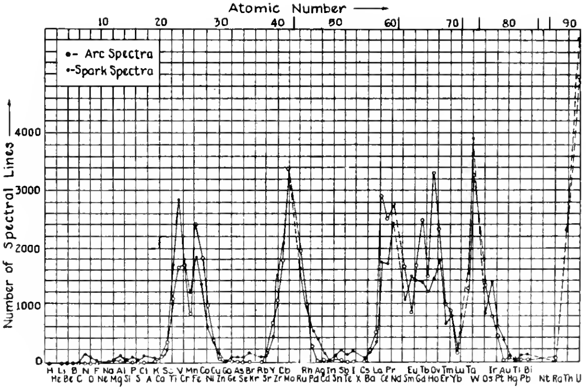

Fig. 3. Number of spectral lines of the various chemical elements

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* This curve is taken from H. S. King, Jour. Amer. Chem. Soc. 44, p. 323, 1922.

† King made his compilation from Exner and Haschek, Die Spektren der Elemente, 1911.

‡ The search for this series was undertaken by Mr. Brackett at the suggestion and under the direction of Dr. A. H. Pfund of John Hopkins. The results have not yet been published.

TABLE I

VERY SENSITIVE LINES AND SHORTEST WAVELENGTHS OF THE ELEMENTS IN THE DISSOCIATION SPECTRA

	Visual Observation	BY PHOTOGRAPHY	
		Uviol Crown Glass Spectograph	Quartz Spectograph
Aluminum	6245.1, 6233.8	**3961.5, 3944.0**	3092.7, 3082.2
Antimony		3267.5, 3232.5	**2598.1, 2528.5, 2311.5**
Silver	5465.5, 5209.1	**3383.0, 3380.7**	2437.7
Argon (1)			
Arsenic			2860.5, **2780.2, 2745.0, 2349.8**, 2288.1
Nitrogen (2)			
Barium	5535.5	**4934.1, 4554.0**, 3981.8	2335.3
Bismuth	4722.5		**3067.7**, 2989.0, **2938.3, 2898.0**, 2780.5
Boron		3451.4	**2497.7, 2496.8**
Bromine (2)			
Cadmium	6438.5, 5085.8, 4800.0	3610.5, 3261. 1	2748.6, **2288.0, 2265.0**, 2144.4
Caesium		**4593.2, 4555.4**	
Calcium	**4226.7, 3968.5, 3933.7**		
Carbon		4266.9	**2478.6**, 2296.9
Celtium (3)			2685.2
Cerium (4)		4186.6, **4040.9, 4012.6**	
Chlorine (2)			
Chromium	5208.4, 5206.1, 5204.5	4289.7, 4274.8, **4254.3, 3605.3, 3593.5**, 3578.7	
Cobalt	5353.5, 5342.7	**3453.5, 3405.1**	**2388.9, 2378.6**, 2363.8, 2311.6 2307.9 2286.2
Colombium		4101.0, **4079.7, 4059.0**, 3358.4	
Copper	5218.2, 5153.3, 5105.6	**3274.0, 3247.5**	
Dysprosium (1)			
Erbium (4)		3906.3, 3692.7, 3499.1	
Tin	524.7	3801.0, 3330.6, **3262.3**	**2863.3**, 2840.0, 2706.5
Europium (1)		4205.1, **4129.8**	
Iron	4404.3, 4383.6	4045.8, 3820.4, 3737.1, 3734.9, 3570.2, 3565.4	**2755.7, 2749.3, 2739.6, 2395.6, 2382.0**
Fluorine (2)			
Gadolinium (1)			
Gallium		**4172.1**, 4033.0	
Germanium		3269.5	**3039.1**, 2651.4
Glucinium		3321.4, 3321.4, 3321.1	**3131.1, 3130.4**
Helium (1)			
Holmium (1)			
Hydrogen	**6562.8**		
Indium		**4511.4, 4101.8**	
Iodine (2)			
Iridium (4)		**3513.7**, 3437.1 **3220.8**	
Krypton (1)			
Lanthanum (4)		4333.8, 4086.7, 3995.8, 3988.5, **3949.1**	
Lithium	**6707.9**	**4602.2**	
Lutecium (1)			
Magnesium	5183.6, 5172.7, 5167.3	3838.3, 3832.3	**2852.1**(1), **2802.7, 2795.5**
Manganese	4823.6, 4783.5, 4754.1	**4034.5, 4033.1, 4030.9**	**2605.7, 2593.7, 2576.2 2536.5**
Mercury	5460.7, 4358.3		
Molybdenum	5570.5, 5533.2, 5506.5	**3903.0**(2) **3864.1, 3798.3**(2), 3635.2	
Neodymium (3)		4303.6, 4177.3, 3951.2	
Neon (1)			
Nickel	5476.9, 5081.1, 4714.4	3619.4, 3524.5, 3515.1, **3414.8**, 3380.6	2437.8, **2416.2, 2316.1, 2303.0**
Gold	6278.2, 5837.4, 4792.6		2802.2, **2676.0, 2428.0**
Osmium (1)			
Oxygen (2)			
Palladium (4)		**3634.7, 3609.6**, 3421.2, **3404.6**	

TABLE I (Continued)

VERY SENSITIVE LINES AND SHORTEST WAVELENGTHS OF THE ELEMENTS IN THE DISSOCIATION SPECTRA

	Visual Observation	BY PHOTOGRAPHY	
		Uviol Crown Glass Spectograph	Quartz Spectograph
Phosphorus			2555.0, 2553.3, 2535.6, 2534.0
Platinum (3)	5475.8, 5390.8, 5301.6, 5227.6	3966.4, 3923.0, 3268.4	3064.7, 2929.8, 2734.0, 2659.4
Lead	5608.9, 5005.5	4057.8, 3683.5, 3639.6	2614.2, 2203.6, 2175.8
Potassium	5832.0, 5801.8, 5782.4	4047.2, 4044.2, 3447.4, 3446.4	
Praesodymium (1)			
Radium (1)		4825.9, 4682.2, 3814.5(3)	
Rhodium (4)		3799.3, 3692.4, 3658.0, 3434.9	
Rubidium		4215.6, 4201.8	
Ruthenium (4)		3499.0, 3436.7	
Samarium (1)			
Scandium (4)		4246.9, 3651.9, 3613.8, 3630.8	
Selenium (2)			
Silicon	6370.9, 6346.8, 5057.0, 5042.3		2881.6, 2528.5, 2516.1, 2506.9
Sodium	5895.9, 5890.0	3303.0, 3302.4	
Sulphur (2)			
Strontium		4607.3, 4305.5, 4215.5, 4077.8	
Tantalum (3)	6045.5, 5997.4	3631.9, 3406.9, 3318.8, 3311.2	2963.4
Tellurium			2769.8 2530.8, 2385.8, 2383.3
Terbium (1)			
Thallium	5350.5	3775.7, 3519.2, 3229.8	2767.9
Thorium (4)		4019.1 3601.1, 3539.6	
Thulium (1)			
Titanium	Green lines (4014.3 to 4981.8)	3372.8, 3361.2, 3349.4	
Tungsten (3)		4302.4, 4294.7, 4088.8, 3613.8, 3215.6	2397.1
Uranium (2)			
Vanadium (3)		4408.5, 4379.2, 3185.4, 3184.0, 3183.4	3110.7, 3102.3, 3093.1
Xenon (1)			
Neo-Ytterbium (4)		3988.0, 3694.2, 3289.4	
Yttrium (4)		3774.3, 3710.3, 3633.1, 3600.7	3242.3
Zinc	6362.3	4810.5, 4722.2, 4680.2, 3345.0	2138.5
Zirconium	Blue lines (4815.5 to 4687.8)	3496.2, 3438.2, 3392.0	

(1) No results obtained by the author.
(2) Giving neither very sensitive nor ultimate lines.
(3) In course of investigation; results tentative.
(4) Investigation only with Crown Uviol; results tentative.

(1) Masked by sodium line 285.8.
(2) Hidden by lines from iron.
(3) Runge and Precht.

where *m* and *n* are integers, *n* identifying the series and *m* the position in the series. For alkali metals similar series have been observed expressible by

$$\frac{1}{\lambda} = N\left(\frac{1}{[n+a+f(n)]^2} - \frac{1}{[m+b+f(m)]^2}\right)^*$$

$$=(n, a)-(m,b) \text{ for ease of reference.}$$

The most interesting and far reaching relationship that has recently come to light in spectroscopy is the correlation between the frequency of the radiation and the energy required to make the atom give out the radiation. This relationship is due to Einstein and Planck. It is a simple one and states that $h\nu = eV$ where ν is frequency; V is voltage; e, the elementary charge (4.744×10^{-10} e.s.u.) and h is the quantum constant (6.55×10^{-27} erg. sec.).

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* F. A. Saunders, A review of the Series in the Spectra of the Elements, Jour. Optic. S. A. 5, p. 1, 1922.

From this we derive $\lambda V = \text{constant} = 12345$ (easy to remember), where λ is wavelength (Ångstrōms) and V is voltage (volts). Such a relationship has been found to hold from infra-red to the shortest Roentgen radiation. This we may generalize in the words: for every frequency whatever there is a corresponding voltage. Of course such a general relationship, however interesting, could not simplify the classification of spectral lines in itself, for there are an infinite number of voltages and an infinite number of wavelengths possible.

The simplifying element which comes to our service is the fact that there are certain critical values* of the voltage which will cause the atom to emit a particular line or lines without ionization, or will ionize with emission of certain lines whose frequeneies are less than a definite limiting frequency; so that the spectral lines may be associated with these critical values of the voltage or their differences. The fruitfulness of these relations has already been demonstrated.

Fig. 4† is inserted to illustrate these relationships. The curve was drawn from data (probably not the latest) immediately available and is intended to be merely illustrative of the facts. The radiation (dots) and ionizing (crosses) potentials for several elements are given as ordinates against wavelength as abscissa. In this way spectroscopy will lend a ready method for determining ionization potentials, which are of fundamental importance in connection with arcs and discharge tubes.

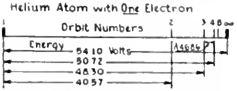


Fig. 5. Diagrammatic illustration of the structure of an atom

So we may form a simple picture in which straight lines represent critical voltages and the lengths of these lines and their differences represent the corresponding wavelengths. This is merely a picture of an arrangement of lines, but a simple process of the imagination transfers the lines into the atom to represent there the energy of the orbits of the electrons which radiate. This is all a matter of fact, but the paths leading to the facts were illuminated by a brilliant theory which we cannot here consider in detail.

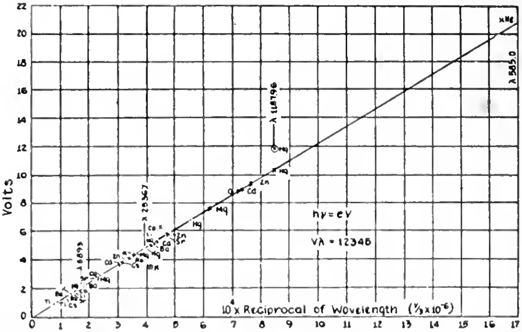


Fig. 4. The quantum relationship or the relation between frequency and voltage; critical values of voltage of a few elements are shown

In Fig. 5‡ is shown a schematic representation of an atom as just outlined. The simplest atom which accounts for some spectroscopic and other data is one in which a small nucleus (Rutherford) is surrounded by orbits allowing definite quanta of energy (Bohr and Sommerfeld), for electrons which radiate definite quanta of energy (Einstein, Planck) for all interorbital jumps (Bohr).

Spectroscopy continues in the romantic story begun with the vastest things in time and space (Fraunhofer's discovery of dark lines in the sun's spectrum) and now bidding well to disclose the insides of the tiniest thing in the universe (the atom with its nucleus and electrons).

---

* Franck and Hertz (Verh D. P. Ges. 16 p. 512, 1914); Davis and Goucher, and many other names should be posted here, but for bibliography see Bul. Nat. Res. Council, Report on Photo-electricity; Including Ionizing and Radiating Potentials. 2 p. 83, 1921.

† The curve is based upon or calculated from data given in the papers of Foote and Mohler, McLennan, Lyman and others.

‡ Taken from Hughes, Bull. Nat. Res. Council, 2 p. 83, 1921. For a more complicated but excellent illustration see Foote and Mohler, Phil. Mag. 1921.

ELECTRIFICATION OF MERCHANT SHIPS

We have received the letter printed below from William Beardmore & Company, Limited, with the request that we publish it. We do not wish to open our columns to a controversy and do not hold ourselves responsible for the opinions of our contributors, but we certainly wish to avoid doing any one an injustice.—EDITOR.

WILLIAM BEARDMORE & CO., Limited

Naval Construction Works,
Dalmuir,
Dumbartonshire.

April 10, 1922.

The Editor,
GENERAL ELECTRIC REVIEW,
Publication Bureau,
Schenectady, N. Y.

Sir:

In the issue of the GENERAL ELECTRIC REVIEW, dated December, 1921, there appears an article on the "Electrification of Merchant Ships," by Mr. E. D. Dickinson of the General Electric Company, in which it is stated that "*the WULSTY CASTLE was not a success. In our opinion the equipment was not designed for the service.*" Such a drastic statement requires an emphatic protest, as it is made under an entire misapprehension of the facts.

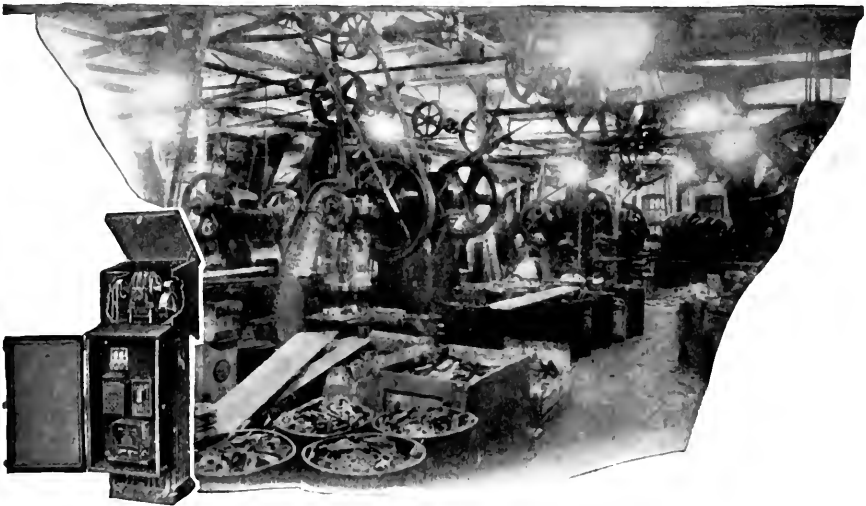
The equipment of this ship was designed and carried out on the lines of the earlier Swedish electrically-propelled craft, and every possible consideration was given to the conditions of service, and so far from proving a failure, the electric gear has, as with the Swedish vessels, operated with great satisfaction.

It is true that some difficulties were experienced in the early part of her career with some boiler and ventilation fittings, totally unconnected with the electrical portion of the plant, and since these were rectified, the ship has made several voyages without a hitch of any description. So far from being unsuccessful, she has shown a fuel economy higher than can be attained by direct geared or reciprocating steam equipment of the same power.

As this vessel is now operated by the subscriber's firm, and the statement made in your article is likely to prejudice the vessel, I shall be obliged if you will insert this letter in an early issue.

Yours faithfully,

It is hard enough for industry to take its unavoidable losses. There is no excuse for exposing it to avoidable ones



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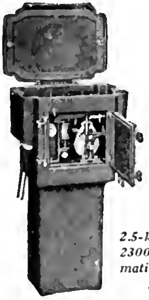

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SEPTEMBER, 1922

CONTENTS

Crystal Analysis by X-ray Diffraction Apparatus, as described in this issue, has been used in scientific laboratories for some time. Its application to factory control work is more recent but is extending. Our illustration shows an apparatus designed for this purpose

GENERAL ELECTRIC REVIEW

SCIENCE AS THE HANDMAIDEN OF INDUSTRY

We publish in this issue an article entitled "A New X-ray Diffraction Apparatus" by Dr. W. P. Davey. With this apparatus qualitative analysis of materials can be carried out and results can be obtained which cannot be arrived at by the older methods.

Chemistry and physics are both playing a wonderful, and more useful than wonderful, part in our present industrial developments. Physical chemistry, the child of the last few decades, seems destined to open up new fields in our ever increasing knowledge of those natural laws which it is the function of the industrial research laboratory to convert to commercial practice for the useful service of man.

But the physicists and chemists have gotten so far ahead of the engineer and layman that there is a serious danger that the usefulness of much of this work will be limited if we do not try to get at least a broad understanding of some of these advanced methods.

In the present instance here is a piece of apparatus developed to the stage of commercial usefulness and capable of extensive application in many industrial institutions but based on principles which are not known at present except to a few scientists. Is it not time that our engineers and laymen tried to inform themselves about what the physicist has learned in recent years concerning the geometric arrangement of atoms in space? A broad understanding of this work is necessary to keep abreast with modern *commercial* developments.

One of the extraordinary things about the piece of apparatus under consideration is that it has not only been brought to commercial form but has been made almost a penny in the slot machine—a kind of "you press the button and we do the rest" business.

It is our purpose in this editorial to try to give our readers at least a general idea of the principles upon which this machine is based.

It is common knowledge that most materials may be found in, or reduced to, crystalline form. It is also well known that crystals are classified into families, each family having a definite geometric form which may be expressed in terms of axes of reference in much the same way as are the forms and shapes in solid trigonometry or analytic geometry.

It ought, perhaps, to be better known than it is that crystals are built up of orderly layers of atoms and that for every crystalline substance there is an arrangement of atoms in space which is quantitatively just as characteristic of that substance as is any other measurable property—*e.g.* solubility, density, or melting point, etc.

Now the interpretation of the structure of a crystal is a two-stage process. First—the distances between the various planes of atoms is found. Then, second—a search is made for that arrangement of atoms in space which will give the interplaner distances found in the first stage of the process.

If we find some scientific trick for measuring the distances between these layers of atoms we have accomplished the first stage.

Now these distances are very small and we should not get far if we try to measure them with a foot rule, but the mechanic in the workshop is accustomed to measure small distances with a micrometer gauge. In such a gauge the small distances are more readily discernible by the use of a calibrated scale which measures the small distances by means of graduations in larger divisions so that the larger, easily read, divisions really represent smaller unreadable distances—just a mechanical trick. Instead of using a mechanical micrometer in the present instance, X-rays of known wavelength are used.

Just for one minute imagine a piece of crystal built up of layers of atoms subjected to a beam of X-rays of definite known wavelength, and beyond the crystal imagine a photographic film. Now most of the X-ray beam will pass clear through the crystal but a portion of the beam will be diffracted according to the number and arrangement of atoms it meets.

The picture that we get on our film is a series of straight lines and the position of each of these lines depends upon how much or how little the atoms in the crystal have diffracted the X-rays.

Now the angle of diffraction is not what we want but it is the means of arriving at what we want. We get what we are seeking—the distances between the centers of the individual atoms—by solving a very simple equation which expresses the relationship between the wavelength of the X-ray (known), the angle of diffraction (what we measure) and the distance between the centers of adjacent atoms (what we find by calculation).

If you will refer to Fig. 7, page 569, you will see the photographic film placed in a simple slide rule calibrator which does these calculations for you in much the same way as the ordinary slide rule, only more simply.

With such a device it is as easy to measure a distance of 1.164×10^{-8} cm. or 0.000000005 in. accurately as it is for the mechanic to read his little distance of 0.001 inch. The one is a mechanical trick—the other is a physical trick, which is made use of in order to solve the first stage of our problem, namely, to find the distance between the planes of atoms in the crystal.

The second part of the problem, namely finding the arrangement of atoms in space, which will account for the interplaner distance is solved in the following manner: The interplanar distances are first plotted on a piece of paper laid against a logarithmic scale found at the bottom of a chart as in Fig. 8, pages 571-580. In this way the plot is made to show the ratios of interplanar distances rather than the distances themselves. The paper bearing the plot has then the same relation to the chart that the slide of the ordinary slide rule has to the rest of the rule The plot is then moved over the chart until an exact fit is found The charts shown in the article do not of course represent every possible arrangement of atoms in space, but they do represent the most common arrangements When an exact fit has been found the system of the marshalling of the atoms in space is given by the title of the chart; and the ratio of the lengths of the vertical axes to the length of the horizontal axes is given by the ordinate of the chart.

To date the crystal structures of most of the common chemical elements and of many of their compounds have been worked out and are available. More data of this sort are being published in nearly every issue of the various scientific magazines so that it should not be long before crystal analysis becomes a routine method of qualitative identification of materials. It should be especially useful in metallurgical work and in factory control laboratories which deal with crystalline materials.

An example of exactly how these operations are carried out will be of interest to our readers.

Let us assume some factory product such as carbon, an alloy, or some special chemical compound which the manufacturer desires to keep to a definite standard composition which has been found to give commercially satisfactory results and which he desires to duplicate.

A small pinch of this standard product is crushed to a very fine powder and placed in a tiny glass tube. This tube in turn is inserted in the X-ray diffraction apparatus.

The switch is closed and the X-ray picture taken. After the film is developed it forms the standard of reference for the manufacturer's standard product. Other films taken of samples of other batches of factory products should give exact duplicates of our standard of reference. If they do not, the product is not the same as the standard.

The chemical content of the sample may be found by determining the crystal structure of the specimen by means of the charts and then from these data calculating the dimensions of the unit crystal.

The structure and dimensions are then compared with published data as a means of identifying the material.

It is likely that in the future purchasing agents will specify the grade of material they wish to buy by simply specifying the specific crystal structure as determined by these charts.

J. R. H.

ALEXANDER GRAHAM BELL

Since our last issue went to press a very famous inventor has died—Alexander Graham Bell died on August 2nd at Sydney, Nova Scotia. He was born in Edinburgh, Scotland, in the year 1847.

"A man shall be known by his works" and so it happened that 13 million telephones were silent as a tribute of respect through those brief moments when the inventor of the telephone was laid to rest.

Although Bell was world famous on account of his epoch-making invention—the telephone—his genius was by no means confined to this field. He was an all-around scientist, a man of broad vision and possessed of untiring energy. To him the world was full of secrets waiting to be learned by man and he was anxious to learn them. The secrets of mechanical flight and skimming boats held equal fascination for him with the secret locked up in anthropology, entomology, physics, chemistry and geology.

He had all the attributes of a real inventor—imagination—faith—energy—and perseverance—all were necessary to give the world the telephone.

The telephone was no haphazard invention. It was arrived at only after years of experimentation and study. He and his brother had built models of the human throat in an effort to produce mechanical speech years before he tried his bolder experiments in trying to transmit human speech over a wire.

He had spent three years working in a cellar before that memorable date, March 10, 1876, when he succeeded in transmitting speech for the first time.

Bell was one of the comparatively few inventors who have lived to see their work recognized and used in every corner of the world. Most inventors give much more than they receive and even the successful ones who reap the benefit of their work give to the public many thousand fold, compared with what they get. The inventor gets a monopoly for 17 years for divulging his invention to the public and after that 17 years it becomes public property. How much has he given? It would be hard to estimate the value of the telephone to mankind.

There is a curious misunderstanding in the public's mind about inventions—most people seem to assume that each invention limits the field of future inventors—in reality just the opposite is true. Bell's original invention of the telephone has led to more than 8000 patents being filed in Washington on the telephone alone.

When such an invention is made no one can measure the scope of its possible usefulness. The wireless telephone of today would have been impossible without Bell's land telephone—progress leads to progress and one invention leads to another invention. The work that Bell did during his life will serve mankind through many future ages.

J. R. H.

Hazards in Hydroelectric Plants

By Alex. E. Bauhan

Superintendent of Stations, Pennsylvania Water and Power Company

The world's work is being performed daily in the face of hazards to life and limb. There is no legitimate reason, however, why these hazards should be allowed to result in accidents. The responsibility for the accomplishment of a task without fatality or injury lies equally upon those who arrange for the work to be done and upon those who actually do the work. In the following article Mr. Bauhan describes some of the hydraulic and mechanical hazards present in the operation of a low-head hydroelectric plant and outlines corresponding precautions that the power company has taken and found to be effective if supplemented by thoughtful conduct on the part of the employee.—Editor.

The hazards to life and limb which are peculiar to the operation and maintenance of a waterpower plant are of sufficient importance and frequence to warrant their enumeration and a consideration of the precautions which may be taken to avoid them. Reference will not be made to the electrical hazards, which are more or less common to all types of electrical stations, nor to the hazards which are found in any industrial plant, but to those in connection with the hydraulic works, such as floods, outside structures, flashboards, screens, headgates, and wheel pits.

It is difficult to deal with this subject in a way which would take in all types of power plants under varying conditions of head, general design, and type of unit; and the article will have in mind more particularly the low-head type of plant. On account of these many varying conditions each plant will be found to have hazards of its own which are not found in other plants and which must be treated specially in each case.

However one generalization that can be made is that safety to men when working on hydraulic machinery as well as any other power-house machinery requires that there be in effect an adequate hold-off system—some kind of a systematized procedure by which men are reported on apparatus and protected in such a manner that this apparatus cannot be made alive or started until they are reported clear. Such systems are in general use on the electrical end and can very well be extended to cover not only the major hydraulic apparatus but also governor piping, lubricating systems, compressed air systems, window mechanisms, and in fact everything in any way involved in the operation, whether electrical or mechanical. For the purpose of graphically recording where men are reported on apparatus other than electrical, particularly on the governor piping system, a hydraulic mimic board such as shown in Fig. 1 which corresponds to the mimic board on the electrical end has been found useful in one case. The condition of every valve in the governor system is indicated and the operation of pumps is shown by pilot lights. The hold-off cards for the hydraulic piping equipment are attached to this board.

Clear and unified designation of equipment has an important bearing on safe hydraulic operation. The operation of a plant requires that orders referring to various equipment be given from man to man either in person or over the telephone. In order that the danger of misunderstanding orders may be minimized, it is advisable to have all equipment in the station officially designated and to make it the practice for everybody to use these designations. If a man who has been in the habit of calling a piece of apparatus by a certain name works with another man who may have been using a different name for it, confusion and possibly an accident may result. Every piece of equipment in the station and every part of the plant should have a name and it should be called by that name by everyone, not only in the operation but in the office and engineering forces of the company. It should appear by that name on all prints. Designations should be posted on a diagram and should appear as far as possible on the apparatus itself in prominent lettering.

Floods

One of the less frequent, but nevertheless important, hydro-plant hazards occurs in connection with floods. Hydro plants are always laid out with the "highest possible" river flow in mind. In many cases river flows or elevations in excess of the "highest possible" have occurred due to unusual precipitation or ice gorges. It is wise to give thought to what would be done in such an emergency. Even flows no higher than expected may require special attention because of their infrequence. There may be warnings to be given to those concerned or endangered by the high flow or high water elevations.

There may be possibilities of washouts around dam abutments or around the powerhouse entrances or deflection walls. There may be drains in the power house which should be stopped up to prevent tailwater backing up into the station. There may be doors and openings in the building at low elevations which may be flooded by high tailwater, for which barricading should be provided. A quantity of burlap bags, which can be filled with sand or dirt, should be kept on hand if these dangers exist. Such water as may come in or result from drainage in the station may be taken care of by the regular pumps used for other purposes. It may be advisable to have special suction and discharge connections made up and ready for use.

Outside Structures

As far as the dam itself is concerned there is in most plants practically no maintenance work to be done and such work as there may be will probably be peculiar to each plant and require special treatment from the safety standpoint. Generally there should be life preservers at those points around the dam, forebay, and tailrace where there may be occasion to use them. The rope attached to the preserver should be made up in a bundle which comes loose with a yank and not require any untying. Railings should be installed on all walkways above or adjacent to the water. The feeling of security which is present where the water elevation is near to that of the walkway is not a reason for omitting the use of railings. Railings are sometimes omitted in places where they occasionally interfere with work, such as at the screens. If the railings are mounted in floor sockets and made portable they can be easily removed in sections when necessary. In the winter time, covered boxes containing sand should be placed at advantageous points around the plant so that this can be frequently spread on walkways when ice is forming from sleet or spray. Infrequently used railroad tracks on grades should be cleared of weeds before passing loaded cars over them. Weeds on the track may result in sliding and loss of control of the cars. For the same reason de-railers should be used at curves, switch backs, and other danger points on grades.

Flashboards

In many cases the dam is equipped with flashboards for the purpose of increasing the effective head on the plant and these flashboards require operating and maintenance attendance which involves certain hazards. Work on the flashboards is usually done from floating equipment and the special hazards involved are: security of scows, man overboard, and that of a man being washed over the dam. If the work on the flashboards is always done at times when the elevation of the water is below the crest of the dam, the hazards are reduced to only the danger of a man falling overboard and obviously the provision for this should be one or more life preservers on each piece of floating equipment. When the work is done with water flowing over the crest of the dam or over the tops of the flashboards, particular attention must be paid to the mooring of the scows and to the danger of men being washed over.

At one plant certain precautions are taken with regard to the security of the floating equipment, which are more or less general in their application and will therefore be given in detail. The flashboards in this case consist of wooden boards made up in the form of panels about 10 ft. long, from 3 to 4½ ft. high, and 1½ in. thick. These panels are supported by steel pins set in cast-iron sockets in the crest of the dam. The principal operations consist of inserting the pins in the sockets, placing the boards, fastening them, stopping leakage with cinders after the water elevation has come up; and, previous to freshets, in dismantling the boards and pulling out the pins. If the boards have been left on the dam through a freshet which has caused failure of the boards by the pins bending over, the boards will be washed away and the work consists in pulling out the bent pins and clearing the crest of floating debris. This work is usually done with up to 18 in. of water flowing over the crest of the dam, and ordinarily by hand with the aid of an ordinary decked scow. If water is spilling over the top of the flashboards at the time when a freshet is predicted, it is necessary to remove the boards by means of a derrick boat.

The derrick boat or the scow (Fig. 2) is brought into position and maneuvered to and from the dam by a motor boat. They are prevented from going over the top of the dam by the use of anchors and of guard pins inserted in the crest of the dam. A series of anchors have been planted about 1000 ft. upstream from the face of the dam at 500-ft. intervals across the river. A cable held up by a buoy is attached to the anchor. In

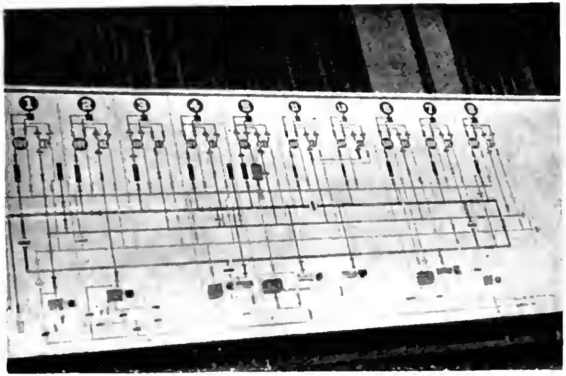

Fig. 1 A Hydraulic Mimic Board to which Hold off Cards are Attached. It covers the piping and valves of governor and hand-control systems and other related piping. The operation of the pumps is indicated by red pilot lights

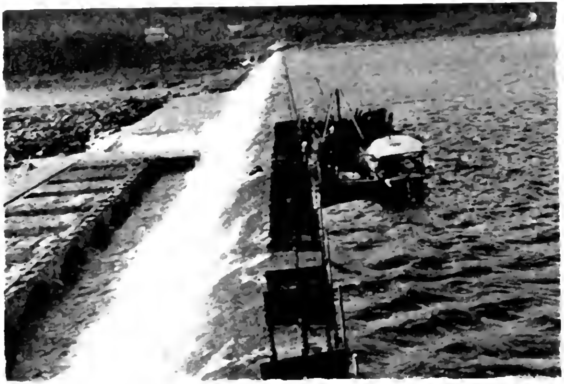

Fig 2. Use of Guard Pins for the Security of Floating Equipment on Flashboard Work. Anchors are also used for the purpose

Fig. 3. When men must get out on the crest of a dam, handlines about the waist are necessary

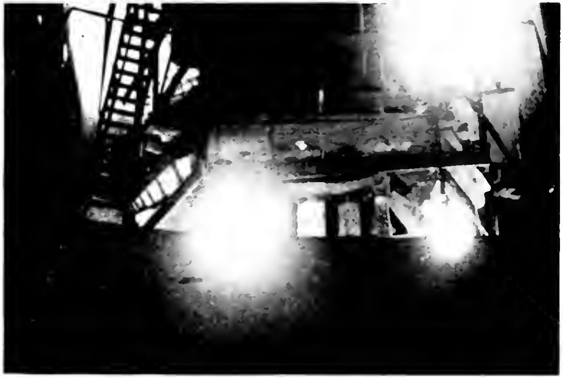

Fig. 4. The use of a stairway instead of a ladder in the scaffolding for this wheel-pit job not only made the work safer but expedited it

bringing the floating equipment out for work the scows are first brought to one of the anchor buoys and a line attached. The scow is then moved across the stream to the next anchor and another line attached. The two lines to the anchors are then played out from the scow as the scow is advanced to the face of the dam. One anchor is sufficient to hold the scow without dragging under the most adverse conditions, but the second anchor is used as additional security. The use of two anchor lines also assists in maneuvering the scow along the face of the dam. By pulling in on one line and letting out on the other the scow can be moved without the aid of a motor boat.

It is necessary to remove the anchors during the winter season for the reason that the buoy cables would be torn loose by the ice. For this reason the anchors must be of a design which can be pulled up and yet have sufficient holding power. Steel rails cast into a concrete block were originally used but were unsatisfactory from this standpoint. Ordinary mushroom anchors about three feet in diameter were then used for this purpose but were found to be inadequate in rough weather and high stream velocity, and it was necessary to increase the effective area of the anchors in the manner shown in Fig. 6.

In addition to these facilities the scow is prevented from going over the crest by a series of guard pins. These pins are of steel $3\frac{1}{2}$ in. in diameter set two feet into the crest of the dam in cast-iron sockets. These pins are set about two feet upstream from the pins which support the flashboards and are of sufficient strength and height to prevent any of the floating equipment from going over.

When the work requires that men get out of these scows and work on the crest of the dam they are protected from going over by handlines around their waists (Fig. 3). Men on board the scows are delegated to take care of these handlines and keep them from getting tangled.

The men engaged for this class of work are principally experienced river men and the foreman in charge is an ex-seafaring man. Skillful as such men are around floating equipment, they sometimes exhibit a certain amount of delight in doing their work in a hazardous way and a tendency to scoff at safety precautions. Nevertheless, the chance of recovering a man who goes over the dam is so slight that insistence on the use of the handline is necessary. If the dam crest is wide and is dry or if the dam is not high this may not be necessary.

Screens and Headgates

Work in that part of the plant which includes the intake screens and the headgates for the turbines, usually called the gate house if indoors, consists of raising and lowering screens, removal of debris and cake ice, raising and lowering of headgates in connection with the normal day to day operation of the plant, dismantling of headgates for painting and repairs, dropping and raising of stop logs in front of the headgates as well as other work of a more general nature.

Much of this work, especially removal of debris on screens, requires that men place themselves in positions where a slip or fall would throw them into the water and for this, as in other places, the handline around the waist is the preventive. A number of life preservers in readily accessible places should also be provided. Particular attention should be given to handrailings which can be made removable in sections if necessary to facilitate work.

In connection with the handling of screens there is a certain hazard if no special shackles are provided for the purpose of lifting the screens. Fig. 5 shows a lifting follower developed for the purpose of lifting screens below water level. Previous to the use of this device it was necessary to grapple for the submerged screen, pull it to the surface, send a man down to put a sling through the screen, and attach it to the crane hook. This was hazardous work particularly when the screens and guides were covered with frazil ice.

The usual facilities for lifting screens include some kind of a crane. Where an ordinary traveling crane is used, the pull is normally vertical whereas the screens are mounted at an angle. In attempting to lift the screens with this vertical pull undue forces are put on the screen guides which may cause breakage of either the guides or the cables or may make the movement of the screen jerky and hazardous. The practice of running the crane carriage over to a position which makes the pull in line with the guides and holding it there with the controller is likely to result in burned out motors and rheostats and is difficult to say the least. A device has been developed to take care of this difficulty. A cable fastened to the crane carriage structure is run through a gripping device attached to the crane truss above the operator's head and operated by a handwheel within his reach. The cable then passes through a sheave on the truck and runs across to a similar sheave on the truck at the other end of the crane and then back to the carriage where it is fastened. This makes a loop of cable which, so long as the gripping device is open, idles back and forth with the movements of the carriage. When a screen is to be lifted the carriage is run over to the position to give a straight line pull on the screen and the cable is gripped by turning the handwheel. This holds the carriage securely against the horizontal pull resulting from lifting the screens at an angle.

Fig. 5. This Screen Lifting Device eliminated the hazardous practice of grappling for the screen, pulling it to the water surface, and sending a man down to sling it to the crane hook

Another idea which is more for convenience than for safety is to mark the craneways and to place a pointer on the crane in such a way that the crane can always be brought quickly and accurately to the correct position for lifting screens or gates, so that the pull is in a vertical plane and not sidewise.

Needless to say, the screen lifting equipment should receive that inspection and attention which is usually required of such devices. The importance of such detailed inspection was emphasized in one instance by a heavy grease cup dropping from the crane and falling on the head of a man below. In connection with the use of lifting equipment around the gates and screens, it is wise to caution all by-standers not engaged in the immediate work to stand back so that in case of the breaking of a cable they will not be caught by it.

A matter of design which affects maintenance rather than safety, but which nevertheless involves safety to a certain extent, is that the guides for gates and screens should be designed substantially or so that the wearing parts can be renewed. In one plant where the guides were built up of light channel iron and flats, these wore through and finally broke out in several places in such a way that the gates were jammed. This in turn caused breakage of the gate lifting mechanism in a manner that might have caused parts to fly around and strike someone.

Fig. 6. A Modified Anchor for Holding Floating Equipment on Flashboard Work

Provision for inserting stop logs in front of headgates should be made so that the gates can be taken out for repairs. The placing of stop logs is also advisable when extended work is being done in the wheel pit for the reason that the main headgate may accidentally be raised. The calamity which might result is so serious as not to justify the dependence on headgates alone, unless they can be disconnected from their mechanisms and made completely inoperative. Such stop logs should be designed so that jamming with consequent breaking of lifting tackle is unlikely. Special lifting followers are advisable.

Wheel-pit Work

Work inside of the wheel pits requires special consideration. While the amount of work which it is necessary to do in the modern single-runner turbine is very small and does not offer any special difficulties, such is not the case in turbines having two or more runners, which is the prevailing type in all but the more recent installations. In such turbines the entire operating mechanism is usually mechanically complicated and subject to frequent repair due to breakage, corrosion or erosion and entails special hazards particularly when the setting is vertical. The principal work in turbines of this kind consists of periodic and emergency inspections, removal of obstructions, minor repairs or adjustments of a few hours' duration, major repairs and overhauling requiring the replacement of parts, some of them heavy and involving difficult rigging problems extending over periods of several weeks.

The special hazards involved are slipping, stumbling, inadequate scaffolding, dropping of tools or parts, inadequate rigging facilities, loss of illumination, defective portable lamp cords, accidental opening of headgates, operation of turbine vanes while men are working in or around them, and starting the unit electrically.

The danger of slipping or stumbling is particularly great because when a unit is first taken out it is likely to be wet and very slimy and the many projecting parts of the castings make a very uneven surface to walk on. Furthermore, the pit is usually partly filled with tailwater and if a man should fall and injure himself physically he might not be able to get himself out of the water. The slipping hazard is particularly present in single-runner units where the wheel pit casing does not present level surfaces to walk on. In a particular case where a man, after going down through the manhole, stepped off the ladder, slipped on the inclined concrete surface, and slid down into the tailwater remaining in the wheel case, he was extricated only with difficulty because of the slimy inclined surfaces all around him. Hazards of this kind are best taken care of by the man having a handline around his waist and by laying cleated planks for him to step on.

When extended work is to be done on a vertical multi-runner unit, careful attention must be given to the scaffolding. The flooring of course should be heavy enough not only to hold the men but to take the weight of the parts which may be placed upon it. A handrailing should be built around the scaffolding. In order to get to the different levels it is safer to build a staircase in the scaffolding rather than use ladders (Fig. 4). As the men make many trips up and down with heavy parts or tools on the shoulder, a staircase results not only in safer work but facilitates and speeds up the work. When the job is of a minor nature or short duration, there is a tendency not to use safe scaffolding. For such work it is advantageous to have special planks and scaffolding parts available and kept in a convenient location so that they will always be used.

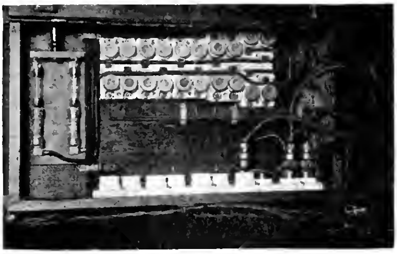

Fig. 7. Portable Distribution Box mounted in wheel pit for general lighting and hand-lamp circuits during extended repairs. On account of the wet conditions existing, 32 volts are used in preference to higher standard voltages

The dropping of tools or parts needs to be watched, particularly in this class of work as speed usually requires that gangs of men work simultaneously above and below. The men should be cautioned particularly about this because it is a hazard which does not occur so frequently around the hydroelectric plant and the men are inclined to become thoughtless. It may be advisable severely to discipline men who are careless in this respect even though no accident results. The use of kick boards around the scaffolding is helpful.

When parts have to be taken out which are too heavy to handle by hand, difficult rigging problems frequently occur and rigging skill of the highest order is called for in order to do such work safely. Particular attention should be given to the type of hitches used and to the soundness of the various details of the rigging equipment. We had a case where a sling parted while a casting weighing several tons was being lowered into the wheel pit from the intake and allowed the casting to slide down the incline about 40 ft. and crash into the turbine. Fortunately none of the several men who were in the pit at the time were injured but considerable damage was done to the turbine.

Fig. 8. A Hold-off Sign, Chain, and Lock which prevent the operation of either the governor or the hand controls. The turbine gates are half-way open to prevent the formation of an accumulation of headgate leakage that might move the rotating element

Fig. 9. The hazard of reaching valves difficult of access can in many cases be lessened by the use of non-slip tread plates on the piping

Illumination of wheel pits while work is going on requires special attention. We are all familiar with the hazards which result from insufficient illumination generally, and it is more than ever a hazard in wheel-pit work for the reason that no permanent facilities for illumination can be installed and because of the inherent difficulties. For this reason it is advisable to have portable lighting equipment made up and used when needed in accordance with a predetermined plan. General illumination can best be provided by a few high-power units with suitable reflectors, particular attention being paid to avoid the creation of deep shadows. Provision must be made for an adequate number of hand lamps. If the number of circuits needed is large, a pipe connection through the wall of the pit, normally capped at both ends, can be used for leading in a pair of main supply wires. A portable distribution box (Fig. 7) made up for the purpose, equipped with fuses and receptacles to which the various circuits can be plugged, may be hung on supports permanently mounted on the wall of the pit. Whenever any extended work is to be done in the wheel pit, electricians can install this distribution box and all the necessary lighting equipment before the work is started.

The duty on the drop cords is particularly severe as they are pulled over castings, stepped on, and frequently lie in the water. A rugged type of heavily braided waterproof or vulcanized rubber cord is needed. The portable hand lamps themselves are subject to the same abuse and should be of a type which has no metallic parts which might be made alive by defective insulation. A defective drop cord may short circuit in a man's hand and burn him. Furthermore, a wet leaky cord in the hands of a man wet all over and climbing around on wet castings is a hazard of the worst order. Under these circumstances a shock even at 110 or particularly at 220 volts may be fatal. In any event a shock may result in the man losing his hold or balance and result in a bad fall in the pit. On account of this hazard we have abandoned the use of 220 volts in wheel pit work and changed to a 32-volt system. A 220/32-volt transformer has been permanently installed at a central point in the station and a 32-volt circuit run the length of the station with connectors at each unit to which the leads going into the wheel pit can be attached. At each unit there is also installed a 32-volt receptacle in which a single drop light can be plugged to take care of the frequent case of a man going in the pit for a brief inspection with only a single light. In order to prevent the danger of 32-volt lamps and drop cords being used in the ordinary 220-volt receptacles in other parts of the station, all of the 32-volt equipment has been made up with bayonet type receptacles instead of the usual Edison base receptacles. The lamps themselves are also purchased with bayonet type bases instead of the Edison base. If this were not done there would be danger of a 32-volt lamp being inserted in a 220-volt receptacle and of the lamp exploding in a man's face.

The danger of all of the lights in the wheel pit being extinguished, as may be caused by electrical trouble in the station, by the blowing of main fuses, or the accidental pulling of switches, should be guarded against by hanging a lighted oil lantern in the pit. Needless to say, this should be the practice throughout the station at night.

One of the most serious hazards in connection with wheel-pit work is the danger of accidentally opening the headgates while men are working in the pit. Not only would the men be caught and drowned but the station would be flooded by water coming from the manhole. To guard against this requires that a well established hold-off system be in force and that suitable warning signs or locks be installed on the headgate mechanism in such a way as to make the opening of the headgates impossible (Fig. 8). When the work in the wheel pit is of an extended nature, such as for instance of more than 24 hours' duration, it is our practice not to depend on the headgate alone but in addition to lower the stop logs in front of the headgates. If the job requires that the pit be kept dry, leakage through the stop logs is lessened by the use of cinders. What leakage there may be is taken care of in the wheel pit by building dams of concrete three or four inches high to guide the leakage off into the draft tube manhole. The headgates should be raised a few inches to prevent the accumulation of leakage in front of them.

Fig. 10. An Application of Hold-off Signs to prevent mistakes. The generator disconnecting switches cannot be closed without moving the door, and the door cannot be moved until the sign is removed. Workmen's tags, placed and removed by the men who are reported *on*, decrease the likelihood of the sign being removed until each of the workmen has reported clear

We once had a rather hair-raising experience in this connection. The headgates had been lowered and the stop logs put in place. The leakage through the stop logs accumulated behind the headgates. Several hundred cubic feet of water accumulated between the gate and the stop logs. A gang of men including a number of recently hired laborers were working in the wheel pit. Part of the job consisted in taking one of the headgates out for some repairs. On lifting the headgate the volume of water which had accumulated behind it rushed down into the wheel pit. The men thinking that the headgate had broken and that the river was being admitted to the pit scrambled for their lives and all tried to get out of the manhole at once. Fortunately some of the more experienced men appreciated what had happened and that there was no particular danger and succeeded in calming the gang, but not until several of the laborers had managed to get out and disappeared from the job. They have never been seen since.

Another hazard which might be gruesome in its consequences is that of the turbine vanes being moved while men are working in them. It frequently becomes necessary to move the vanes for some adjustment or trial and while the man in charge ordinarily warns his men to stay clear of the vanes while they are moved, it is possible that somebody perhaps not directly under this man may be working elsewhere in the vanes or on some other part of the mechanism. It is also possible that one of the men may have been previously sent away from the job to get some tool and on his return go down into the pit and unnoticed get in the vanes or the mechanism when it is moved.

On one of our pit jobs one of the helpers had crawled through the vanes into the runner of the turbine to enjoy a quiet smoke. The man in charge knowing that no work was being done on the vanes at that moment went upstairs and ordered the operation of the vanes for a trial. The man fortunately was in the runner and clear of the vanes when they were moved. It is now the rule that when the vanes are to be moved the man in charge must see that everything is absolutely clear and then post a man at the turbine to see that no one goes near it.

The danger of the unit being started from the electrical end must also be considered. We have on record a case where the generator was accidentally thrown in on the bus and acquired considerable speed before it was cleared. There was no one in the pit at the time but the accident suggested how serious might have been the effects. The answer to this hazard is the grounding of the generator even though the work be only on the turbine.

Tailrace

The tailrace of a hydro plant ordinarily requires no special consideration from the safety standpoint but at Holtwood we have a peculiar condition which has resulted in fishermen getting into some rather humorous if not dangerous predicaments. The rough river bed, through which the tailrace was cut, is flooded to a depth of several feet when the station is fully loaded, but in the light-load periods the tailwater flows through the cut channel leaving the rocks on the side high and dry. Fishermen occasionally get out in the early morning to fish in the tailwater and make themselves comfortable on these rocks. About seven o'clock when the load on the station picks up the fisherman is likely to turn around and discover that his retreat is cut off by the rising water. He usually discovers it before wading is impossible but if he does not he sets up a commotion. A rescue party in a row-boat then has to be organized to bring him in.

Another incident once occurred in the tailrace when the water went down. There is a deflection wall between the main channel of the river and tailrace and shad fishermen are in the habit of mooring their boats to this wall while fishing with dip nets. The flow of water coming from the draft tubes at this point is very favorable for catching the shad. On this particular occasion there was an interruption of service and the station load was suddenly lost. This resulted in a sudden 10-ft. drop in the tailrace and the two men who were in their boat moored to this deflection wall suddenly found themselves precipitated into the water with their boat hanging up in the air above and their day's catch raining down on them. A large warning sign has been erected to caution people of this danger of fluctuating water level.

Radio Communication

By W. R. G. Baker

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In the introduction of this article the operation of the ordinary wire line telephone is briefly sketched to make clear, by analogy, the later explanation of the radio telephone. It is shown that both systems have four primary units in common; viz., some sort of energy conductor between stations, some form of energy capable of being modulated to conform with sound waves, a transmitter, and a receiver. Since the type of radio equipment discussed is really "built around" the vacuum tube, a section of the article is devoted to furnishing an unusually lucid description of the principle and characteristics of this device. The remaining sections show: (1) how the transmitter, in accordance with the sound wave impressed upon it, modulates the radio-frequency carrier wave that it broadcasts; (2) how the receiver, by rectification of the otherwise inaudible incoming wave, reproduces the sound wave; and (3) how two types of amplification are accomplished. —Editor.

The progress in the field of radio communication during the last few years has probably been greater than in any other branch of electrical science. Considerable development was due to the impetus given by the war, but the device that made possible this rapid advance was the three-element vacuum tube or pliotron.

In order to obtain an idea of how radio telephony is accomplished and of the requirements for radio telephony, it is quite logical first to consider the ordinary wire line telephone system.

Considering the simplest sort of telephone circuit shown in Fig. 1, there is a telephone transmitter, battery and telephone receiver, all in series. Speaking into the transmitter varies the amplitude of the normally constant current due to the fact that the sound waves, impinging on the diaphragm of the microphone transmitter, cause this device to vary its resistance, which results in a variation of the circuit resistance. A variation in the circuit resistance produces a corresponding modification of the line current. This varying line current passing through the winding of the telephone receiver produces variations in the magnetic pull on the receiver diaphragm. These varying pulls, since they correspond to the sound waves striking the microphone transmitter, cause the receiver diaphragm to reproduce sound waves so that the words spoken into the transmitter are repeated at the receiver.

In Fig. 2 attention is called to the variation of line current due to the operation of the transmitter diaphragm. The straight line represents the current when the transmitter is not operated. The irregular line represents the current when the transmitter is spoken into. It is evident that the effect of the microphone is to mold or modulate the direct current flowing through the circuit so that it resembles the sound waves spoken into the telephone transmitter.

Therefore there are at least four primary units required for telephone communication:

1. Some sort of conductor by means of which energy is carried from the transmitting to the receiving station. In land wire telephony this usually consists of two copper wires as in Fig. 1.

2. A form of energy must be supplied that is capable of being molded or modulated to conform with the sound waves. This energy must be of such form that it can be transferred from the transmitting to the receiving station. An additional requirement under normal conditions is that when the transmitter diaphragm is not actuated, the receiver should not be affected by the line current. The last requirement is of course obvious, since, if a 60-cycle supply replaced the battery, the receiver would emit a 60-cycle howl which would prevent speech reproduction.

3. A transmitter which must provide means for modulating the energy, and which may in some cases be considered to provide the energy in a form suitable for modulation.

4. A receiver which must provide means for converting the received energy into sound waves.

The Radio Line

In wire telephony the line usually consists of two copper wires, or one wire and an earth return. The radio line, as shown in Fig. 3, consists of an elevated metallic structure at each station called the antenna which is connected to ground through the radio transmitter and receiver. Since a consideration of the propagation of electromagnetic waves is beyond the scope of this article, they will be assumed to be established by extremely high frequency alternating currents and potentials set up in the antenna circuit at the transmitter. Also, it will be assumed that energy in the form of electromagnetic waves is radiated from the transmitting antenna. A small proportion of this radiated energy is absorbed by the receiving antenna and in it sets up a high-frequency potential causing high-frequency current to flow through the antenna system.

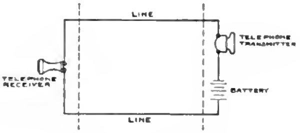


Fig. 1. Diagram of Simple Telephone Circuit

The Two-element Vacuum Tube

Before considering the radio transmitter and receiver, it will be necessary to obtain a working knowledge of the theory and operation of the pliotron, or radiotron, as the three-element vacuum tube is sometimes called. The first to be considered is the electron tube having but two elements, viz., plate and filament. From this type of tube, which is called a kenotron, the present day pliotron was developed.

The two-element vacuum tube consists of an evacuated glass vessel containing a tungsten filament and a metallic plate as shown in Fig 4. The filament is heated by a battery or any other source of electrical energy.

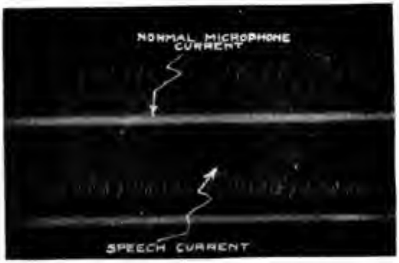


Fig. 2. Oscillogram showing Speech Current in Telephone Circuit

The starting point with all electron tubes whether kenotrons or radiotrons is the electron theory According to this theory the "atom" of electricity is called an electron. The electron is then the indivisible unit of electricity, or more specifically the unit of negative electricity. If an atom of matter has electrons in excess of normal, it is considered as being negatively charged. Conversely, an atom of matter is positive if the number of electrons are less than normal and is then called a positive ion. When a current of electricity flows, we may consider it to be due to a definite movement of either electrons or positive ions or both.

In a conducting material there is constantly occurring a shifting of the electrons, but unless an electric field is applied the unattached electrons have no definite movement. When, however, a difference of potential is maintained between two points of the conducting material a steady movement of the electrons takes place toward the point of higher potential. Under this condition the electrons leave the conducting material at the point of higher potential and are returned at the point of lower potential.

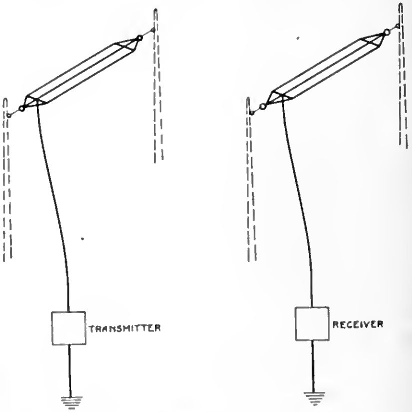


Fig. 3. Diagram of the Radio Line

Under ordinary temperatures the electronic movement is continually occurring within the boundaries of the body. When the temperature is increased the velocity of the electrons increases until finally the attraction between the electrons and the atoms of matter is overcome and the electrons pass through the boundary surfaces and leave the body. This evaporation of electrons from the hot body is termed emission and while dependent upon the temperature is also materially affected by such factors as the nature of the material, the condition of the surface, etc.

The application of these facts to the kenotron is shown in Fig. 5. If the plate is positive with respect to the filament, then electrons emitted by the filament will be drawn toward the plate. If the plate is negative with respect to the filament, or if it is at the same potential as the filament, the electric field necessary to attract the electrons to the plate is not present, with the result that the electrons accumulate around the filament. This accumulation of electrons creates a negative charge which reacts on other electrons and forces them back to the filament. It is only by neutralizing this negative charge, or space charge, that the electrons leaving the filament can exceed those returned, due to repulsion by the space charge. For any given filament temperature a certain number of electrons are emitted but these will be balanced by an equal number of returning electrons unless after emission the electrons are carried away.

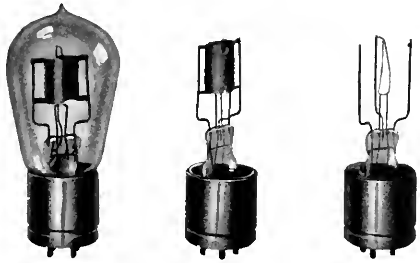


Fig. 4. Kenotron Rectifier Tube (UV-216) Complete and in Two Stages of Assembly

It is evident then that the current between the filament and plate depends, not only upon the emission of electrons, but also upon the potential between the plate and filament. As the potential of the plate is increased, the current between the filament and plate increases, until the potential becomes so great that the electrons are removed as fast as they are emitted. An increase in plate potential beyond this point results in no further increase in current. The current at this point is called the saturation current and the potential of the plate at which the saturation current occurs is called the saturation voltage.

Fig. 6 shows the saturation current obtainable with different filament currents. The plate is maintained at a direct-current potential sufficiently high to carry all the electrons from the filament. This means that no space charge effect is present due to the fact that the electrons are not permitted to accumulate around the filament and thus create a negative charge. It should be noted that with this no load condition the entire potential drop occurs in the kenotron. The plate current in this case is sometimes termed the emission current in that it represents the maximum electron emission possible since no space charge effect is present.

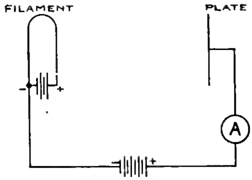


Fig. 5. Diagram of the Kenotron Circuit

The I_p E_p characteristic curves in Fig. 7 illustrate the variation of plate current with the voltage applied to the plate when different filament voltages are used. It should be noted that for a given filament voltage an increase in the voltage applied to the plate results in an increase in the plate current up to a certain value of E_p. If this value of E_p

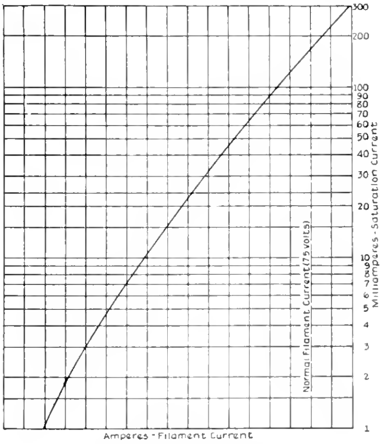


Fig. 6. Saturation Characteristic of Kenotron (UV-216) with Different Filament Currents

is exceeded, the rate of increase of I_p gradually decreases until finally a further increase in E_p results in practically no increase in plate current. This limitation in plate current is due to the fact that at the filament temperature corresponding to, say, 7.5 volts practically all the electrons are drawn to the plate when the plate voltage is 160.

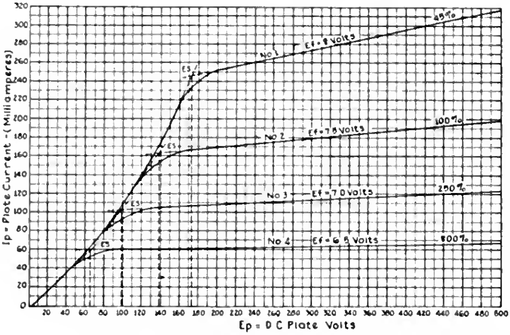


Fig. 7. Plate-current Plate-voltage Characteristic of Kenotron (UV-216)

It is seen that as the filament voltage is increased the value of the saturation voltage and current is also increased. This is due to increased emission caused by the increased filament voltage. The greater emission in turn requires a stronger electric field to remove all the electrons and this is obtained by increasing the potential drop through the kenotron.

The family of curves shown in Fig. 8 illustrates the variation of the plate current as a function of the filament voltage. The circuit arrangement still is the same as shown in Fig. 5.

It will be seen that for a given plate voltage, I_p increases with the filament voltage until a point is reached at which the rate of increase in I_p falls off until finally the plate current is independent of the filament voltage. At this point the emission is so great that the plate voltage cannot draw all the electrons to the plate. The space charge, therefore, limits any further increase in I_p by repelling electrons back to the filament at the same rate they are emitted. The saturation current is, in this case, called the space charge current, since the current is independent of the filament voltage.

These curves indicate that a certain minimum temperature must be reached before the full space charge effect is obtained and that the higher the applied voltage, that is, the drop of potential through the kenotron, the higher must be the filament temperature to obtain the full space charge effect.

So far as the two-element vacuum tube is concerned the following general characteristics have been established:

1. If the voltage applied to the plate is sufficiently high, the space charge effect does not occur and we obtain the emission current.

2. The plate current may be limited by the filament temperature, that is, the applied

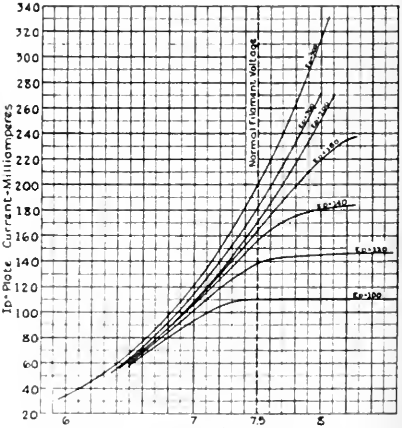


Fig. 8. Plate-current Filament-voltage Characteristic of Kenotron (UV-216)

voltage is sufficiently high to draw all the electrons to the plate.

3. The plate current may be limited by the space charge effect in which case the emission is so great that the voltage applied to the plate is insufficient to withdraw all the electrons from the neighborhood of the filament.

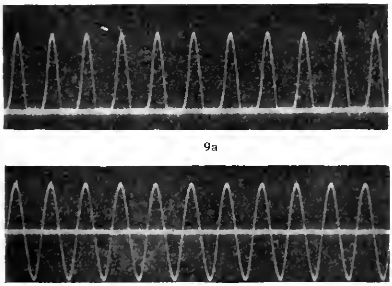
4. Obviously this device has the characteristic of unilateral conductivity in the direction from filament to plate. This can be illustrated by the oscillogram shown in Fig. 9 which shows the wave shape of the plate current when an alternating-current supply is inserted in the plate circuit.

The Three-element Vacuum Tube

The structure of the three-element vacuum tube or pliotron is, in general, similar to the two-element tube or kenotron with the exception that a wire grid or mesh is placed between the filament and plate as may be seen in Fig. 10.

Since the characteristics of the two-element vacuum tube may be applied directly to the pliotron, the effect of the third element or grid only will be considered.

The function of the grid can be explained by considering the effect of this element on the space charge existing in the tube, since the addition of the grid to the tube structure has no effect on the electron emission from the filament.



9a

9b

Fig. 9. Oscillograms Illustrating Rectification Properties of Kenotron (UV-216)

Under normal conditions there is usually a space charge formed by the cloud of electrons on their way to the plate. The effect of this space charge is especially noticeable in the neighborhood of the filament. Newly emitted electrons, if they are to reach the plate, have to overcome the repulsion of the whole mass of electrons between the filament and plate. Many electrons fail to overcome this repulsion and return to the filament unless the plate potential is high enough to overcome the effect of the space charge.

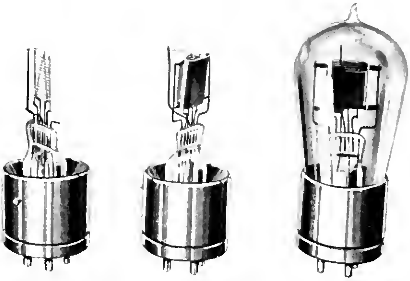


Fig. 10. Radiotron Receiving Tube (UV-200 and UV-201) in Two Stages of Assembly and Completely Assembled

Anything that can be done to decrease or increase this space charge will evidently have a marked effect on the current passing through the tube. If, for example, we make the grid negative with respect to the filament, the grid will repel electrons which would normally go to the plate. These repelled electrons collect in the space between the filament and grid and assist the negatively charged grid in preventing electrons from passing to the plate. The reduction in plate current, consequent to the placing of a negative potential on the grid, is therefore the result not only of the repulsion of the grid but also of the repulsion exercised by the additional space charge produced by the negative grid potential.

When a positive potential is placed on the grid its electrostatic effect on electrons in the neighborhood of the filament is very considerable and tends to neutralize the effect of the space charge. The result is a sudden increase in the plate current. If the grid potential is sufficiently positive it may considerably neutralize the effect of the space charge. It should be noted that the space charge is now moved into the grid-plate region. Electrons pass through the grid and collect in the space between the grid and plate. If the plate is not at a sufficiently high potential to draw away all the electrons as quickly as they pass through the grid, a space charge will form in that region. Finally if the grid is made alternately positive and negative, corresponding pulses or variations will be set up in the plate circuit. To obtain these variations satisfactorily, the electron current must be below the saturation value. Evidently very small variations in the grid filament potential may result in comparatively large variations in plate current.

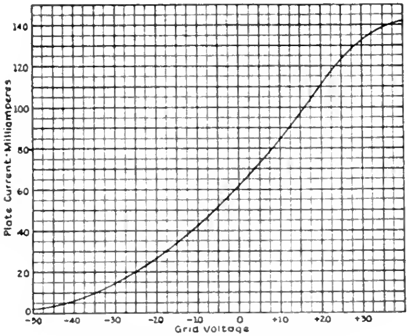


Fig. 11. Plate-current and Grid-voltage Characteristic of a Radiotron

The variation in plate current with changes in grid voltage varies from 0.25 milliamperes per volt change in receiving tubes up to 10 milliamperes per volt or even higher in transmitting tubes.

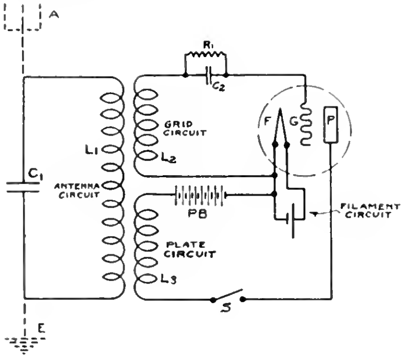
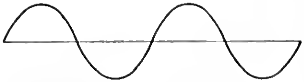


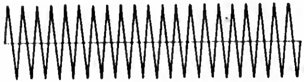
Fig. 12. Diagram of Transmitter Circuit

Considering the characteristic curve in Fig. 11, it is shown that two bends are present, one at the lower part of the curve, the other at the upper. The lower bend is due to the effect of the space charge. The upper is due to saturation. Between these two limits is a portion which is practically a straight line hence variations in grid potentials corresponding to this portion produce corresponding variations in the plate current. Attention is called to the important characteristic of this device which permits the grid element to exercise control over the plate current and at the same time consume power only when the grid is positive, at which time currents flow in the grid circuit.

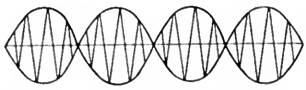
Having considered very briefly the characteristics of the principal element of the radio equipment, the operation of the radio transmitter and receiver will be investigated.



(A) AUDIBLE FREQUENCY



(B) HIGH FREQUENCY (INAUDIBLE)



(C) MODULATED HIGH FREQUENCY

Fig. 13. Diagrams of the Voice Wave to be Transmitted, the Carrier Wave, and the Modulated Carrier Wave

(A) Audible Frequency Wave
(B) High-frequency Wave (Inaudible)
(C) Modulated High-frequency wave; Combination of (A) and (B)

The Radio Transmitter

From the consideration of the wire telephone system, it will be obvious that the radio transmitting equipment must supply energy in such form that, unless speech is being transmitted, the telephone receivers are not affected. In addition, the transmitter must provide means for modulating or molding this energy to conform with the voice so that speech may be reproduced at the receiver.

The radio transmitter consists in general of four circuits as shown in Fig. 12:

1. Antenna circuit.
2. Filament circuit.
3. Plate circuit.
4. Grid circuit.

The antenna circuit comprises the necessary inductance L_1 and capacitance C_1, which in actual practice is the capacitance of the antenna. A portion of the inductance in the antenna circuit, called the secondary of the oscillation transformer, is inductively coupled to the plate circuit.

The plate or output circuit of the pliotron contains a source of high-voltage direct current *PB* and an inductance L_3, called the primary of the oscillation transformer, which is coupled to the antenna circuit.

The grid circuit comprises an inductance L_2 which is coupled to a portion of the antenna circuit. A condenser C_2 and resistance R_1, called the grid condenser and grid leak resistance, form part of the grid circuit.

The filament circuit contains a suitable source of energy for heating the filament of the tube.

The action of a pliotron in generating either high or low frequency oscillations is essentially the same, whatever the nature of the circuit employed. The circuits connected to the tube have capacitance and inductance, in consequence of which they can oscillate freely at particular frequencies. If an electrical shock is given to such systems, a series of oscillations at these frequencies will be set up, the amplitude of which is dependent upon the energy given to the circuits when the shock is applied.

These shock-produced oscillations act upon the grid of the tube and, depending upon the nature of the circuit employed, cause changes of the potential of the grid with respect to the filament, these being of the same frequency as the natural frequency of the oscillations. The changes of grid-filament potential in turn lead to changes in the plate current of the tube. The plate current thus becomes a pulsating current which is equivalent to a steady current having imposed upon it an oscillatory current, which is of the same frequency as the natural frequency of the initial shock-produced oscillations. This oscillatory component is made use of to supply high-frequency power to the antenna system.

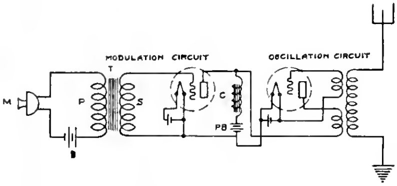


Fig. 14. Diagram of Transmitter Modulation and Oscillation Circuits

Under ordinary conditions, if a capacitance-inductance circuit is shocked, the resulting oscillations rapidly die out, rarely exceeding from 100 to 200 complete cycles before the amplitude has become smaller than 1 per cent of the original value. This dying out is of course due to the resistance of the circuits which can be made small but never eliminated.

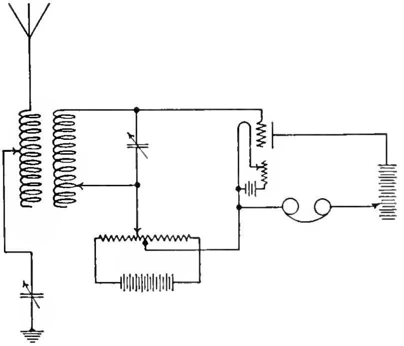


Fig. 15. Diagram of Receiver Circuit

The case of the oscillator tube is, however, different in that after the initial shock has set up the oscillations a supply of radio frequency energy from the tube is always available. If this supply of power is great enough, the losses due to the resistance of the oscillatory circuit may be made up, in which case the amplitude of the oscillations will be just maintained. If the supply of power more than makes up for the losses due to resistance, then the amplitude of the oscillations will increase. This increase will continue until a point is reached where a balance between the power expended in the resistance and the power supplied by the tubes is just maintained. This is the normal operating condition of the tube when used as a generator.

On the other hand, if the supply of power from the tube is less than the power expended in the resistance, then the amplitude falls off until a balance is maintained at some oscillation of smaller amplitude.

The operation of the tube as a generator may be briefly described as follows. When the circuits are closed a surge occurs in the plate circuit. This shock excites the antenna circuit which is inductively coupled to the plate circuit. Oscillating currents are thus set up in the antenna circuit at a frequency determined by the constants of this circuit. Since the grid circuit is inductively coupled to the antenna circuit some of this oscillating energy is transferred to the grid circuit and sets up a varying potential between the filament and grid. The variations in the grid potential react upon the plate circuit causing the plate current to fluctuate at the same frequency. This variation in plate current is transferred to the antenna circuit and the whole cycle repeated again. The result is that the antenna current builds up until finally limited by the constants of the antenna circuit and the characteristics of the tube.

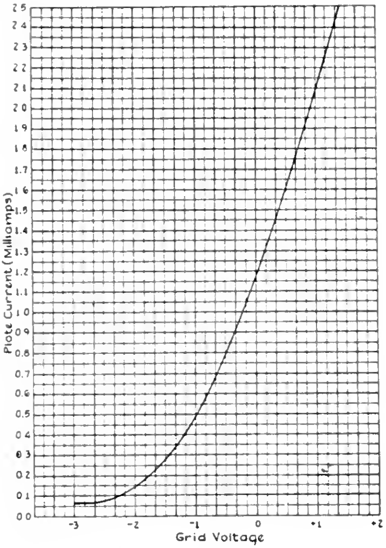


Fig. 16. Typical Characteristic Curve of Plate Current and Grid Voltage of a Radiotron

Up to this time it has merely been shown that in order to utilize the so-called radio line between two stations, consisting of the antenna systems, it is necessary to produce high-frequency oscillations in the antenna circuits. In the wire telephone system the direct current was acted upon by the microphone and molded to conform with the voice. In place of this direct current, radio telephony employs a very high frequency current which, being far above audibility, can be molded quite like the direct current and thus act as a carrier. Assume it is desired to transmit to the receiving station the voice wave shown in Fig. 13A. As a carrier for this wave there is the inaudible radio-frequency oscillations shown in Fig. 13B. Placing the voice wave over the radio-frequency waves and limiting the amplitude of the radio-frequency waves by the envelope of the voice wave results in the condition shown in Fig. 13C. There is thus available a possible means of telephoning by radio, providing the radio-frequency supply is constant and many times higher than the audio frequency.

Having generated the necessary power in the form of radio-frequency current, there is now required a method of modulating or molding it to conform with the voice. A number of modulation systems are possible using the pliotron, but the most successful for moderate powers is the constant-current or choke system illustrated in Fig. 14.

Attention is called to the fact that the plate circuit of the oscillator and modulator tubes are in parallel and are supplied from the direct-current source *PB* through the reactor *C*. When the telephone transmitter is inoperative, the potential difference across the reactor is constant, so that the amplitude of the high-frequency current in the antenna and the plate current of the modulator tube are also constant. When the telephone transmitter is spoken into, the voltage induced in the coil *S* changes the potential of

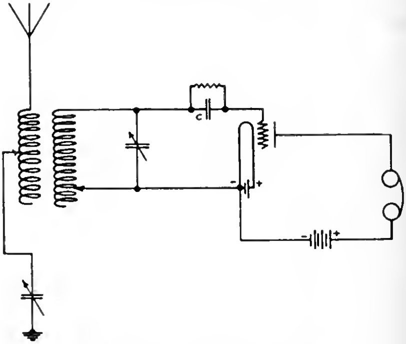


Fig. 17. Diagram of Connections for Rectification by Grid Condenser

the modulator grid in accordance with the variations of the current through the telephone transmitter. These changes in the modulator grid potential, which occur at audio frequencies, cause fluctuations in the plate current of the modulator circuit. The result of this sequence of events is that the battery *PB* is required to supply a current varying at speech frequencies, which current must pass through the reactor *C*. Now the impedance of the reactor is considerable at audio frequencies so that a large audio frequency potential is built up across the reactor. It should be noted that this potential difference which is varying in accordance with the pulsations in the telephone transmitter circuit is impressed upon the plate of the oscillator tube. Since the amplitude of the high-frequency current in the antenna circuit is proportional to the oscillator plate voltage, it is evident that the current variations in the telephone transmitter circuit are eventually reproduced in the antenna circuit as variations in the amplitude of the antenna current.

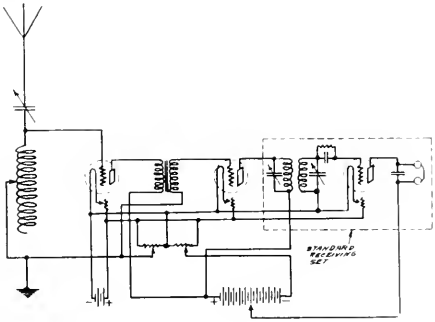


Fig. 18. Diagram of Connections for Radio Amplification

The Receiver

Having generated and modulated the radio-frequency energy, it is transferred to the antenna system where it is radiated in the form of electromagnetic waves. The receiving antenna absorbs some of this energy and it now becomes necessary to convert the modulated radio-frequency waves into sound waves, that is, transform the energy from the state shown in Fig. 13C to that shown in Fig. 13A.

It should be realized that the potentials produced in the receiving antenna are of the order of a microvolt and the power available in the order of a microwatt. In addition, the frequency of the potentials produced in the antenna circuit is extremely high, possibly a million cycles or even higher.

Two obvious methods of detecting the high-frequency currents in the receiving antenna are temperature effect of these currents on some device such as a hot-wire meter, or rectification of the currents so that the mean value is not zero. The disadvantage of the temperature method is chiefly the inability of obtaining apparatus sufficiently sensitive and rugged. The rectification method permits the utilization of a polarized electromagnetic device, which in practical work is the telephone receiver.

Rectification may be accomplished either by a crystal rectifier or by utilizing a three-element vacuum tube, which has been shown to have unilateral conductivity.

The tuning system of a simple receiver consists of two parts, one providing inductance and capacitance to tune the antenna system to the frequency of the incoming wave, the other, also a tuning circuit, draws energy from the antenna system and applies it to a three-element vacuum tube, called in this case a detector or rectifier tube. An elementary diagram of these connections is shown in Fig. 15

Considering first one of the simplest systems of rectification, attention is called in Fig. 16 to the bend in the characteristic curve of the three-element vacuum tube when the grid potential is quite negative. The normal grid potential is adjusted to a value where the plate current increases if the potential becomes more positive, while if the potential becomes more negative the result is practically no variation in plate current. Hence it is only necessary to adjust the potential of the grid so that the tube is worked at the bend in the characteristic curve, with the result that the modulated radio-frequency wave will be rectified. The current in the plate circuit of the tube, in which are connected the telephone receivers, is varied in accordance with the fluctuations of the grid potential. Now the amplitude of the radio-frequency oscillations is varied in accordance with the sound wave spoken into the transmitter, so that the mean value of the plate current which passes through the receivers will also fluctuate to reproduce a wave of the same form. This fluctuation of the plate current, since it occurs at an audio or voice wave, can operate the receiver diaphragm and result in the reproduction of the sound waves spoken into the transmitter. The ultimate result of this series of operations is to convert the curve in Fig. 13C back to the form shown in Fig. 13A.

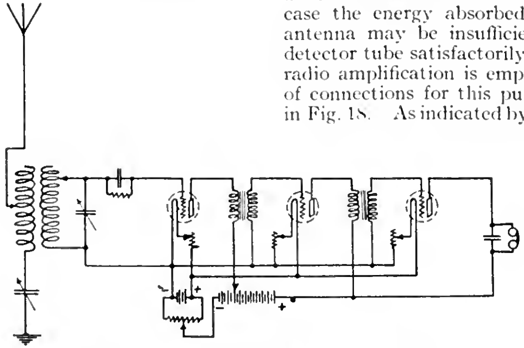


Fig. 19. Diagram of Connections for Audio Amplification

A more common method of rectification is that which is diagramed in Fig. 17 and which functions due to cumulative rectification by a grid condenser. The insertion of the grid condenser C prevents the flow of a grid current. The normal potential is usually zero volts. When the grid has a positive potential impressed on it, due to the received signal, electrons are drawn to it and charge the condenser. When the received signal impresses a negative potential on the grid, the effect is additive and the grid is forced still further negative. The drop in mean grid potential during a signal is thus cumulative, and if it were infinite the grid might be left at a large negative potential so that the plate current would be permanently reduced. In order to prevent this condition a high resistance is connected across the grid condenser which permits the negative charge to leak away. The function of the grid-leak resistance may be regarded as gradually undoing the work of the signal, the plate current gradually rising again to its value previous to the signal. The resultant effect in the plate circuit is an average variation in the plate current which actuates the receiver diaphragm.

Amplification

The requirements for amplification may arise from two different sources. In the first case the energy absorbed by the receiving antenna may be insufficient to operate the detector tube satisfactorily, in which instance radio amplification is employed. A diagram of connections for this purpose is illustrated in Fig. 18. As indicated by its name, this type of amplification occurs before the signal is rectified or detected. In the second case it is often desirable to increase the volume of sound from the telephone receivers. In this instance, audio amplification is employed and the output of the detector tube amplified until the desired volume is obtained. Fig. 19 illustrates a diagram of connections for this latter purpose.

Both types of amplification are accomplished by connecting the output of the plate circuit of one tube to the input or grid circuit of another. The transfer between tubes may be accomplished by means of transformers, reactors, condensers, resistances, or combinations of these units depending upon the type of amplification desired and the characteristics of the tubes. It is obvious that amplification should take place with the minimum distortion possible, hence only the linear portion of the characteristic curve in Fig. 16 can be used.

The Place of the Electric Truck in the World's Work

By Day Baker

Chairman Legislative Committee, Mass. Auto. Dealer and Garage Association

In the world's work the electric vehicle has established a place for itself due to its economy and reliability of operation. Where these factors are of prime consideration, no other vehicle as satisfactorily fills the gap between horse haulage and railroad haulage; and in fact some companies, which keep accurate account of their transportation or delivery costs, have even replaced their horse-drawn vehicles by electrics. In the following article the author mentions some of the many classes of business in which the electric has demonstrated its superiority and also some of the widely separated foreign countries in which it is today rendering service that cannot be surpassed by vehicles of other motive power. Recent analyses of the design, qualifications and applications of the electric vehicle appeared in our April and May, 1922, issues.—Editor.

At the present time there are recognized three fields of road vehicle transportation; fields which are distinct, but in practice are frequently overlapping.

The first is the field of the horse-drawn wagon or truck which can be said to be limited to trucking within a five-mile radius as the horse is capable of travelling only from 12 to 16 miles per day.

The second is the field of the electric truck which is practical for deliveries within a 10 to 15-mile radius, covering a mileage from 30 to 60 miles according to the size and weight of the vehicle and the capacity of the battery. The operation of the electric truck is so economical that frequently it invades what might well be considered the horse-drawn field, and produces results that are from operative and financial standpoints very satisfactory. This is illustrated by the success attained by the electric truck in the pick-up and delivery service of the American Railway Express Company in New York, Boston, Philadelphia, and other large cities.

The third is the field of the gasoline motor driven truck which shows its efficiency of operation at a point where the economy and practical operation of the electric truck ceases. The gasoline truck may be said to show economy of operation for the so-called "short-haul" of commodities, from 15 to 50 miles. At the latter point the railroads commence to show their economy from a financial standpoint; and if they would give the efficient *service* rendered by the motor trucks, it is to be doubted if motor truck haulage would be much used beyond that point, except for movement of household goods.

Beyond the field of the motor truck, and often within its radius of action where the factor of time consumed in transportation does not enter, the steam railroad is the efficient carrier.

From the foregoing it will be seen that the electric truck, from point of numbers which could be used, has a remarkably large field in which to expand its application. There are thousands of potential buyers for this form of transportation equipment who know practically nothing about the electric truck; and many who do not even know that electrically driven trucks are built.

Listed in the following are a few of the many practical exemplifications of the economic fields in which the electric truck fills its place in the World's Work:

Express and transfer companies utilize between two and three thousand electric vehicles and these, with the continual additions being made to the fleets, should prove a most conclusive argument to the man who thinks of transportation in terms of cost per package. The express and transfer companies are using electric trucks solely on the basis of the low cost of handling per package and per mile of haulage.

Department stores in the large cities of the country have found the economy and reliability of the electric truck of greatest value in their freight hauling and their delivery of goods. This is shown by the constantly increasing fleets of the Marshall Field Company, John Wanamaker, R. H. Macy Company, Arnold Constable Co., Tiffany Company, and others which have had fleets of electrics on the road for 15 years or more; while they have purchased gasoline driven trucks for their long hauls, yet wherever the work can be performed by the electric, this form of vehicle is used on account of its economy of operation.

Terminals and warehouses in the great cities are finding the heavy type of electric truck of great economic value, as is shown by many of the great installations such as those in use at the Bush Terminal and Warehouses

Fig. 1 Part of the Electric Truck Express from Cape Town, South Africa, to the Kimberley Diamond Fields

Fig. 2 Two Five ton Electric Transfer Trucks at the Boston Freight Terminal

Fig. 3. One of Four Electric Police Wagons in Use at Boston, Mass.

Fig. 4. Electric Truck in Textile Mill Service

of New York, and the Terminal Wharf and Storage Warehouse of Boston.

Confectionery manufacturers and other dealers in foods have found the electric truck especially adapted to their use on account of the cleanliness of the power plant and the entire lack of contaminating odors. The fleets in use by the confectionery and chocolate manufacturers of Boston and New York, many of the units of which have been 10 to 15 years in service, are evidence of the satisfaction which the electric truck is giving this branch of the industries.

Textile mills and machinery manufacturing works have employed electric trucks for the past 15 years or more, and these vehicles have been the accepted method of transportation around the yards of the great manufacturing industries. The Amoskeag Manufacturing Company, Nashua Manufacturing Company, Pacific Mills, and Lynn and Pittsfield Works of the General Electric Company, all located in New England, are admirable examples of industrial plant transportation.

"*Door to Door Transportation*" is the term which might be applied to the type of service which in England the railroads offer to the less-than-car-load shipper. In London a shipper advises the railroad company that he has one, two, or five tons of goods to be shipped to Manchester or Liverpool. Within a short time an electric truck belonging to the railway system backs up to the shipper's door, the freight is loaded, and then taken direct to the car (not the freight house) in which the goods are to travel. During the night, or early morning, the train arrives at the city of destination, and at once electric trucks are backed up to the car doors, the freight placed on the trucks and shortly is delivered at the door of the consignee, completing the "door to door" delivery, which is real service—a service scoffed at by many of our American railroad officials, who often wonder why they are losing much of their profitable business to the companies operating motor trucks.

Laundries have during the past few years discovered that the electric vehicle is the desirable unit for their work. As a result hundreds of small electric units are already installed, from Boston to San Francisco.

Bakeries also have not failed to recognize the desirability of the electric for delivering bread, which so easily absorbs the fumes of any volatile fluid. Practically every large city from the Atlantic to the Pacific Ocean has a fleet of electrics delivering bread.

In the far-off city of Manila, a large fleet of electric trucks deliver food and ice to the population of that city; while in Hong Kong, China, and in Bangkok, the capital of Siam, American-made electric trucks will be seen darting in and out of the rather lazy traffic.

In South Africa at Cape Town, and at the diamond fields of Kimberly, numbers of American-made electric trucks are performing their work consistently day in and day out.

In Denmark, in Norway, and in Sweden, the electric truck has been steadily increasing in numbers, and many of the American-made electric trucks will be found.

In Germany, the fire departments and the street cleaning forces are equipped with scores of electric machines, which have shown their efficiency for many years.

In Brazil, at Rio Janeiro, the street railway company and other transportation organizations have for many years successfully and profitably operated electric trucks.

In Italy and in Spain the interest in electric trucks that was shown before the war is now being again manifested. In the city of Rome, the municipal lighting department is making especially low rates for current to be used for charging electric vehicles.

Thus it will be seen that the Electric Truck has a very definite place in the World's Work, which will be filled as fast as the manufacturers and advocates of electric trucks take advantage of the golden market.

In the commercial truck manufacturing field, the true value of the electric will be attained when some of the great truck manufacturers with a clear vision realize the advantages of the electric truck, and its almost unlimited sales possibilities. But they must employ active business men, not alone technical engineers, but men who have the commercial instinct, the merchandising ability, and the vision of the future of economic transportation, to head their departments which will specialize on electric truck building, selling and service.

Maintaining the Efficiency of Turbine Lubricating Oil

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and
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The Power Equipment Company, Boston

The authors have summarized some of our previous articles on this and kindred subjects discussing the principal types of oil purifying equipment and have given the theory of the centrifugal oil purifier. They then discuss the improvements made in modern centrifugal purifiers and their application to power plant problems, including the marine power plant. They give data to show how these purifiers maintain the lubricating value of the oil.—Editor.

The general problems of steam turbine oiling systems have been covered very thoroughly in the May, July and September, 1921, issues of the General Electric Review (pages 414-421, 651-655 and 788-793). Especial attention is called to the article entitled "Keeping Steam Turbine Lubricating Oil in Good Condition," which appeared in the May issue and which is devoted particularly to the necessity of keeping lubricating oil free from impurities.

Summarizing the article just mentioned, it has been clearly shown that in spite of the high grade oils now available for turbine lubrication there is a slow but continuous breaking down of a portion of the oil in every lubricating system. That even with improved shaft packings and water cooling systems it is impossible completely to prevent water from getting into the circulating system. That an absolutely emulsion-proof oil is practically non-existent, and that the only way to prevent emulsion is to remove this water at the same rate, and as nearly as possible at the same time, as it enters the system.

So far as the effect of these impurities on the lubricating value of the oil is concerned, it has been demonstrated that they cause a greater degree of deterioration when acting in combination than when acting singly. Obviously, then, the method of purification which simultaneously eliminates dirt (including broken down oil) and water is the most efficient means to employ. Such a method makes it impossible for the various impurities to unite in an emulsion and greatly decreases the amount of sludge and of acidity which is formed.

These previous articles in the General Electric Review have exploded the somewhat common belief that the quantity of oil in a turbine system slowly deteriorates uniformly or en masse. The statement is often heard that after a certain period of use lubricating oil "loses its body" or "requires a rest." That is merely an untechnical way of saying that the oil has become fouled with dirt, broken down oil cells, water, acid and all the heterogeneous substances called "sludge." Those who have studied the characteristics of oil know that a complete removal of these substances from an apparently fouled lubricant restores its efficiency and makes it for all practical purposes as good as new.

The causes of the fouling of turbine lubricating oil which begins as soon as the oil is put into service are inherent and cannot be eliminated. The logical method of offsetting the deteriorative effect of such fouling is to introduce in the oiling system a means of removing the sludge. It is equally logical that the sludge should be removed as fast as it is generated and before it has time to settle out in the passages and piping of the oiling system where it may eventually cause clogging or at least diminish the flow of oil to the bearings or gears, in the case of a geared turbine.

Two Types of Oil Purifying Equipment

Having decided that keeping turbine oil clean is a paying proposition, the engineer is confronted with the problem of selecting one or the other of the two general types of equipment which are now in general use for this purpose. One is the gravity type oil filter and the other is the centrifugal oil purifier. Either is adapted for use in connection with the continuous by-pass system of purification, the batch system, or the continuous complete filtration system, although, as pointed out in the article previously mentioned, this latter method is not as a rule practicable or necessary.

In the operation of a gravity type oil filter the used oil is brought to rest, or nearly to rest, in a tank or other receptacle and the thoroughness of purification depends upon the effectiveness of gravity in settling out dirt, broken down oil cells and water. This settling action is generally supplemented by passing the partially purified oil through some form of filtering material, such as excelsior, curled hair, cloth bags, sponges or the like. Filters of this type have been in use for many years. They are generally well understood and have been fully described in the article which appeared on pages 414-421 of the May, 1921, issue of the REVIEW. The present article will consequently deal more particularly with oil purifiers of the centrifugal type which have come into rather general use during the past few years.

Theory of the Centrifugal Oil Purifier

The centrifugal oil purifier depends for its action on the same factor as does the gravity filter; that is, the difference in specific gravity between the oil and the relatively heavier dirt, water and sludge. Instead of relying on the slow action of gravity settling, however, the oil is subjected to the action of centrifugal force developed in a rapidly rotating receptacle or bowl. The force thus generated to effect purification is many thousand times greater than the force of gravity.

There is nothing new about the principle of separating or purifying liquids by centrifugal force. Centuries ago the Chinese utilized this force in a crude way to separate fruit juices. Gourds containing the juices were whirled at a rapid rate by means of cords attached to them, a few minutes of this effecting a better separation than many hours of gravity settling. The vessel was then brought to rest and the lighter or purified liquid skimmed or poured from the top. It was this necessity of stopping to skim off by hand the liquid separated by centrifugal force that baffled inventors and retarded the application of centrifugal force to industrial problems for several centuries. In 1878, however, the problem of continuously discharging the two liquids separated by centrifugal force was solved by Dr. Gustaf De Laval, a Swedish engineer, and since that time the machines have been adapted to the needs of many industries.

The earliest type of continuously operated centrifugal separator had for its bowl, or separating chamber, a hollow tube placed vertically in the frame of the machine in such a way that it could be revolved at high speed, thus generating sufficient centrifugal force to effect separation. The lower end of this tube was sealed, and in the upper end there was an opening at the center through which the incoming liquid flowed into the bowl; one near the center through which the lighter part of the liquid was discharged, and one nearer the periphery through which the heavier part of the liquid was discharged. Solid impurities which may have been present in the liquid were retained in the bowl.

The manner in which such a machine does its work will be immediately apparent to anyone who is at all familiar with the action of gravity upon liquids of different specific gravities. Centrifugal force causes the heavier parts of the liquid to move outward toward the periphery of the bowl, while the lighter parts remain near the center. The pressure of the incoming liquid, which is constantly being delivered to the bottom of the bowl, forces the two parts of the liquid upward and they are discharged separately through the proper openings into the receiving covers, from which they are delivered by means of spouts.

Improvements on Original Centrifugals

While this early type of centrifugal separator, or purifier, was entirely practical and did its work better than any device previously known, it was, of course, subject to considerable improvement. Separation within even closer limits was to be desired and, if possible, the machine should operate at lower speed so that there would be less wear on the parts. Some years ago it was discovered that both of these results could be obtained by placing a series of conical disks within the bowl, and the more modern centrifugals in use today are built in that way.

These disks divide the liquid being separated or purified into thin sheets or layers so that there is less conflict between the currents of purified liquid and that which is unpurified. Therefore, when running at about one-third the speed, these machines of improved design develop sufficient centrifugal force to effect an even finer degree of purification or separation than those of the earlier type. Aside from the thin-sheet distribution made possible by the disks, the action which takes place within the bowl of the present-day centrifugal is almost identical with that described earlier in this article.

From the preceding paragraphs it will be seen that the principle of purifying or separating liquids by centrifugal force has been proved sound by centuries of use; that the continuously operated centrifugal has been a reality for more than forty years; and that the modern type of machine has passed through the stages of evolution which are necessary before any piece of equipment can be called mechanically perfect—or as nearly so as it is possible to make it. All that now remains is to fit the machine to the problem and during the past few years this has been done in many industries.

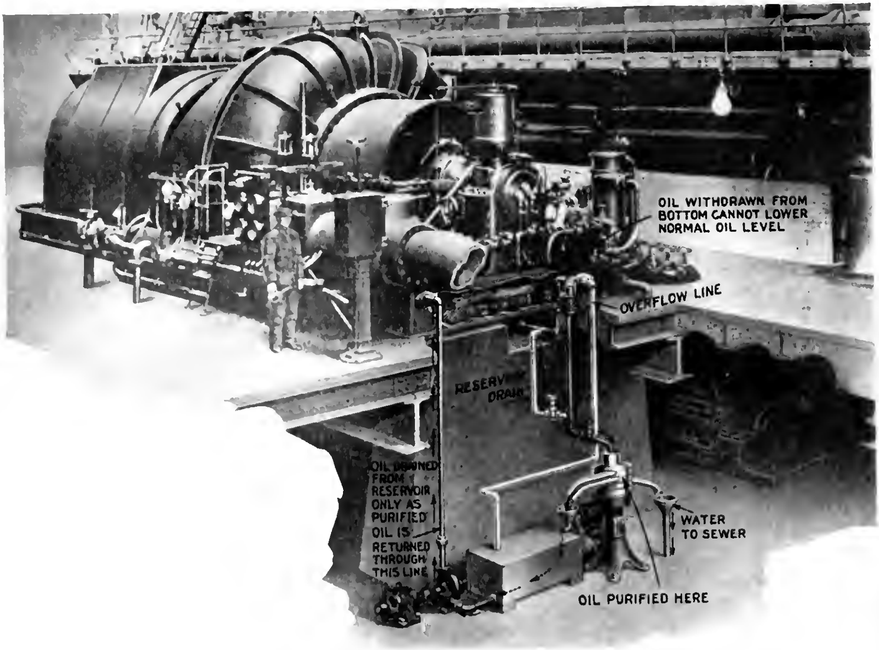


Fig. 1. Cross-section in a Central Station showing how a Centrifugal Oil Purifier is Connected into the Turbine Lubricating System

Application of Centrifugal Purifiers to Power Plant Lubricating Problems

At the outset it is probably best to correct an erroneous impression given in the article which appeared in the May issue of the Review. The statement was made that "If a centrifugal separator is used (to purify turbine oil) 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." From this it would seem that before it could be centrifugally purified the oil must first be heated. This is not the case, however, except in unusual instances where the batch system of purification is employed and the oil has been allowed to become exceptionally dirty. The treatment then is one of reclamation rather than of purification.

Such a case came to light some time ago when a group of engineers representing a well-known oil company and another group representing a large steel company decided to test the effectiveness of centrifugal purification. A series of tests was made on oil taken from various engines in the steel mill, representing the most severe service that lubricating oil is required to perform. The quotations are from the report of the oil company engineers. "The oil used in connection with this test was taken from the gravity circulating system of the blowing engine room. The capacity of the oiling system is about 12,000 gallons. However, at the present time the system contains approximately 9000 gallons of oil. One barrel of oil for test purposes was taken from the return tank of the system. The results of the analyses which follow will show the condition of the oil in this system when delivered to the return tank and before passing through the centrifugal purifier connected with this system."

Oil After Centrifugal Purification

Water .	0.5 per cent
Gravity Bé .	21.2
Flash, open	340 deg. F.
Fire. .	405 deg. F.
Univ. Visc. at 100 deg. F.	334 sec.
Ash. .	0.13 per cent— Iron Ox.
Sed. by 86 deg. Naphtha	0.05 cc.
Free Carbon	0.25 per cent
Acidity as SO_3	0.068 per cent
Acidity as Oleic	0.42 per cent
Compound. .	None
Saponification. .	4.8

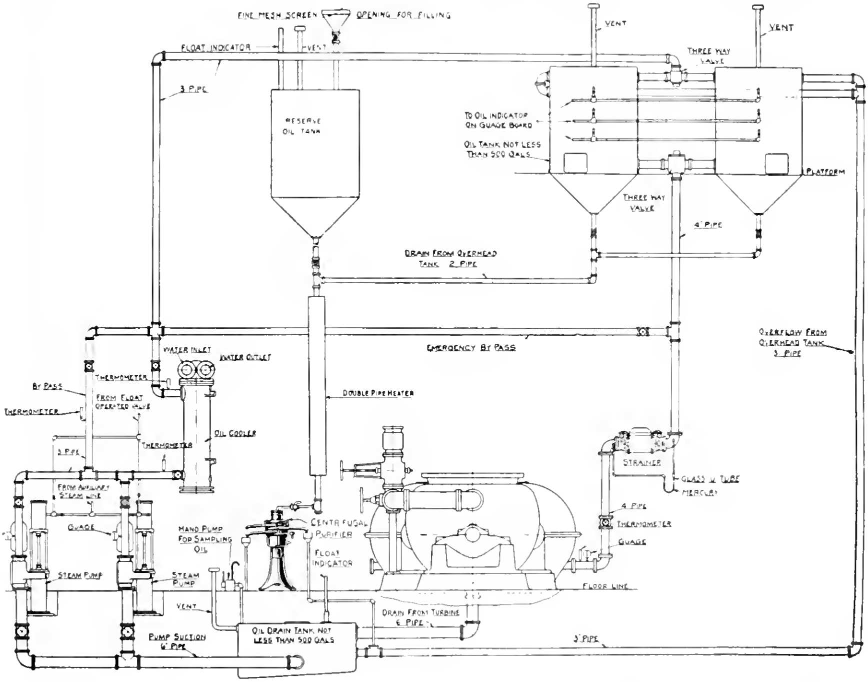


Fig. 2. Diagram showing how a Centrifugal Oil Purifier may be Connected into the Lubricating System of a Marine Turbine

Oil Before Purifying

Water	25.0 per cent
Gravity Bé	18.0
Flash, open	345 deg. F.
Fire. .	410 deg. F.
Univ. Visc. at 100 deg. F.	594 sec.
Ash	0.54 per cent— Iron Ox.
Sed. by 86 deg. Naphtha	1.7 cc.
Free Carbon . .	1.72 per cent
Acidity as SO_3 . .	0.07 per cent
Acidity as Oleic	0.52 per cent
Compound . . .	None
Saponification .	4.7

Analyses of Total Sediment Removed From Purifier After Test

Sol in CS_2 . .	45.93 per cent
Sol in CCl_4 .	15.94 per cent
Sol in 86 deg. Naphtha	35.80 per cent
Ash . . .	50.16 per cent
Analyses of Ash:	
Iron Oxide. .	41.38 per cent
Aluminum Oxide .	14.92 per cent
Copper Oxide	4.57 per cent
Silicon Dioxide	36.81 per cent
Sulphates . .	Heavy trace

After purification this oil was returned to the lubricating system in a proper condition for efficient lubrication. The report concludes as follows: "This test showed that with the oil in the condition of that used in this test it can be thoroughly purified, and the purified oil returned to the bearings with its necessary high lubricating value which would naturally prolong the life of the oil in the system to an indeterminable period."

Such oil as that mentioned above might preferably, of course, be heated before purification; if for no other reason than to raise its fluidity so that it will flow more freely through the machine. The continuous by-pass method, however, from the very nature of its operation is intended to filter and clarify the oil continuously, and is so superior to batch purification that most plants which have installed centrifugal purifiers are using them in connection with this method. This avoids the necessity of applying heat before purification and of providing tankage to hold the oil while it is being purified.

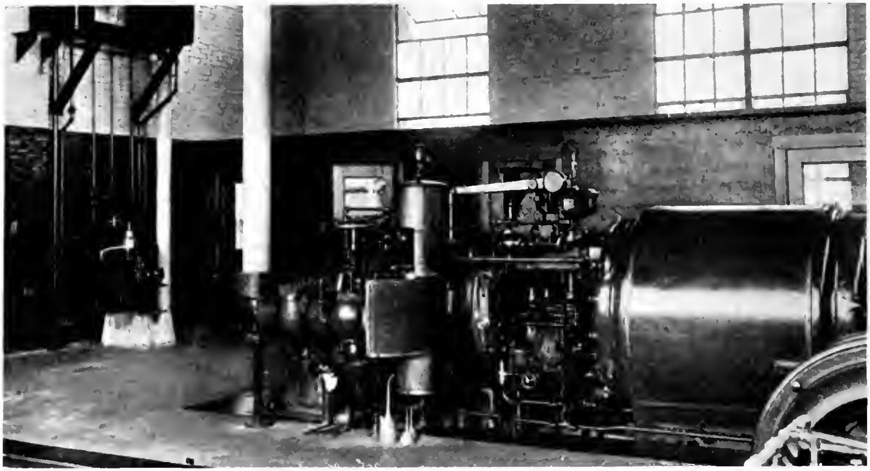


Fig. 3. Typical Installation of a Centrifugal Oil Purifier in a Small Power Plant. A diagram of the oil connections used is shown in Fig. 4

How Centrifugal Purification Maintains Lubricating Value of Oil

It has been shown above that the centrifugal oil purifier is capable of restoring the lubricating efficiency of badly contaminated oil. But it is generally acknowledged that it is not a good policy to allow oil to reach the state—or anywhere near the state—of that used in the test previously referred to. The average engineer is interested in a means of constantly maintaining the efficiency of the oil in his turbine system. A typical example of the results obtained by using centrifugal purifiers for this purpose is found in the experience of the Des Moines (Iowa) Water Works. In this plant a centrifugal purifier is used to purify the oil in the system of a geared turbine pump. The oil now in the system has been used for more than nine months, and the following tests show how well the centrifugal purifier has maintained the characteristics of the new oil:

	Original Oil	Used Oil
Gravity	31.4	29.1
Flash	400	395
Fire	450	445
Visc. at 100 deg	211	216

The turbine in this plant is of the gravity lubricated type and the overhead tank from which the purifier takes its oil is an integral part of the continuous lubricating system. A part of the used oil pumped from the turbine into this tank is taken off and returned to the turbine by means of an overflow pipe located about half way up the side of the tank. Connection to the purifier is made at the bottom of the tank where the dirtiest oil will naturally be found. The purifier removes the impurities from this oil, which is then delivered to the turbine together with the comparatively clean oil which overflows from the tank. In this simple manner the lubricating efficiency of the oil is being indefinitely maintained as has been shown.

Centrifugal Purification of Marine Turbine Lubricating Oil

The article which appeared on pages 414-421 of the May, 1921, Review made no mention of the problem of maintaining the efficiency of marine turbine lubricating oil. As brought out in the article on pages 788-793 of the September, 1921, Review, centrifugal oil purifiers are extensively used for this purpose.

The service which lubricating oil must perform aboard ship is particularly severe because of the necessity of lubricating the reduction gears which are commonly used to drive the propellers at proper speed. This gearing makes it necessary to keep a greater quantity of oil in the system and adds to the volume of impurities which must be removed from it. And if the gears are to give long service the oil must be kept free from impurities at all times.

Maintaining the efficiency of marine turbine lubricating oil is further complicated by the fact that the motion of the ship when at sea interferes with the operation of a gravity settling system. For this reason it has until recently been inevitable that a large proportion of the oil used aboard ship should be wasted. The common practice has been to remove from the oil by means of gravity settling or filtration as much of the impure matter as possible. When the amount of impurities became so great that the oil could no longer be used with safety it was pumped overboard and new oil substituted.

The centrifugal purifier has now changed this and today there is no more excuse for wasting oil in the marine power plant than in a shore plant. The operation of centrifugal machines is not affected by the motion of the ship. Purification goes on regardless of weather conditions. The efficiency of the oil is maintained indefinitely so that none of it need ever be taken from the system.

Purification of Oil Used on Diesel-powered Ships

While by far the largest number of ships equipped with centrifugal oil purifiers are of the turbine driven type, many vessels driven by Diesel engines have recently been equipped with these machines. The purification of the oil used on these ships probably represents the most severe test to which the centrifugal oil purifier can be put. In addition to the water and dirt which are found in every lubricating system, the system of a Diesel engine after a comparatively short run becomes loaded with a large amount of carbon. Eight quarts of badly contaminated oil which was recently taken from a submarine after a 1200-mile cruise yielded one pint of heavy black sediment when run through a centrifugal oil purifier.

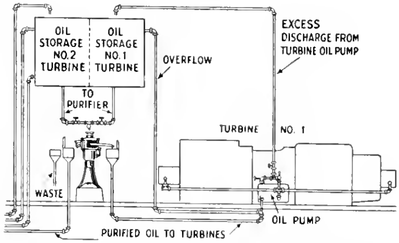


Fig. 4. Diagram showing a Method of Connecting up a Centrifugal Purifier so that the oil in either of two units may be handled by simply swinging the discharge spout of the purifier from one funnel to another

This sediment, which was practically all carbon, had made the oil opaque, but centrifugal treatment completely restored its lubricating value. It has been proved in actual service that by continuously by-passing a portion of the oil through a centrifugal purifier the lubricating value of Deisel engine oil can be indefinitely maintained so that batch purification is not necessary or desirable.

One such case which is on record concerns the S. S. *Fabia*, of the Chisholm Fisheries Company. The engine on this vessel is a Nelseco, 360-h.p., six-cylinder, 240-r.p.m., with 13 by 18-in. cylinders. About 80 gallons of oil is kept in the system. The purifier is operated continuously, delivering a $\frac{3}{16}$ in. stream of purified oil, and removing about one pint of black sludge from the oil every 18 hours. About eight quarts of new oil is put into the system every day to make up for the various losses which occur, but in more than a year of operation no oil was taken out of the system. The lubricating value of the oil has been fully maintained at all times.

This engine has recently been thoroughly inspected and the lubricating system proved to be free from deposits or pockets of sludge, dirt or water. At this time, the relatively small amount of oil remaining in the system was taken out as a precautionary measure, new oil being substituted. All bearings, pins, oil grooves and piping were shown to be in a perfectly clean condition. No adjustments were necessary on any of the main bearings and it has only been necessary to remove 0.012-in. shims from four of the crank boxes.

Conclusions

The installation of any purifying device which prolongs the useful life of turbine oil and insures greater reliability of operation is a worth-while economy. In selecting equipment of this nature the engineer must choose between the gravity type filter and the centrifugal purifier.

Both methods of purification are adapted for use with the continuous system, the continuous by-pass system or the batch system. It is, therefore, a question of choosing the type of equipment which is best suited to the needs of the individual plant. This can be determined only after a thorough study of all the factors involved: reliability; economy of operation; oil economy; thoroughness of purification; layout of the plant; present handling method; and all the other features which are usually considered before installing new equipment of any kind.

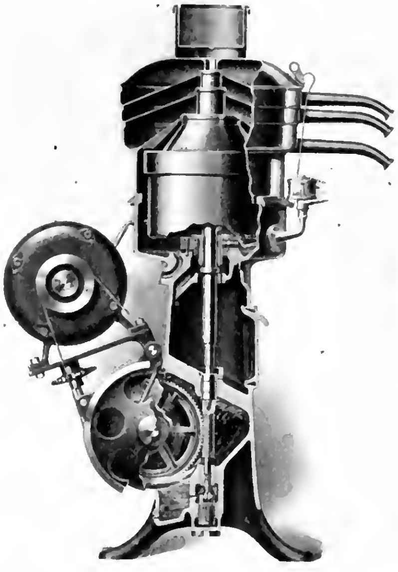


Fig. 5. Cross-sectional View of a Disc-type Motor-driven Centrifugal Oil Purifier

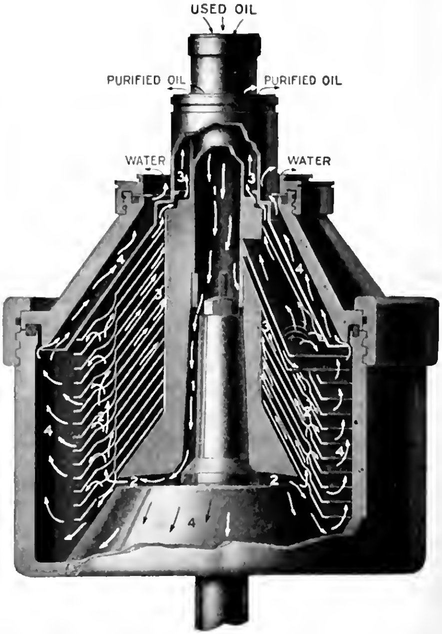


Fig. 6. Cross-section of the Bowl of a Disk-type Oil Purifier. The arrows indicate the course of the oil through the bowl as follows: (1) Inflow of dirty oil into the central feed shaft; (2) delivery of incoming oil beyond that which has already been partially purified; (3) upward passage of the pure oil from the inner ends of the disks to the oil outlet; (4) upward passage of the water from the outer ends of the disks to the waste outlet. As explained in the text, the solid impurities are retained in the sediment pockets of the bowl

Some Features of the High-Intensity Motion-Picture Arc

By Frank A. Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

Many war-time developments have found useful adaptation to peace-time activities. The high-intensity motion-picture arc projector, counterpart of the high-intensity military searchlight, promises to be a distinct advance in the art of exhibiting motion pictures for at least two reasons: (1) it will make possible the construction of larger motion-picture theaters because it furnishes sufficient light to illuminate satisfactorily a larger screen than is the present standard, and (2) it will enable the use of a higher degree of general room illumination from the side lights, which condition promotes safety and lessens eyestrain through reduction of contrast. The light characteristics and manipulation of the high-intensity arc differ greatly from the plain carbon arc, and the differences and methods of making the measurements are fully described in the following article.—Editor.

There has appeared on the market within the last few years a new type of projection arc that holds great promise for the future. It is a distinct step in advance over the common carbon arc, and as it is still being studied there is every reason for looking for further development. This is the "high-intensity" or gaseous arc, first brought out for military purposes by Mr. Heinrich Beck, some ten years ago. As not everyone is acquainted with this extremely interesting arc, a few words describing its characteristics may not be out of place.

The positive electrode of the high-intensity arc is smaller than that of a plain carbon arc for the same current, but the core is larger and is heavily impregnated with salts that vaporize at a high temperature. The current passes through this core gas as it flows into the crater and heats it to a still higher temperature. Pure carbon can be raised to a temperature of about 3800 deg. absolute (equivalent to temperature in degrees Centigrade plus 273) under ordinary conditions and no amount of increased current will raise the temperature above this point. The core gas of the high-intensity arc is not hampered by any such fixed limit and there is evidence that the gas reaches a temperature of at least 5500 deg. absolute, or about that of the sun. Photometric measurements have shown the center of the gas crater to be over five times as bright as carbon at its best brilliancy. The total amount of light is not five times, however, because the crater is smaller and the projection efficiency is between two and three times that of the plain carbon arc.

There have been gaseous arcs on the market for a number of years but the Beck arc is the first one in which the gases are sufficiently stable to be used for projection purposes. By making the positive core half the diameter of the shell, baking the shell as hard as possible, and having a number of other features such as diameter of negative and angle between axes of electrodes all adjusted properly, a deep crater will be caused to form in the end of the positive electrode. This crater is almost a hemisphere in form, being slightly more than half the diameter in depth, and the walls are very thin. The carbon is rotated slowly so that all sides burn equally and the crater is kept symmetrical with the axis of the electrode. The gas from the core fills this crater and the current passing through the gas causes it to reach such a high brilliancy that the carbon wall seems dark by comparison. The gas, being confined by the crater walls, is much more stable than if it were out in the open; and the use of luminous gas for motion-picture projection thus becomes possible.

The temperature of the arc is variable and by raising or lowering the current the brilliancy of the gas can be changed. At the same time the crater diameter and depth will be altered and the stability of the gas will become less as the current is raised. The upper limit of current may be determined by the gas stability or by the rate of carbon consumption. As a rule the rated current of a given electrode should not be exceeded on account of the flicker set up by the gas that is then given off in greater volume than can properly be contained within the crater. It is true that at higher currents the volume of crater increases but not at the same rate as the evolution of gas and as a result the gas boils over the sides in place of escaping out of the top of the crater in a steady stream.

One of the most interesting features of this arc is the manner in which the various electromagnetic forces may be used to control the convection currents set up by the hot gases. The negative electrode is somewhat smaller than used with the ordinary arc, and the ionized carbon vapor leaves the tip of the electrode with considerable velocity. The gas evolved from the positive core has but little velocity so that it has small tendency to flow outward and if the stream of negative gas is directed properly it will oppose the escape of the core gas and keep the crater filled with the luminous gas that is the real source of the light. We are dealing here with gases that are, at any given instant, of extremely small mass, and the electromagnetic and convection forces are relatively large. It is thus apparent that the core gas particularly may be driven about almost at will by using the forces available in the arc.

Fig. 1. High-intensity Arc at 72 Amp., 61 Volts, 18-mm. Length. Negative axis at 14 deg. 30 min.

The angle at which the negative electrode is placed with respect to the positive electrode is determined by the service for which the arc is intended. For military searchlights the negative axis is depressed 14 deg. 30 min. below the positive axis, which coincides with that of the searchlight. This has been found by trial to be the angle that gives the best results in efficiency and steadiness. For studio lamps the negative is placed 30 deg. below the axis in order to secure unobstructed radiation, while for projection lamps the angle must be increased to 60 deg. to keep the condensers free from shadows.

It is rather a fortunate circumstance that the arcs of 50 and 75 amp. are not so sensitive to the angle of the negative as those of higher currents. As the current increases, the electromagnetic force due to the relation of the arc stream to the surrounding magnetic field grows at a rapid rate; and while arcs up to 450 amp. have been operated and tested, still there are many unsolved problems at these currents.

With a given angle of negative, the height of the negative (or point where the negative axis pierces the plane of the crater) must be carefully selected. A change of one millimeter (0.04 in.) is of importance in arcs of 120 and 150 amp., while the 50 and 75-amp. arcs should be within two millimeters of the specified height. If the negative is improperly set so that the stream of carbon gas from the negative does not strike the crater opening in the right direction, the luminous core gas will be agitated instead of stabilized, or perhaps driven rapidly out of the crater.

Fig. 2. Measuring the Effective Light Output of a Motion-picture Projector Lamp

It is possible, by giving the negative electrode a side tilt of several millimeters, to increase the diameter and depth of the crater to some extent through the unsymmetrical direction of the negative gas causing it to drive the luminous core gas out of one side of the crater but this action lowers the efficiency of the arc.

These various features of the gaseous arc have been detailed in order to bring out more clearly the fact that the high-intensity arc is radically different from the plain carbon arc and in service and testing the arc must be treated differently. For example, it is common practice to have control handles on both carbons of the plain arc so that they can be moved around and thus keep the crater properly formed. The high-intensity electrodes on the other hand are held in a fixed position that must not be varied. The crater of the plain carbon must be oversize so that the operator will not have to adjust too often for the movement of the crater. The high intensity crater being fixed in diameter needs but little extra size in order to cover the screen because it is held in position and once adjusted does not readily get out of alignment.

The testing equipment used in this laboratory for investigating studio and projection arcs is somewhat unusual in design and size. It is very desirable to test any given arc under working conditions as nearly as may be duplicated. This allows the arc to be used with its proper condensers and projection lens, and what is extremely important, the arc, condenser, aperture, and projection lens may be placed in their proper relationship. Each part of the optical system then functions normally and the results obtained apply directly to the equipment in actual service. One of the prime conditions of projection is a screen illuminated with a certain uniformity from edge to edge. Whether we can obtain this uniformity with a given equipment can be best determined by projecting the light under conditions similar to those obtaining in a theater. The equipment here illustrated allows this to be done.

Fig. 3. Measuring the Beam with the Ends and Corners Cut Off

Fig. 4. Measuring the Central Part of the Beam

In Fig. 2 is shown the arrangement when the light in the entire beam is being measured. The beam is projected some 65 ft. down a tunnel formed by curtains with circular openings through their centers. These curtains are on rollers and may be raised or lowered and the integrator, whose white hemispherical interior is seen at the far end of the tunnel, can be moved so that its distance from the lamp is anything desired up to 150 ft.

A photometer is attached to the rear wall of the integrator and the reading on the photometer tells the amount of light entering the instrument. It is thus possible to measure at one time the entire effective output of a projection lamp under conditions that are as close as desired to those found in the theaters. This way of taking measurements marks a great advance in the art of photometry, for while nothing is accomplished that could not have been done before, still the convenience and accuracy of testing have been raised to the point where much testing is now done where formerly the cost was prohibitive. The older method was to measure intensities of illumination in various parts of the beam or curtain. If accurate and constant data were required the test had to be repeated over and over again. With the equipment here illustrated the test is repeated only enough to make certain that the variations in the electrode itself are taken care of.

The degree of uniformity of illumination over the screen is sometimes roughly determined by visual observation. If, however, it is desired to get photometric readings of intensity at the corners and center of the screen, we may proceed as follows:

A reading of the whole quantity of light in the beam is made with the iris shutter of the integrator wide open. The shutter is then closed down until it cuts off the corners and a second reading is made. This reading is less than the first by the amount of light going to the corners and sides of the screen, and therefore we immediately have a determination of the desired quantity of light. By closing the iris shutter still further, only the central part of the beam enters and we then have a direct measurement of the center of the beam and an indirect measurement of the middle zone between the corners and center.

A close up view of the integrator is given in Fig. 5 to show more in detail how the instrument works. The iris shutter, which has a maximum opening of 110 in., is closed in slightly so that its position can be more readily seen. This shutter may be closed down to a four-inch opening and the aperture is always a circle.

The black prongs extending inward from the shutter ring are for the purpose of correcting for the optical peculiarities of the plaster on the inner surface of the hemisphere. The theory of this type of photometric instrument starts with the assumption that the reflecting surface is perfectly diffusing in action. Such an ideal surface has never been discovered and in these instruments it was necessary to make a correction for the lack of perfect diffusion. Thus, if a narrow beam of light enters the instrument parallel to the axis of the tunnel, when striking near the edge of the hemisphere it will give readings 33 per cent higher than when it strikes near the center. The entire surface was explored to find its action under light entering parallel to the axis, and the prongs were then designed to reduce the amount of light around

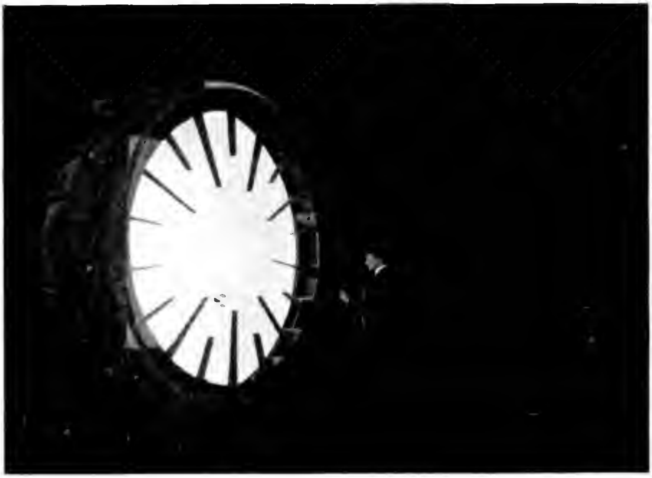


Fig. 5. A Close-up View of the Photometer Receiving Projected Light

the periphery so that all parts of the instrument would give identical readings for identical quantities of light.

The close up view of the integrator, Fig. 5, shows the entering beam shifted to one side in order better to illustrate the curvature of the white inner surface. The optical wedges are seen to have a *T* section with variable widths across the head of the *T*. These wedges are set close to the leaves of the iris shutter so as to support them when in a closed position. The shutter is operated by means of the handwheel and chain shown at the right. The photometer enters a small hole on the axis of the hemisphere and the photometric accessories and operator are carried on the platform shown at the rear. The entire instrument may be rolled the length of the room, giving a working range of 150 ft. for projection.

The high-intensity arc has been the subject of a vast amount of study and experimentation. One of the latest and most interesting experiments was an exploration of the current-light characteristic. It was particularly desired to find how a 120-amp. electrode operated at say 90 amp. compared with an electrode designed for 90 amp. Many of the picture houses have supply and converter equipment that is limited in capacity and they are thus not free to operate under the best conditions. It is often the case that 90 or 100 amp. is the limit of current and the lamp in this case is run far below rating. The curves in Fig. 6 illustrate what happens under these conditions and show how wasteful is the practice of burning high-intensity carbons at less than their current rating. By proper selection of lamp and electrodes, the high-intensity arc can be operated at high efficiency. As an exaggerated example, consider what would happen if an incandescent lamp were operated at three-quarters of its normal wattage. We know from experience that the amount of light would decrease 50 per cent and it is self-evident that this would not be offset by the 25 per cent saving in the light bill.

In making the foregoing projector tests the lamp was equipped with standard condensers and the light was projected as previously described. The 120-amp. electrodes were operated at 120, 110, 100 and 90 amp. Taking the light received on the screen at the highest current as 100 per cent, the other currents gave 81, 62 and 41 per cent. We may therefore say that when near normal rating the light falls off 2.3 times as fast as the current. Thus, if the current is lowered by 10 per cent the light falls off 23 per cent. If the current is dropped to 90 amp., a decrease of 25 per cent, the light will decrease 59 per cent. If, on the other hand, an electrode designed for 90 amp. were used, the loss of light would be only 30 per cent. We may make the comparison in another way. A 75-amp. standard electrode at 75 amp. will give as much light on the screen as a 120-amp. electrode at 97 amp. There are many factors to be considered in an actual installation that have not been mentioned here, but the figures given show that in choosing the lamp or the current the high-intensity arc must be considered as a new and different light to which the older rules of arc practice do not apply.

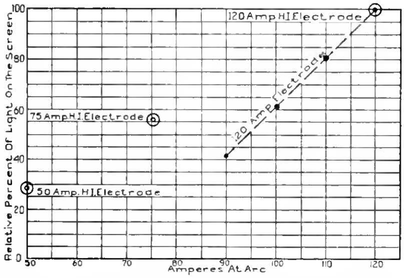


Fig. 6. Photometric Comparison of High-intensity Motion-picture Projected Light Reaching the Screen under Service Conditions. 50, 75, and 120-amp. high-intensity electrodes burned at their normal rating and 120-amp. high-intensity electrode burned at 120, 110, 100 and 90 amp.

A Study of Multigap Lightning Arrester Phenomena

By N. A. Lougee

General Engineering Laboratory, General Electric Company

The author shows the results obtained by testing complete lightning arresters in the lightning generator described in our issue of November, 1921. Our illustrations show the condition of some of the individual gaps taken from different parts of the arrester after these tests. The practical use of these tests is that the general appearance of the burning of the gaps can be used as a guide to tell what has happened in arresters showing similar burning marks in actual service.—Editor.

The familiar type of multigap lightning arrester, shown in Fig. 1, consists of a number of small gaps between brass cylinders, part of which are shunted by low resistance. The action of this arrester when subjected to a high voltage impulse of considerable power with the regular dynamic circuit applied, and the respective effects of each, are interesting.

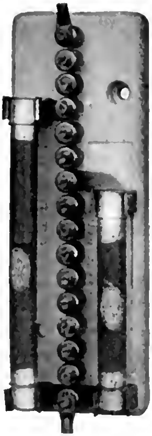


Fig. 1. Single-pole Multigap 2300 volt Station Arrester

It should be noted that the impulse and the normal operating voltage are both applied simultaneously during the test to simulate service conditions.

The static impulse has two possible paths: straight through all the series gaps to ground, or through part of them and the shunt resistance to ground. Which path it takes depends upon the severity or energy of the impulse. If of comparatively large energy, it will take the path through all the series gaps, as this path offers the least resistance for a high current discharge. For small energy impulse discharges, however, there is some value below which the path through the series gaps and shunt resistance offers less resistance than that through all the gaps.

The action of the dynamic or normal circuit during an impulse discharge by the lightning arrester depends upon the amount of energy in the impulse discharge.

For heavy energy impulse discharges, the resistance path through all the gaps, caused by the heavy current discharge, is sufficiently low for the dynamic current also to take this path and to continue for the half wave. The value of the dynamic current during this first half cycle is great, as it is practically a short circuit on the system. After going through zero, however, it requires more voltage to re-establish the circuit through all the series paths than is available, so consequently the dynamic current goes through only the series gaps and shunt resistance with a corresponding decrease in current. Due to this large decrease in current, at the next reversal of current, the path through the series gaps is sufficiently cooled so that the circuit will not be established again. This is explained and shown by oscillograms in the article, "Types of Lightning Arresters," in the General Electric Review for December, 1921.

An impulse of a certain smaller amount of energy, but still of a sufficient value to take the straight gap path to ground, does not establish a sufficiently low resistance path for the dynamic current to follow through all the gaps. In this case, the dynamic current takes the path through the series gaps and shunt resistance. The current value, limited by the resistance, is small, and the circuit will not be re-established at the next half wave; that is, it is like the second half wave in the above case.

If the impulse is sufficiently small in respect to energy that it goes through only the series gaps and shunt resistance, the action of the dynamic is similar to the last case described.

Between these cases there are a number of conditions, that is, when the dynamic just follows during the first half wave, when no dynamic follows at all, etc.

To illustrate all these conditions better and to have standards to go by in analyzing operating data, the foregoing conditions were reproduced with the lightning generator, described in the General Electric Review for November, 1921, entitled, "A Generator for Making Lightning." The appearance of the gaps is shown in the illustrations. The available energy of the impulse is 360 joules, which is believed to be greater than most impulses received in service.

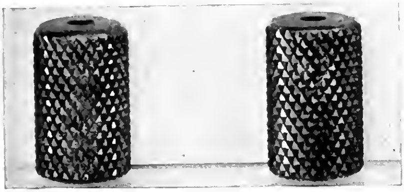


Fig. 2. After Ten Shots, Impulse Only

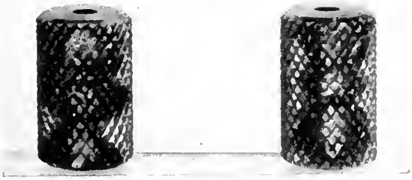


Fig. 3. After Ten Shots, Impulse and Dynamic

Brass Gap Parts from a 2300-volt Lightning Arrester. Left section in each illustration taken from a series gap. Right section from a shunt gap

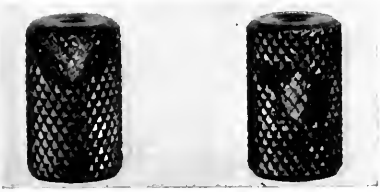


Fig. 4. After One Shot, Impulse and Dynamic

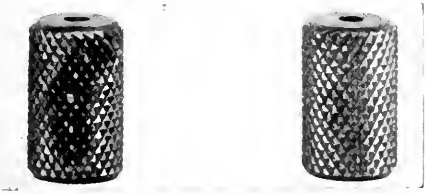


Fig. 5. After Ten Shots, Reduced Impulse and Dynamic

Fig. 2 shows the parts of series and shunt gaps which were given 10 impulse discharges with *no* applied dynamic. It will be noticed the burning is slight; that is, the average lightning discharge affects the arrester but little.

The gap parts in Fig. 3 were taken with the same degree and number of impulse discharges as above, but with the 2300-volt dynamic applied, giving a short circuit current of over 1000 amperes. Here the burning is considerable, and there is no distinguishable difference between the series and shunt gap parts. This would be expected as the shunt gaps carried, say, 1000 amperes for a half cycle and the series 1000 and 80, for each half cycle respectively.

Fig. 4 is the same as above but for one test only.

In Fig. 5, the energy of the impulse was adjusted so that, although it took the straight gap path, the dynamic current followed through the series gaps and shunt resistance. Here the series gap parts show burning only by the dynamic current and much less than in Fig. 3. The shunt gap parts hardly show traces of the impulse. Ten tests were made in this case.

These gap parts will give an idea of phenomena in actual service by comparing them with similar parts from arresters in service, and it is thought a better understanding of the severity and number of outside discharges can be approximated.

Springs for Electrical Instruments

By B. W. St. Clair

Lynn Works, General Electric Company

The continued accuracy of practically all electrical indicating instruments, with the exception of power-factor indicators and frequency indicators, is dependent upon the elastic properties of the material used for the springs. Spring fatigue and spring set are destructive of accuracy, and materials possessing these properties to any extent should be avoided. Other properties that are sometimes important are the specific resistance and temperature coefficient of resistance; the requirements here being contrary, as the lowest specific resistance is often required together with a low temperature coefficient and a compromise must be made. These and other important factors that enter into the manufacture of springs for electrical instruments are discussed by the author.—Editor.

The dependability of practically all of the electrical indicating instruments is a function of several major factors, most of which depend upon the constancy of some specific physical property of some particular material. A discussion of the control springs, one of these important factors, is the basis of this article.

With the exception of such instruments as power-factor indicators and frequency indicators, the constancy of calibration of every electrical indicating instrument is in general no greater than the constancy of the elastic properties of some material, generally some one of the bronzes. Hard drawn and rolled silver was the material used for the spiral springs of some of the earliest indicating instruments. These instruments, in many instances at least, would not return their pointers to zero immediately after removing the current or voltage. The pointer would remain a little above zero and if left undisturbed returned finally and slowly to zero. To this phenomenon the general name "spring fatigue" has been given by instrument designers. A somewhat similar and rarer one known as "spring set" is applied to those cases where prolonged deflection of the pointer up-scale results in a permanent change of the zero position of the pointer.

Fundamentally the torque that the spring shall have is determined by the weight and inertia of the armature and the design of the bearings; though the losses, the temperature, frequency and wave form errors of the proposed instrument must also be given some consideration. The bearing friction must, of course, be so small in relation to the full scale (generally about 90 deg.) torque of the spring that it will not cause discernible errors in the deflections. Thus for a full scale torque of 5 millimeter grams—a fair figure for many a-c. instruments—the static friction torque of the armature in its bearings must not exceed 0.00015 millimeter grams at the very most and should be quite a bit under this maximum figure. This is based upon the fact that on all but miniature forms of instruments the scale arrangements are such that by estimating tenths of a division the instrument can be read to 1/1500th or 1/1000th of its full scale value. For a full scale torque of 0.5 millimeter grams the friction torque figure must not exceed 0.000015 millimeter grams (1.1×10^{-10} foot pounds). The weight of the armature in a large measure determines the friction and consequently the spring torque.

Some idea of the reliability required of instrument springs can be gathered from the minimum perceptible change in the position of the pointer when expressed in angular measure. In a high grade test instrument of 4 in. or 5 in. pointer length this figure is of the order of 3 min. to 5 min. of arc, while for a secondary standard type the minimum discernible angle is 1.5 min. to 2 min. of arc. Precision of an order ordinarily met with only in mathematical instruments is thus required of springs for this class of service.

The silver springs of the early indicating instruments have been in most cases replaced by some form of bronze springs. This has resulted in a general reduction of fatigue and in most cases an elimination of set. Some form of bronze is almost the only material employed in present day instrument practice. A survey of the properties of the various elastic materials that might be considered eliminates almost completely all other materials except the bronzes. The steels, for instance, because of their elastic properties, might be better than bronze, but cannot be used because of their magnetic properties and their tendency toward rusting.

Many properties besides the elastic modulus must be considered; thus the specific resistance of the material should be low, at least for those instruments whose springs must act as lead-in conductors for the armature current. This is a specially important consideration with milli-voltmeters, where the armature resistance is very low, and is nearly always a limiting point in their design and compromises are generally necessary to produce springs whose resistance will be satisfactorily low. In addition to low specific resistance, low temperature coefficient of resistance is also a very desirable quantity, specially in those instruments whose spring resistance is an appreciable fraction of the total circuit resistance. These two desirable quantities are, of course, contrary ones, as high conductivity is generally associated with high temperature coefficient of resistance. The temperature coefficient of the elastic modulus must also be negligibly small to insure inappreciable temperature changes from this source in the instrument. The material must be so homogeneous mechanically that ambient temperature changes do not cause it to shift its zero position. In other words, it must be entirely free from thermostatic actions.

Fig. 1. Photomicrograph Showing Structure of Material in a Spring of Low Fatigue

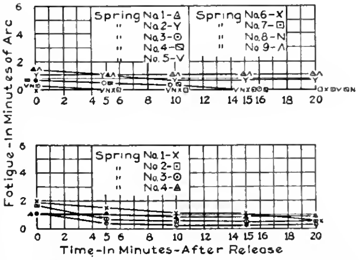


Fig. 3. Actual Behavior of Springs Made from Material Shown in Fig. 1 Under Well Controlled Conditions. Turned through an angle of 90 deg. and held there for 15 min. Torque 6 mm-g.

Fig. 2. Photomicrograph Showing Structure of Material in a Spring of High Fatigue

Aside from the choice of proper material, much consideration must be given to the design of the spring. The torque of a given spring will vary directly as the width of the ribbon from which it is made and as the cube

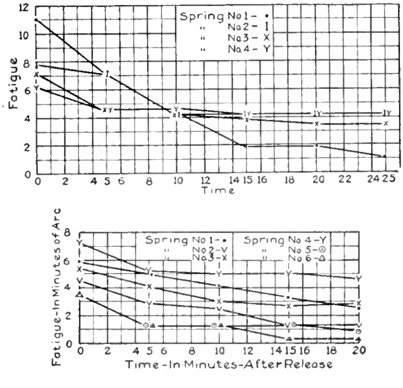
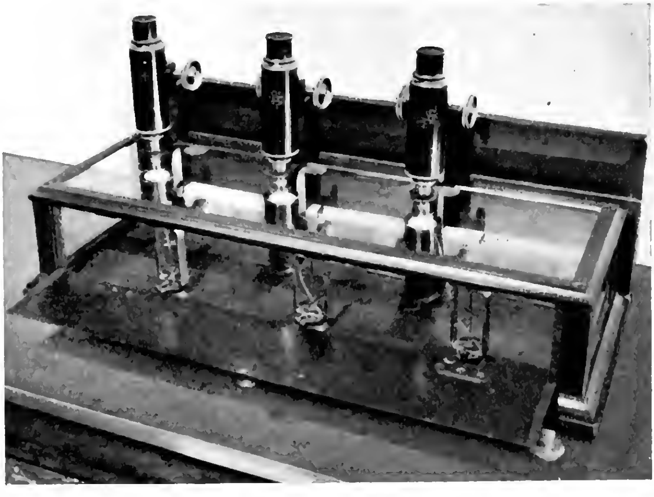


Fig. 4. Behavior of Spring (Upper Curves) Made from Poorly Prepared Material. Turned through an angle of 90 deg. and held there for 15 min. Torque 7.2 mm.g. Lower curves show springs purchased from spring manufacturer. Torque 4.8 mm.g.

of the ribbon thickness. Upon the thickness of the ribbon depends almost altogether the fiber stress of the material and fiber stress has much to do with the fatigue of a spring. Thus in designing high torque springs, i.e., above 5 millimeter grams, the temptation to get high torque by increased ribbon thickness must be resisted in those cases where the fiber stress approaches abnormal values. The condition of the surface material also has more to do with the fatigue than the core material, inasmuch as through the center of the ribbon there is a line of unstressed material while the outer edges are actually elongated and the inner edges compressed when the spring is deflected from its zero position. Thus the physical properties and condition of the surface material is of paramount importance since the surface material is under greater stress than the material nearer the core.

In addition to the material and the design, much attention must be given to the technical processes of producing a spring from a round bronze wire. Proper material and conservative design represent but a partial solution of the problem of producing fatigueless springs. The reduction of the wire to a ribbon and the winding and setting of the ribbon into a spiral spring must be done under such conditions as will leave an absolutely homogeneous material. Some metallurgical features of this part of the problem are illustrated in the accompanying photomicrographs. The well prepared ribbon and the spring of low fatigue (Fig. 1) show very fine grain structure, while the poorly prepared material (Fig. 2) shows a very coarse structure. The spring of high fatigue also shows a very coarse structure with extensive breaks apparent in the fiber at right angles to the length of the spring.

The actual behavior of springs made from ribbon represented by these samples is shown in the curves of Figs. 3 and 4. The fatigue is here plotted in minutes of arc against time to show the recovery rate. In the interpretation of these results it must be borne in mind that fatigues of the order of 2 to 3 minutes of arc is really the maximum permissible fatigue for portable test instruments and 1 to 1½ minutes for secondary standards.



Instrument used for Determining the Fatigue Characteristics of Instrument Springs

A New X-ray Diffraction Apparatus

By WHEELER P. DAVEY

RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

Many materials may be readily identified and their crystal structure determined with a high degree of accuracy by X-ray analysis. The apparatus described in this article has been developed to provide a convenient means for applying this laboratory method of analysis to general crystal research and factory-control work. In the latter field, particularly, it should prove to be of great value. The article is abstracted from a paper of the same title by the author in the *Journal of the Optical Society of America*, November, 1921.—EDITOR.

The use of monochromatic X-rays for the determination of crystal structure is well known. It is the purpose of this article to describe an apparatus by which the characteristic X-ray diffraction patterns of fifteen powdered crystals may be taken at once. Each pattern is recorded on a strip of photographic film placed in a cassette which automatically holds the film on the arc of a circle of 8-inch radius, having at its center the specimen of powdered crystal. The whole apparatus is shown in Fig. 1, and exclusive of the switchboard, occupies a space 3 feet in diameter and about 4½ feet high.

The time required to obtain a satisfactory record of the diffraction pattern varies from 5 to 12 hours for substances like NaCl to 70 hours for substances like CuCl and CsI. The diffraction pattern may be interpreted directly in terms of the interplaner distances in the crystal by means of a metal scale which is calibrated in Ångstrom units. If the crystal happens to belong to the cubic, tetragonal or hexagonal systems its structure may be interpreted directly from these interplaner distances by means of the charts included as Fig. 8 in this article.

The Table

The table-top consists of a disk of steel ½ inch thick, provided with 15 radial guides for the cassettes. A hole is cut in the center. In this hole is fitted a metal cylinder which acts as a support for the slit system, and at the same time, because of the long wavelength of the X-rays employed, provides X-ray protection for the investigator. Fifteen rectangular openings at the level of the slit system allow the rays to reach the glass tubes containing the specimens. Under each of these openings is another opening which may be used when desired for calibrating the photographic film.

The top of the cylinder is closed by a flat brass cover which also acts as a rigid support for the anode end of the Coolidge tube. The cathode end of the tube hangs freely. The cylinder and cover are machined so that the axis of the tube automatically coincides with the axis of the cylinder. A set-screw allows a vertical adjustment of the tube along the axis of the cylinder.

The under part of the table is enclosed by a cylinder of heavy sheet iron, re-enforced with angle iron, and provided with doors to give access to the high-tension transformer which sits inside (see Fig. 2). The primary circuit of the transformer is carried across the front of these doors in such a way that the doors can not be opened without opening the primary circuit as shown in Fig. 1. In this way, when the X-ray tube is in operation, the operator is protected from accidental contact with the high potential.

The whole table is mounted on heavy castors so that it may be easily moved from place to place.

The Tube and Its Accessories

The X-ray tube is of the usual Coolidge type, but with a special water-cooled anode. This anode consists of a hollow copper rod at the end of which is fastened a molybdenum button. The face of the molybdenum button is perpendicular to the axis of the tube, so that X-rays may be taken off all the way around the anode.

The maximum allowable filament current for 1000 hours' life is 4.75 amp. The maximum tube voltage for efficient production of molybdenum characteristic rays is 30 $\text{kv}_{\cdot r.m.s.}$ At this voltage the tube current should be about 30 ma., but will vary from 25 to 35 ma. from one tube to another. The dimensions of the tube are shown in Fig. 3.

The radiation from the tube is filtered through filters of ZrO_2, each having 0.05 g. of ZrO_2 per cm². built into the cassettes. The filter eliminates most of the "white" (general) radiation, makes the molybdenum β doublet negligible, and eliminates a large part of such characteristic rays as may be given off by the specimen itself. The diffraction pattern, as recorded on the photographic film, is therefore caused by the molybdenum α doublet.

The optimum direct-current voltage for the production of molybdenum α is 28–30 kv.,[1] but operation on a-c. at 30 $kv._{max.}$ makes the time required for a satisfactory film so long that it is prohibitive for ordinary work. Experience shows that 30 $kv._{r.m.s.}$ is about the maximum voltage at which the "white" radiation may be easily filtered from the molybdenum characteristic rays. For this reason it was adopted as the standard operating voltage for this apparatus.

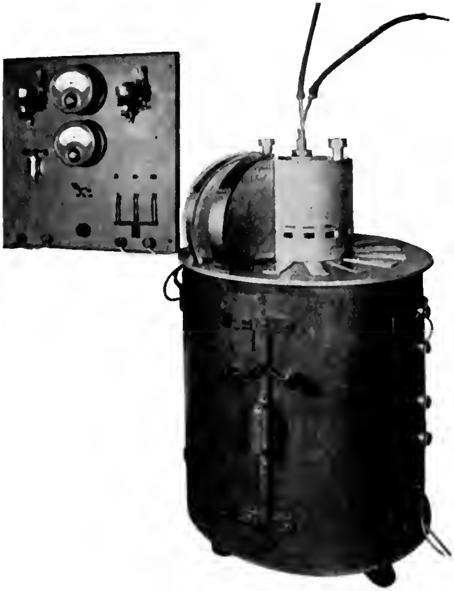


Fig. 1. X-ray Diffraction Apparatus (Doors Closed)

The Coolidge tube is operated directly from a transformer without any additional rectifying device. This necessitates a special design of transformer, for, although the secondary must supply power only on one half of the wave, the voltage of the inverse half-wave must not greatly exceed that of the useful half-wave. Otherwise there will be considerable trouble from corona during the inverse half-wave. The transformer has only one developed terminal, the other end of the secondary being grounded through the milliammeter. A protective spark-gap is provided across the milliammeter circuit so that the meter is always safe to handle even if one of its connections is broken. The filament of the Coolidge tube is heated by an extra coil at the high-potential end of the secondary. Both ends of this coil, as well as the high-potential end of the secondary, are brought out through the high-potential terminal to a Kearsley stabilizer,[2] which automatically lowers the filament temperature in case of excessive discharge currents through the tube. Fig. 4 gives a diagram of the connections. From the Kearsley stabilizer, the high-potential filament circuit goes directly to the cathode of the Coolidge tube which hangs directly above it. The anode end of the tube is in electrical contact with the table-top, as described above, so that the circuit is completed by the grounded metal table and the milliammeter back to the transformer. In this way the high potential is entirely surrounded by grounded metal.

The switchboard contains the customary circuit breakers, operating switch, an auto-transformer for adjusting the primary voltage of the transformer, a voltmeter for reading the primary voltage, a milliammeter and a pressure-stat. This pressure-stat is connected to the outlet end of the water cooled anode of the Coolidge tube. In case the water pressure falls too low, the pressure-stat short-circuits the power line through a small resistance, thus tripping the circuit breakers and protecting the tube from being burned out. The water pressure at the inlet end of the tube should be not less than 25 nor more than 80 lb. per square inch. In setting up the apparatus, enough resistance to the flow of water at the outlet should be provided so that the pressure-stat opens the protective short-circuit when the flow of water is one quart per minute.

The Slit System

The slit system is suspended from a disk of ¼-inch plate glass which has a hole 6¼ inches in diameter cut in the center. The system is composed of 15 radial sets of 3 slits each: the first two of which define the beam, while the third cuts off most of the secondary rays produced by the edges of the second slit. The whole slit system is formed on the surface of a cone whose basal angle is 5 deg. In this way each of the 15 slits utilizes the full projection of the focal spot of the Coolidge tube. The slit system is shown in Fig. 5.

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[1] A. W. Hull, "A New Method of Crystal Analysis," Phys. Rev., *10*, p. 661, 1917.

[2] W. J. Kearsley, Jr., "A New Type of Stabilizer for Use with the Coolidge Tube," Journal of Radiology, July, 1921.

The writer is well aware that numerous special types of slit systems have been devised by means of which X-ray diffraction patterns may be photographed in less time than with the system just described. Although their merits for some highly specialized investigations are undoubted, they are hardly suited for general crystal research, nor for apparatus intended for most forms of routine factory-control work, either because of the large quantity of specimen required, or the cost of preparing the specimen in some special shape, or because certain lines in the pattern are enhanced at the expense of others.

The Cassettes, Films and Specimens

The cassettes, one of which is illustrated in Fig. 6, serve not only as holders for the films but also as holders for the specimens. The powdered specimens (preferably 200 mesh) may be mixed with pyroxylin and formed into thin, flat sheets, or they may be packed into thin-walled tubes of about 1/32 inch inside diameter, of paper, celluloid or special glass. The glass tubes are preferred for most substances because of the possibility of sealing the specimens so that they can not be affected by oxygen or moisture. Whether the specimen is prepared in the form of a flat sheet or packed in a tube, the specimen-holder on the cassette automatically holds it in the path of the X-ray beam. In case the specimen contains elements of high atomic weight, it should be mixed with flour or other amorphous substance to decrease the opacity of the total mass.

A strip of thin, black celluloid is fastened to the cassette in the form of an arc, eight inches in radius, with the specimen at the center. The photographic film is held against this by a wide flat brass spring which is drawn up tight by a screw. A light-baffle over the spring prevents the film from becoming light-struck. The most satisfactory film for X-ray diffraction work seems to be the Eastman "Dupli-tized X-ray" film, 1⅞×16 in.

A "staircase" of copper is placed as an absorber in the path of the zero-beam. In this way there is always some part of the zero line on the film which has an exposure comparable to that of the first lines on the diffraction pattern. A molybdenum staircase is provided below the zero-beam for calibrating the photographic film.

A septum in the median plane of the cassette divides it into two symmetrical chambers, so that diffraction patterns of two substances may be taken on the same film for purposes of comparison. This is done by filling the glass specimen-tube half full of one substance, inserting a tiny plug of cotton, and then filling the remainder of the tube with the second substance. In work requiring the measurement of inter-planer distances with great accuracy it is recommended that one-half of the specimen-tube be filled with NaCl. The theoretical spacings of NaCl (side of elementary cube = 2.814Å) may then be used to give a correction curve for the film, thus avoiding errors due to any possible changes in the film itself.

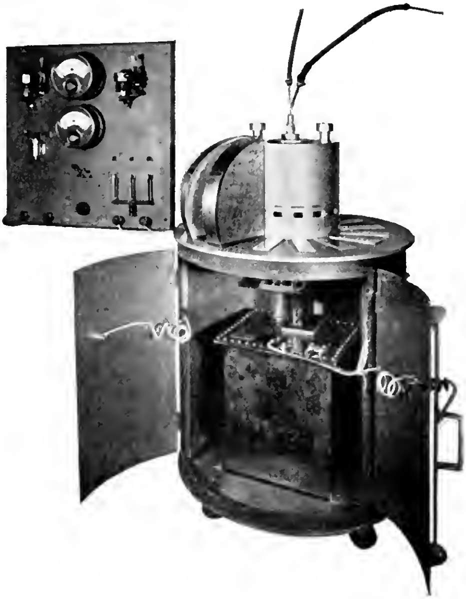

Fig. 2. X-ray Diffraction Apparatus (Doors Open)

A "range finder" is provided for adjusting the height of the Coolidge tube. It is built to fit the guides on the table-top so that it may be slipped into place opposite any one of the 15 slits. A tungsten wire acts as the "specimen." A fluorescent screen is mounted at the outside end in a position corresponding to that of the film in the cassette. The screen is faced with glass as a partial X-ray protection to the operator. The Coolidge tube is at the proper height when the fluorescent screen shows that the shadow of the tungsten wire is in the center of the zero-line.

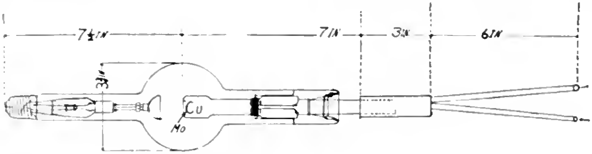

Fig. 3. Diagram of Water-cooled Coolidge Tube

The Diffraction Pattern

The photograph of the X-ray diffraction pattern looks much like the familiar picture of a line spectrum. The diffraction pattern of NaCl, taken with this apparatus, is shown in Fig. 7. A full account of the mathematical theory of the pattern is given elsewhere by A. W. Hull.[3]

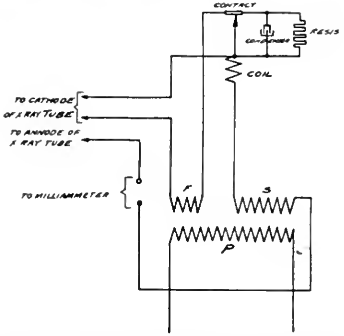

Fig. 4. Diagram of Connections. When the tube current exceeds a predetermined value, the solenoid of the Kearsley stabilizer opens the contact, thereby inserting additional resistance in the filament circuit

Using the classical equation for diffraction,

$$n\lambda = 2d \sin \theta$$

a scale has been calculated by which each line on the film may be directly interpreted in terms of the distance between the planes of atoms which produced the line. The apparatus has thus made a record of the diffraction pattern of the specimen and has enabled the experimenter to record in Ångstrom units the spacings of all planes in the crystal which are more than 0.55 Å apart. Where a solution of the crystal structure can be found at all, it is usually possible to make a valid solution using only lines corresponding to planer distances of more than 0.80 Å. When the doublet is resolved ($\lambda_1 = 0.712$ Å, ($\lambda_2 = 0.708$ Å) the readings of the two lines as given by the scale will be in the ratio of 1 : 1.005. In such a case the pattern is to be considered as showing a single line situated half-way between the two actual lines. The order of accuracy of readings of lines by means of the scale increases from the left-hand end

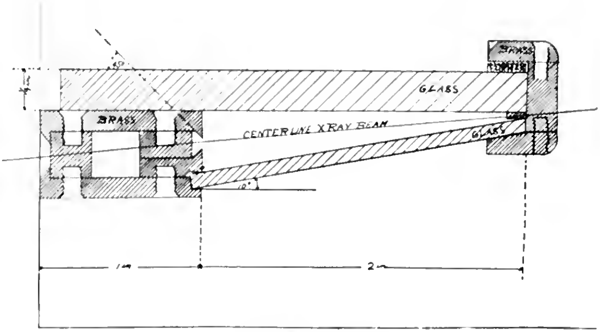

Fig. 5. Diagram of Slit System

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[3] A. W. Hull, "A New Method of Crystal Analysis," Phys. Rev. *10*, p. 661, 1917.

of the scale (large values) to the right-hand end (small values). At 1.00 Å it is of the order of 0.1 per cent. The limiting feature is the accuracy of the investigator in estimating the center of the line on the film. In case a solution of the crystal structure is found by the graphical method mentioned below, the final result is usually accurate to about one per cent. It can then be checked by numerical calculation to about 0.2 per cent.

Uses

The apparatus described has two fields of usefulness: (1) in the identification of materials, (2) in the determination of crystal structure.

(1) All solid metals and their alloys, and most solid compounds are crystalline and show X-ray diffraction patterns. Waxes at ordinary temperature, and glasses are amorphous and show no diffraction patterns. The diffraction pattern of a given substance, as measured quantitatively on the scale described, is as characteristic of that substance as the density, solubility, melting-point or ability to form chemical compounds. As far as is now known, no two substances have identically the same diffraction pattern. At first it was thought that the patterns of molybdenum and tungsten were identical, but Hull has since shown[4] that the measurements of their diffraction patterns differ by about ¼ per cent. All other substances so far investigated which happen to have diffraction patterns of similar appearance are found, upon measurement with the scale described, to differ from each other by several per cent. The apparatus therefore offers a convenient method for the qualitative analysis of crystalline substances. Any substance is completely identified when its pattern, measured on the scale, exactly matches the pattern of some substance whose identity is known. A large mass of such data is already available and will be published in compact form.

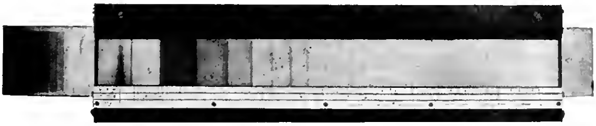

Fig. 7. Diffraction Pattern of NaCl on Scale, Ready for Measurement

This method of analysis has three advantages: (a) only 0.001 cc. of the specimen (ground to 200 mesh) is required; (b) the original sample is still available after the analysis is completed; (c) in a mixture of two compounds, the *state of combination* may be determined:[5] i.e.,

$NaF + KCl$ can be distinguished from $NaCl + KF$

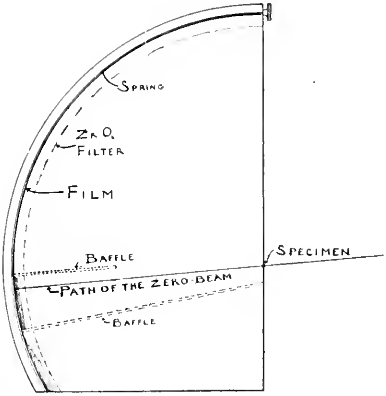

Fig. 6. Cassette

The ease with which substances may be identified should make the method useful as a means of laboratory control of factory products, especially in the case of metals and their alloys. The method of crystal analysis offers the most accurate method known for the determination of coefficient of expansion and density of most substances. In both cases a solution of the structure of the crystal is necessary, as described below.

(2) It is often desirable, not only in purely scientific investigations, but also in factory-control work, to determine the arrangement of atoms in the crystal. In case the crystal happens to belong to the cubic, hexagonal, or tetragonal systems (and most metals, alloys, halogen compounds, nitrates of monovalent metals, and carbonates of bivalent metals do), the crystal structure may be solved directly by the following method.[6]

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[4] A. W. Hull, Physical Review, *17*, p. 5, 1921.

[5] A. W. Hull, "A New Method of Chemical Analysis," Jour. Am. Chem. Soc., *41*, p. 1168, 1919.

[6] For a more complete description of the method see Hull and Davey, "Graphical Determination of Hexagonal and Tetragonal Crystal Structures from X-ray Data," Physical Review, *17*, p. 5, 1921.

The edge of a strip of paper is laid along the logarithmic scale of abscissae which is found at the bottom of each of the charts of Fig. 8, and the distance between planes in the crystal, as read off from the film in Ångstrom units, is plotted on this edge. The strip of paper is now moved across the various plots keeping the edge always parallel to the axes of abscissae. When an exact match is found between the chart and the pattern marked on the edge of the paper then the crystal belongs to the system and sub-division marked on the chart, and the correct axial ratio is given by the intersection of the edge of the paper with the axis of ordinates. It is necessary that every line in the experimental pattern on the strip of paper be represented in the chart. If there is a single experimental line left over, the solution is not valid, no matter how good a match is obtained with the remainder of the lines. The only exception to this is when several lines left over in this way can be shown to all fit some other portion of one of the charts, thus indicating that two crystal forms are present. If the chart predicts lines which are not found in the experimental pattern it is necessary to show either that those lines ought, theoretically, to be too faint to be seen on the film, or that the crystal structure is more complicated than that for which the chart was made, so that certain lines disappear by interference. (Thus any pattern given on the triangular close-packing and rhombohedral charts will fit certain lines of the simple triangular charts at the same axial ratio, and all the patterns of the body-centered and face-centered tetragonal structures will similarly fit portions of the simple tetragonal charts.)

Charts of the cubic system will be found at an axial ratio of 1.00 in the charts of the tetragonal system.[7] The diamond division of the cubic system may be found by omitting the 2nd, 5th, 8th, 13th, and 19th lines, counting from the right hand side of the chart, from the chart of the face-centered division of the cubic system.

After an exact match is found for the experimental pattern, it should be verified by computing the density of the specimen in the following manner—

(a) If the match is in the cubic system, the density of the substance is given by

$$\rho = n\frac{M\times 1.649\times 10^{-24}}{(d\times 10^{-8})^3}$$

where

ρ is the density

M is the molecular weight of the substance; 1.649×10^{-24} is the mass in grams of one unit of molecular (or atomic) weight

d is the side of the elementary cube (it is the distance in Angstroms between the 1 0 0 planes in the crystal)

n is the number of points associated with a unit cube in the crystal lattice. n is
1 for the simple cubic lattice
2 for the body-centered cubic lattice
4 for the face-centered cubic lattice
8 for the diamond-cubic lattice.

If the line corresponding to the "1 0 0 planes" is absent (as in the case of the body-centered and diamond divisions) then twice the distance corresponding to the second-order line, called in the plots "1 0 0(2)—1 0 0," must be used as the side of the elementary cube.

(b) If the match is found in the tetragonal system, the density is obviously

$$\rho = n\frac{M\times 1.649\times 10^{-24}}{c(d\times 10^{-8})^3}$$

where c is the axial ratio, and n has the same values as before.

(c) If the match is found in the hexagonal system, find the distance corresponding to the "1 0.0 planes." (If the match is found in the rhombohedral division, three times the distance corresponding to the third-order line, called in the plots $\left\{\begin{matrix}1\ 0.0(1)\\1\ 0.0(3)\end{matrix}\right.$ must be used.) This is the altitude of the equilateral triangle which forms the base of the unit prism. The side of the unit triangle is $\frac{2}{\sqrt{3}}$ times this distance. The density of the specimen is therefore

$$\rho = n\frac{M\times 1.649\times 10^{-24}}{\sqrt{\tfrac{3}{4}}\,c(a\times 10^{-8})^3}$$

where

a is the side of the unit triangle
n is ½ for a simple triangular lattice
1 for a triangular close-packed lattice
1½ for a rhombohedral lattice.

It is a pleasure to acknowledge the suggestions of A. W. Hull during the course of this work; also the assistance of E. O. Hoffman and H. A. Smith in the design of the slit system and the development of the water-cooled tube; R. Hergenrother in the laborious calculation and drawing of the charts; and Wm. F. Winter in the design and construction of the cassettes and the construction of the slit system.

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[7] They will also be found in the plots of the rhombohedral division of the hexagonal system.

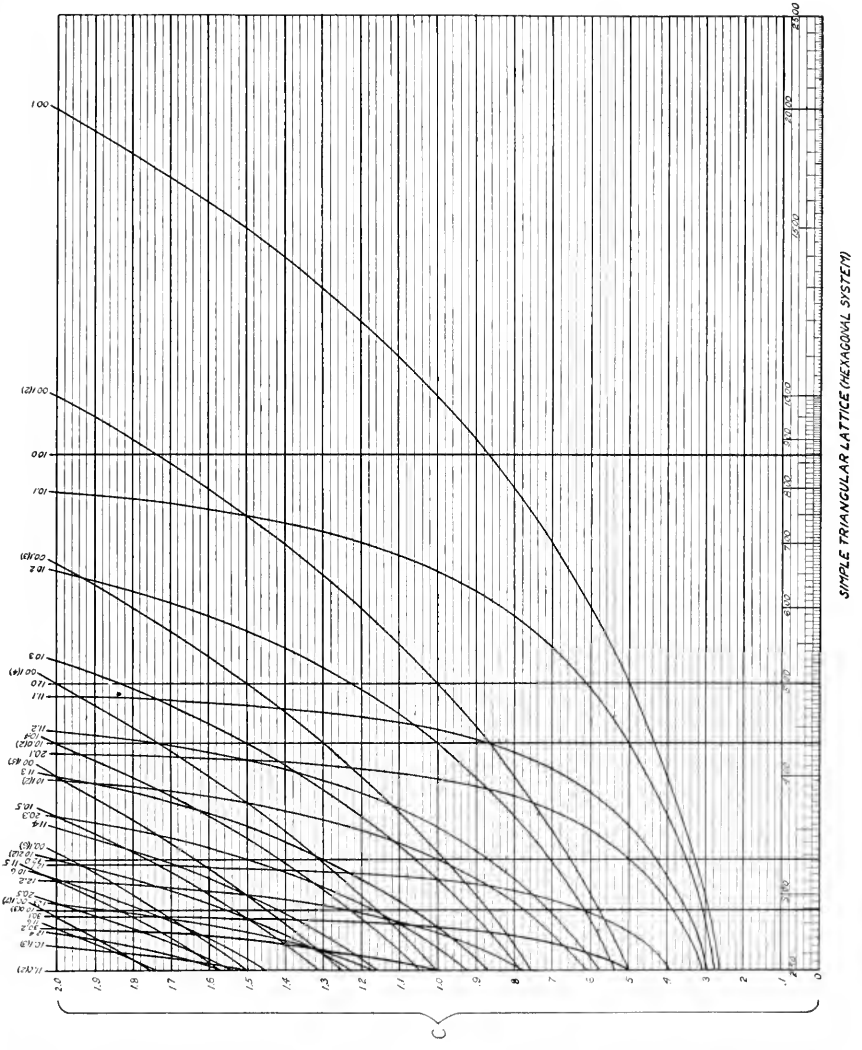

Fig. 8A. Semi-logarithmic Chart of the X-Ray Diffraction Patterns of Crystals Whose Atoms are Arranged in a Simple Triangular Lattice. This type of lattice is built up of prisms whose bases are equilateral triangles. If the side of the triangle is *a*, then the altitude of the prism is *ac* where *c* is the axial ratio. The positions of the atoms are given in hexagonal co-ordinates by the statement that the positions of the atoms along the X-axis may be represented by the integers 0, 1, 2, 3, etc. (called *m*); along the Y-axis by a similar set of integers, *n*; and along the Z-axis by a set of integers 0*c*, *c*, 2*c* ,3*c*, etc. (called *pc*), where *c* is the axial ratio. All this is ordinarily expressed in the abbreviated form $x, y, z = m, n, pc$

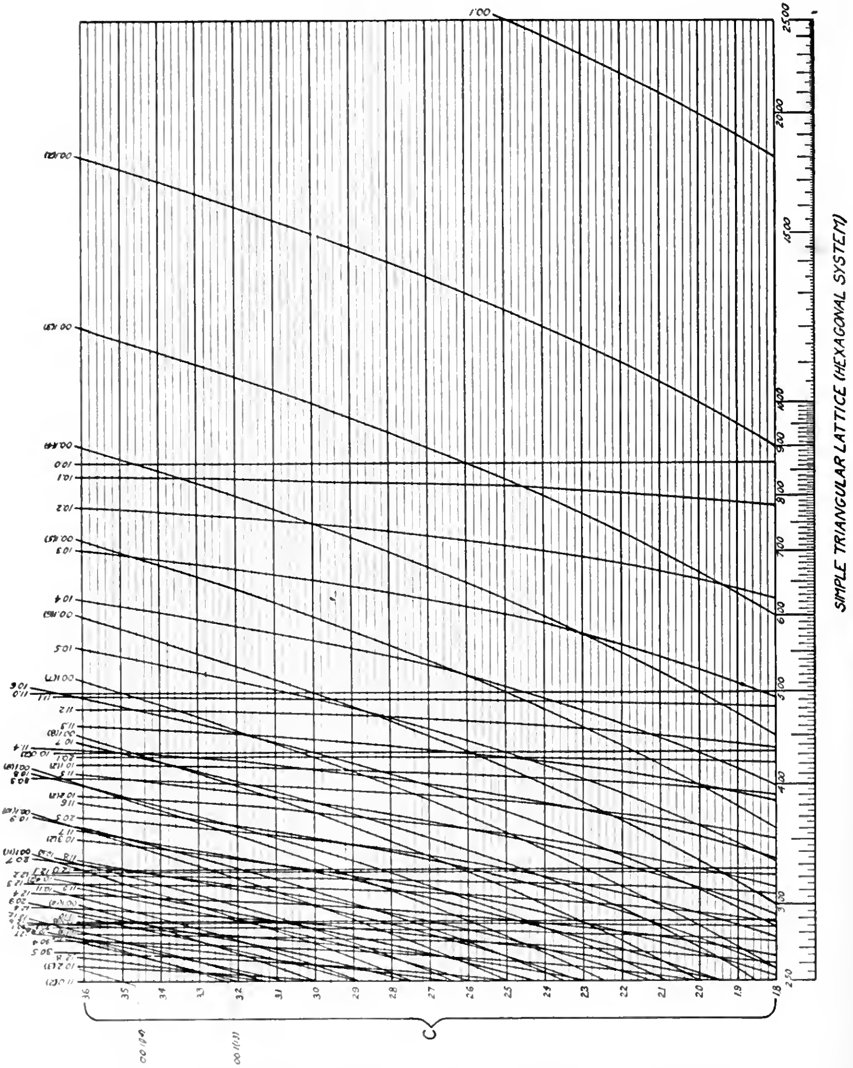

Fig. 8B. This is a continuation of Fig. 8A as may be seen by comparing the values of the ordinates

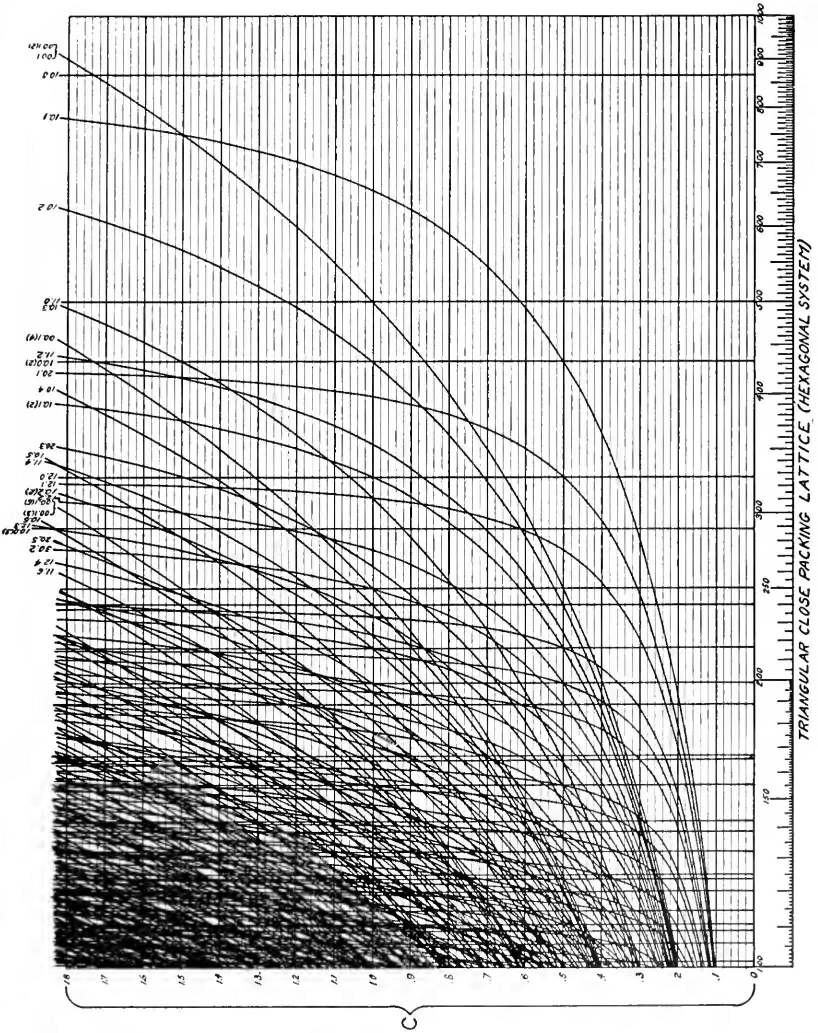

Fig. 8C. Semi-logarithmic Chart of the X-ray Diffraction Patterns of Crystals Whose Atoms are Arranged in a Triangular Close-packed Lattice. This type of lattice is built up of two interpenetrating simple triangular lattices. One corner of the base of a prism belonging to one simple lattice is at the body-center of a prism belonging to the other simple lattice. The positions of the atoms are given in hexagonal co-ordinates by

$$\begin{array}{lll} m, & n, & pc \\ m+1/3, & n+2/3, & (p+1/2)c \end{array}$$

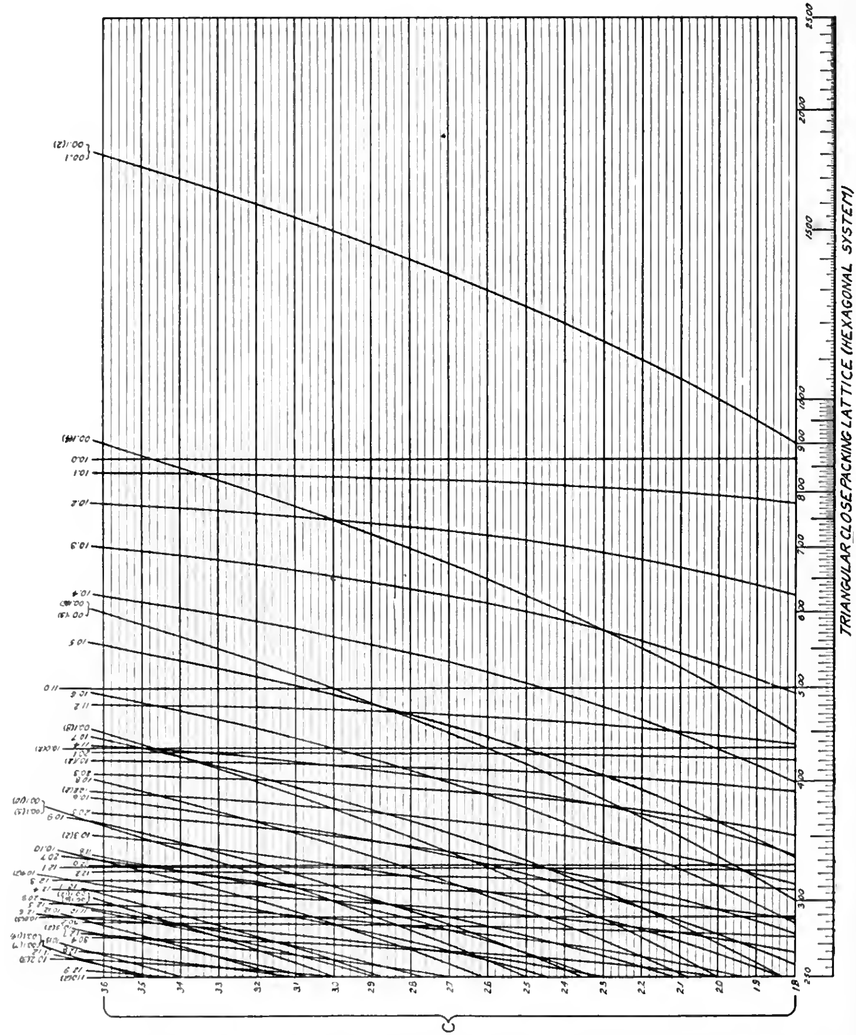

Fig. 8D. This is a continuation of Fig. 8C. This type of lattice receives its name from the fact that when the axial ratio is 1.633 the atoms are in one of the two closest possible packings for spheres of equal size

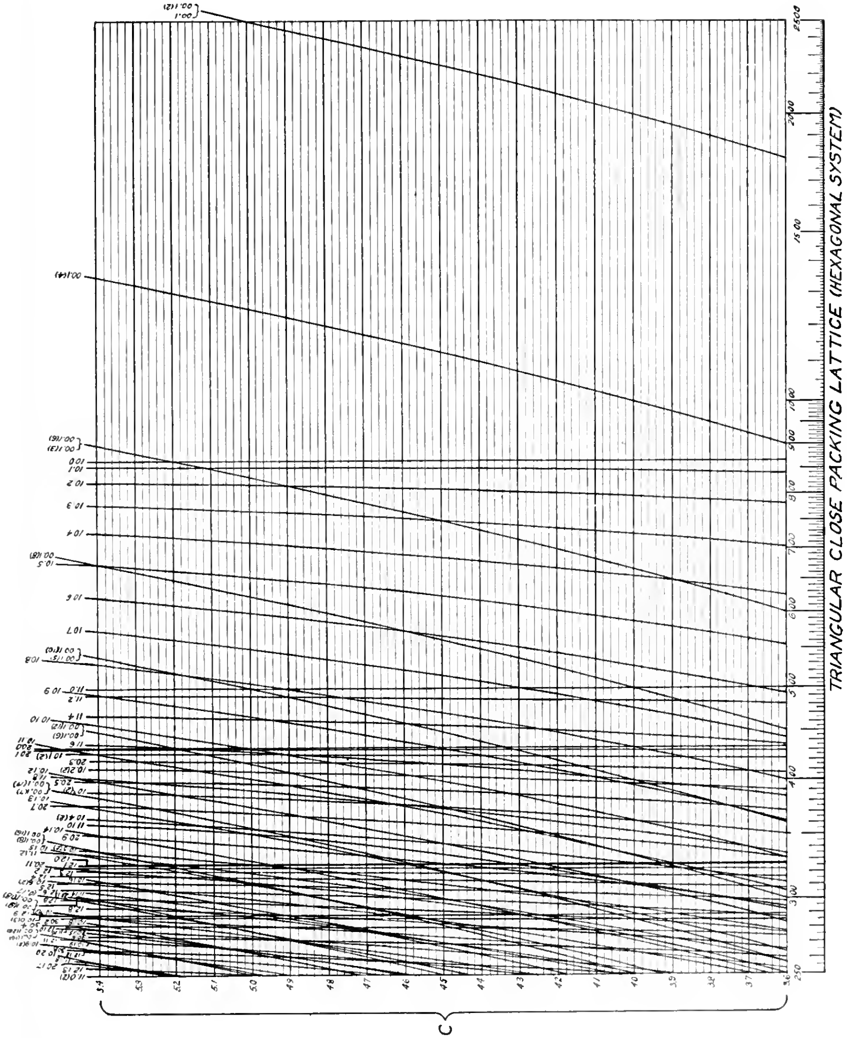

Fig. 8E. This is a further continuation of Fig. 8C. Large axial ratios are found in certain substances like carborundum

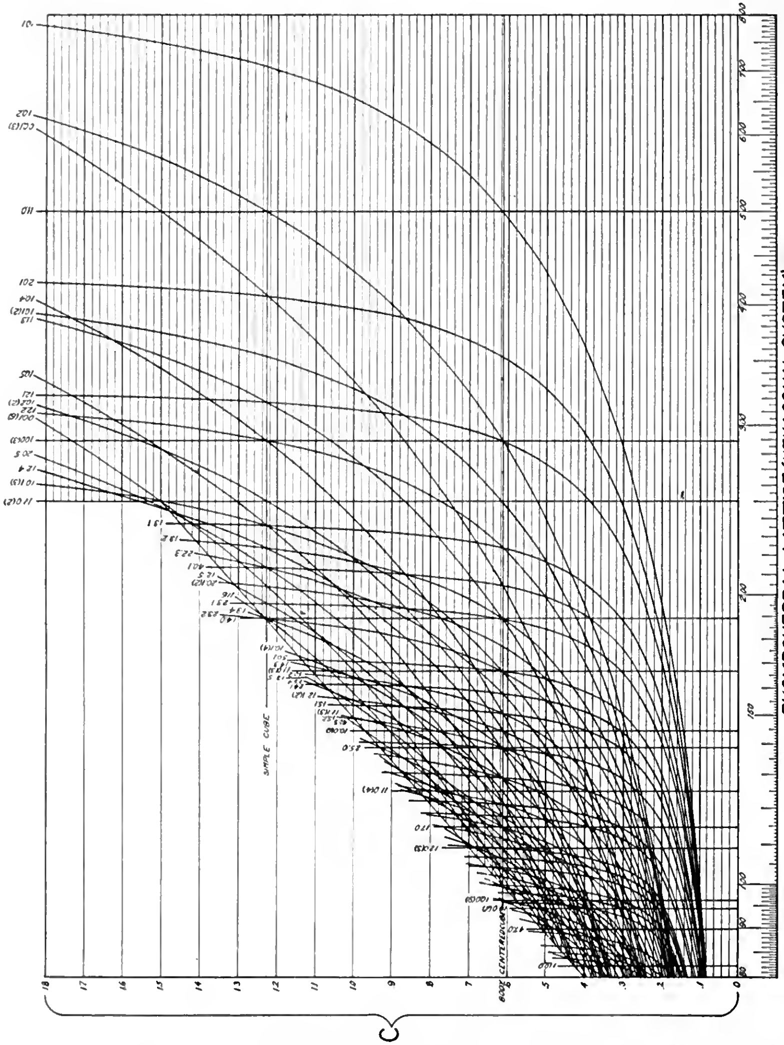

Fig. 8F. Semi-logarithmic Chart of the X-Ray Diffraction Patterns of Crystals Whose Atoms are Arranged in a Rhombohedral Lattice. This type of lattice is built up of three interpenetrating simple triangular lattices. In hexagonal co-ordinates the positions of the atoms are given by

$m,$	$n,$	pc
$m+1/3,$	$n+2/3,$	$(p+1/3)c$
$m+2/3,$	$n+1/3,$	$(p+2/3)c$

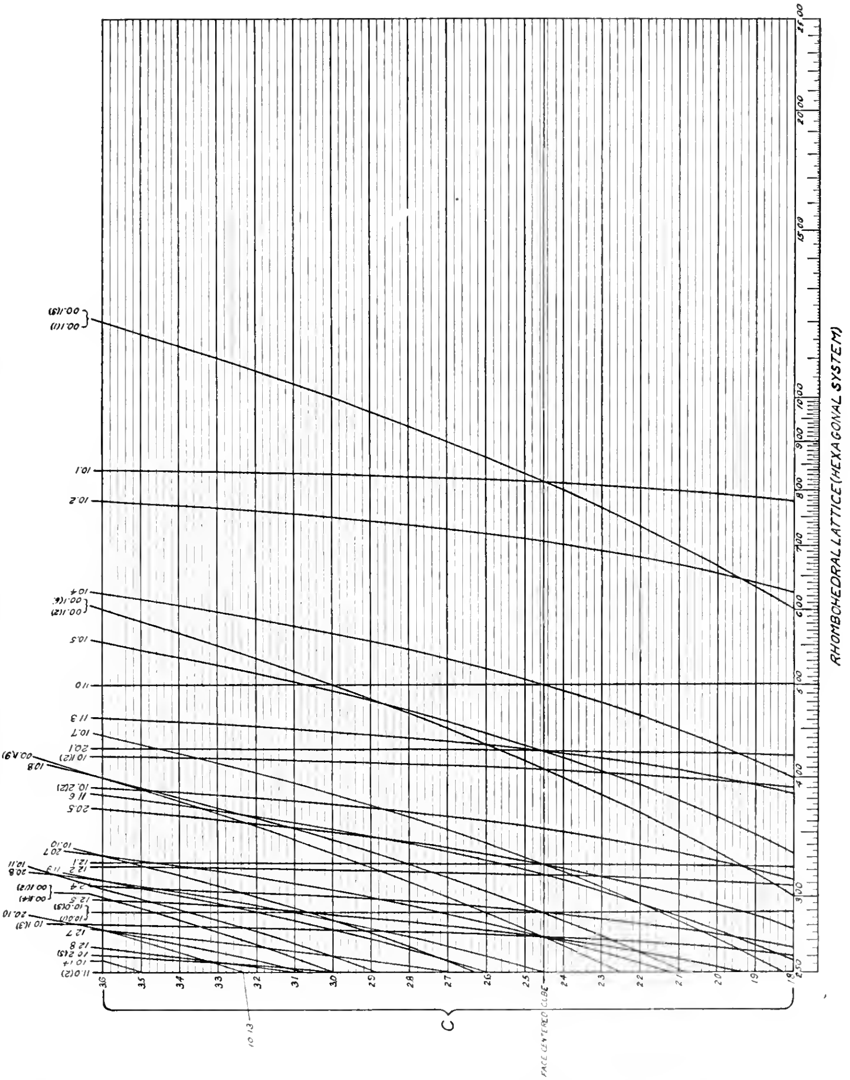

Fig. 8G. This is a continuation of Fig. 8F. It is interesting to note that three of the cubic lattices (simple cubic, body-centered cubic, and face-centered cubic) may be considered as rhombohedrons of axial ratio 1.225, 0.612, and 2.45 respectively

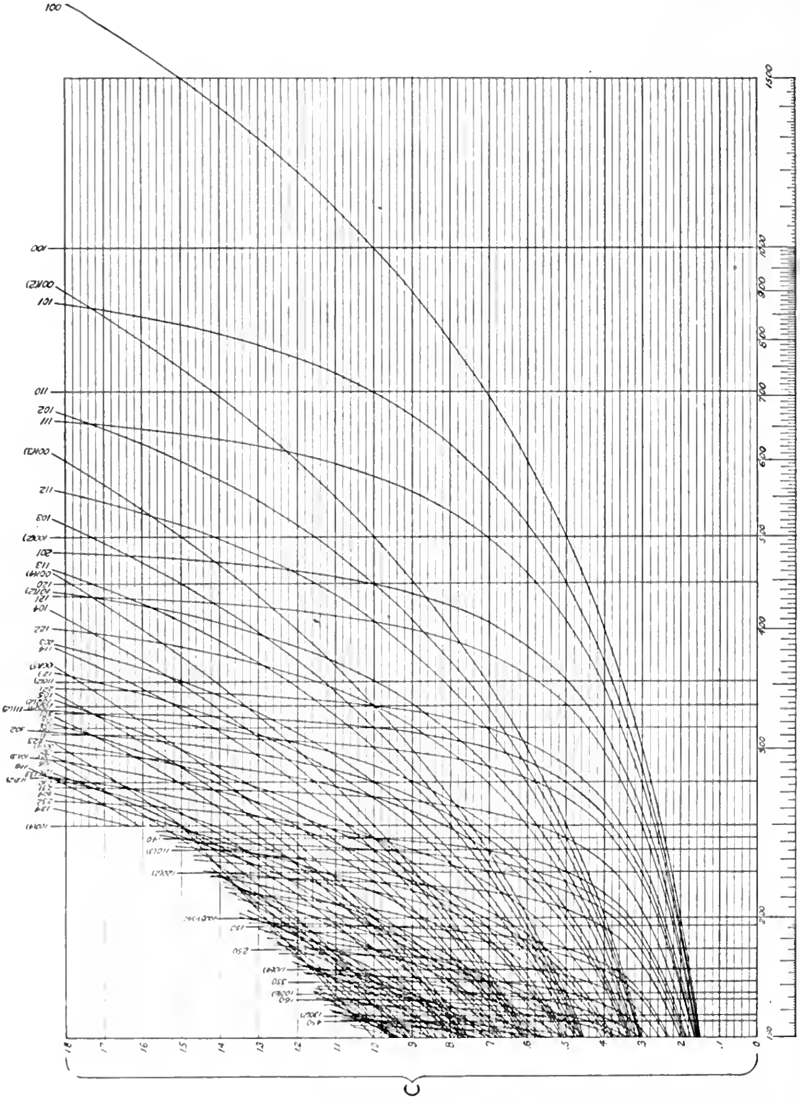

Fig. 8H. Semi-logarithmic Chart of the X-Ray Diffraction Patterns of Crystals Whose Atoms are Arranged in the Tetragonal System. This type of lattice is derived from the cubic system by a stretch or a compression along one axis. In ordinary rectangular co-ordinates, the positions of the atoms are given by *m*, *n*, *pc*

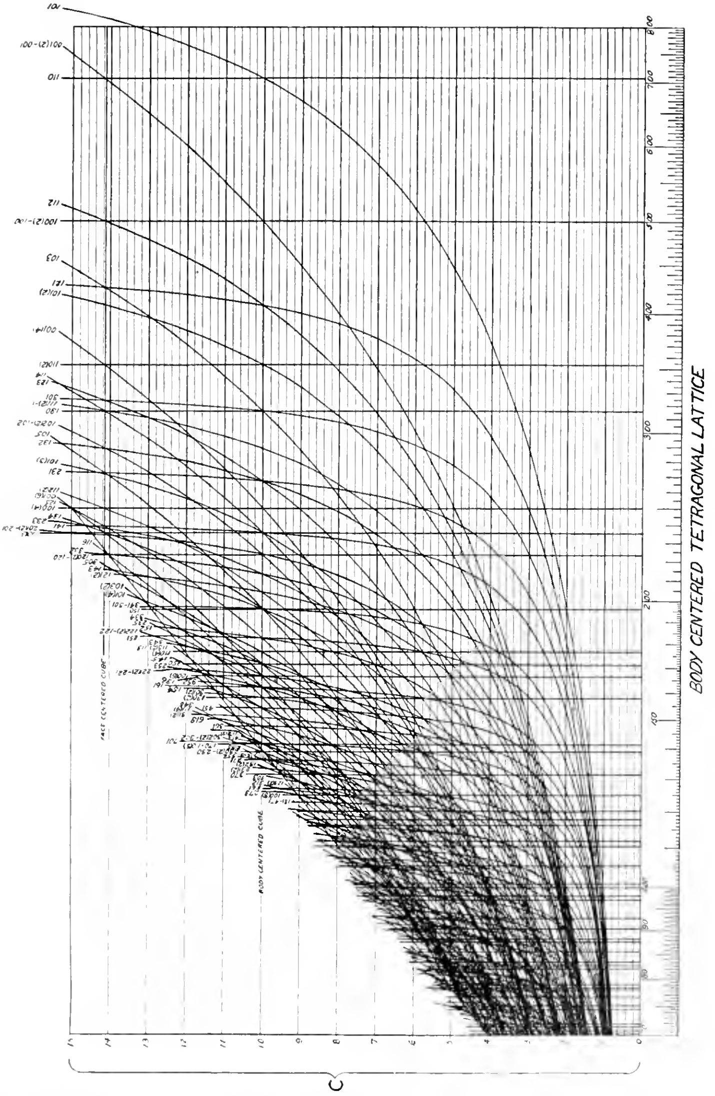

Fig 18. Semi-logarithmic Chart of the X-Ray Diffraction Patterns of Crystals Whose Atoms are Arranged in a Body-centered Tetragonal Lattice. This type of lattice is built up of two interpenetrating simple tetragonal lattices. Each corner of the base of each simple tetragonal prism is at the body-center of some other simple tetragonal prism. In ordinary rectangular co-ordinates the positions of the atoms are given by

$$m, \qquad n, \qquad pc$$
$$m+1/2, \qquad n+1/2, \qquad (p+1/2)c$$

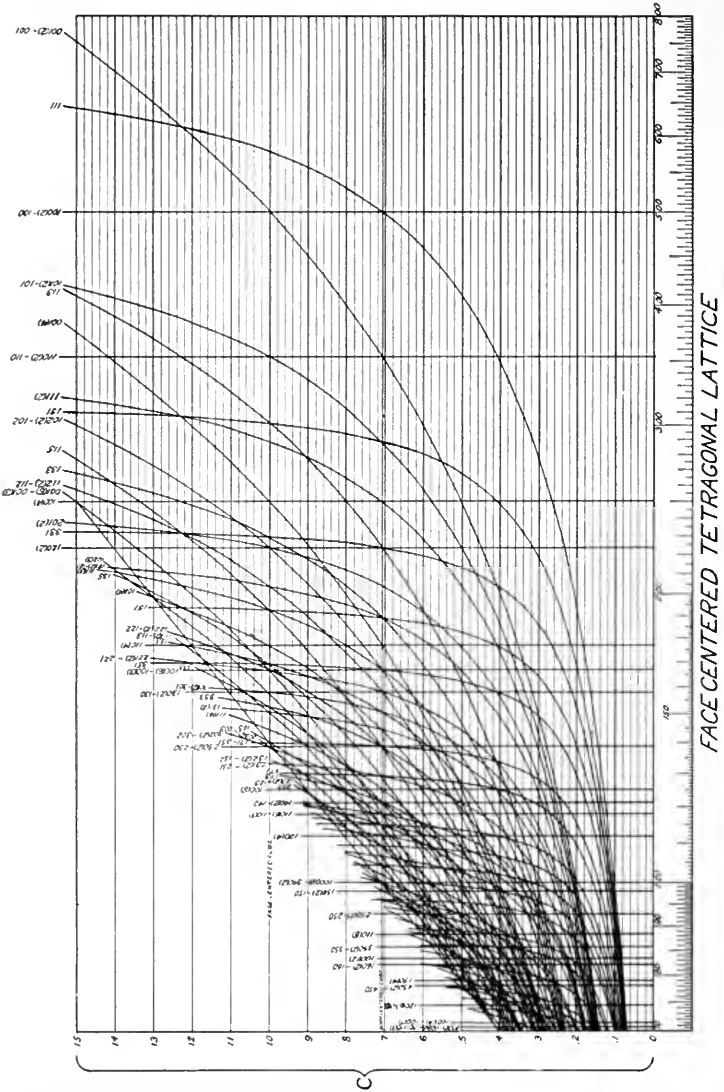

Fig. 8J. Semi-logarithmic Chart of the X-Ray Diffraction Patterns of Crystals Whose Atoms are Arranged in a Face-centered Tetragonal Lattice. This type of lattice is built up of four interpenetrating simple tetragonal lattices. These are so arranged that they give the effect of a single simple tetragonal lattice which has been modified by putting an atom at the center of each face. In ordinary co-ordinates, the positions of the atoms are given by

m,	n,	pc
$m+1/2$,	$n+1/2$,	pc
$m+1/2$,	n,	$(p+1/2)c$
m,	$n+1/2$,	$(p+1/2)$

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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CONTENTS

Copyright, [illegible], by E. J. Frazier, Thompson Falls, Mont.

View of Thompson Falls on Clark's Fork River taken before the development of power at this point. The site has since been developed with a 30,000 kw. plant, operating at 55-ft. head, and supplying power to the Cœur d'Alene mining district and to the Missoula Division of the Chicago, Milwaukee & St Paul Railway

GENERAL ELECTRIC
REVIEW

MATHEMATICS AND ENGINEERS

Engineering is a science that involves many calculations—a realization of this simple fact is all that is necessary to show the importance of mathematics in our schools and colleges. How are we to turn out engineers and scientists capable of mastering the complexities of our modern industrial life unless we give them a good groundwork in mathematics?

That the importance of mathematics in engineering education is realized is shown by the five papers presented before the A. I. E. E. Convention at Niagara Falls last June. While these papers were too long for us to include in our pages in full, we are very pleased to be able to print an article reviewing them prepared especially for us by Professor Walter I. Slichter of Columbia University.

In discussing the teaching of mathematics in our schools and colleges there are two fundamentals to be considered, namely, the aptitude of the pupil for learning mathematics and the aptitude of the teacher for teaching mathematics.

It is not usual to find in the mind of the embyro engineer the aptitude for mathematics. This fact may be disputeb but nevertheless we believe it to be true.

The lad who wishes to become an engineer is usually an inquisitive individual—the kind of young barbarian who has ideas of his own that he wants to put into shape and do something with. He makes things—sometimes it seems almost out of nothing—he is not over fond of discipline. He is not lazy but often appears so when set to tasks that are uncongenial and it is interesting to note what is uncongenial to him—he dislikes any task that is routine—that is easily performed without thought—that does not require originality.

To cut a long story short, the raw material that makes the best engineer is a creative mind—a mind that gives out new ideas more readily than it absorbs old ones

How many teachers of mathematics in our schools and colleges realize this?

How much time is spent in trying to cram in a mass of uninteresting meaningless facts?

How much misdirected effort only tends to deaden the originality?

A boy's mind is something to be cultivated—something to be helped—something to be developed—not something to be crammed with other people's thoughts and with other people's facts and with other people's figures.

How many people who are teaching mathematics have the aptitude for developing an original mind?—That is their task. How many of them really understand mathematics themselves to the point where they can really impart the meaning of a problem—where they can give a pupil a mental picture of both the problem and of the solution? Very few, we fear

Mathematics is too often taught as if it were composed of a mass of symbols that it requires a very clever mind to perform certain mental gymnastics with to get a result

The logic and the reason of why "this" and why "that" is done to arrive at the result is seldom taught—for the simple reason that it is seldom understood by the person who is trying to teach.

Graphical methods are not used as much as they should be,—how many men who are our engineers today went through school and college without ever having seen the graph of a simple, simultaneous, or quadratic equation?

It is quite astonishing to find out how little mathematics many of our successful engineers know and to learn how much of what they know and use has been self-taught after leaving school.

It is of equal interest to find out how few mathematicians have ever become practical engineers.

The truth of the matter is that mathematics is a very useful servant but a very poor master. In fact, we might almost divide the students in any class of mathematics into two broad groups.

The first group will have great trouble with their mathematics. They will work hard but make little or no progress—they may memorize enough to scrape through their examinations but they will promptly forget all or most of what they have learned. The second group wili learn comparatively easily and solve the most difficult problems with comparative ease.

The members of the first group will look up to those in No 2 with a great deal of awe and think they are very clever fellows.

But what is the story in ten or twelve years' time?

You will find a lot of the fellows in the first group successful engineers. This all seems very paradoxical, but it isn't really. It is the original mind that succeeds and the original mind that finds it very hard to absorb other people's facts and figures—they find it very hard to learn mathematics, especially in the way it is usually taught. When they really want to solve a problem that they are really interested in they find their own solution in their own way.

But what of our brilliant mathematicians at school? Where are they? What are they doing? They first of all mastered mathematics and then mathematics mastered them. In this practical everyday world of ours, our problems include so many factors that do not appear in their mathematical formulae that they seldom get the right solution. The solution of most engineering problems demands the consideration of a lot of factors that can only be appreciated by the light of experience. The average mathematician leaves too much out and relies too much on the scope of his formulae. His formulae too often do not include the niceties of design, the human element in use and operation, and the many conditions imposed in production.

The human mind that only absorbs and relies on mathematical results can never give the world as much as the creative mind that originates.

This begins to sound rather like an argument against mathematics and against mathematicians. It is nothing of the kind. Our purpose is rather to show that the type of mind that makes the best kind of engineer needs special treatment in the teaching of mathematics. Show him the proper reasons for what you are asking him to do. Show him that there is a meaning to it. Show him that it is really mostly common sense. Give him a mental picture of the problem, of the working of the problem, of the result.

If our teachers of mathematics can do this they are doing the world a real service as they are putting a priceless tool in the hands of men who can use it and use it efficiently.

Today most of our problems are solved by genius and then mathematical solutions designed afterwards to fit the result—rather than mathematics being used in getting the result. Of course, there are brilliant exceptions.

In talking of exceptions, what makes our exceptional men? What makes a Newton a Newton or a Kelvin a Kelvin? In our opinion it is the combination in one mind of the power to absorb and the power to originate. The mathematical mind in combination with creative genius.

J. R. H.

Engineering Education at the A.I.E.E. Convention

By Walter I. Slichter

Professor of Electrical Engineering, Columbia University

At the A.I.E.E. Convention held at Niagara Falls in June there were six important papers presented on Education. These papers were read by such representative men as B. G. Lamme, S. E. Doane, Philip Torchio, I. C. Forshee, A. M. Dudley and Carl Hering. These papers are of such importance to the Engineering profession that we wish we could find space to publish them in full, but as this is impracticable we asked Professor W. I. Slichter of Columbia University to write a short article bringing out the most important points in the papers and discussions. We believe Professor Slichter's remarks will be appreciated by all interested in this most important subject.—Editor.

The session on Engineering Education at the Niagara Falls Convention of the A.I.E.E. in June was one of the most pertinent and profitable sessions devoted to this subject which have taken place for some time. The speakers represented such a wide field of engineering activity that a composite of their views could not fail to be representative.

The six papers on the program were all written by practicing engineers. The very complete written discussion presented by President Howe of Case School, representing the Society for the Promotion of Engineering Education, was a consensus of opinion of professional educators and the open discussion represented about equally the practicing engineers and the educators.

Mr. Lamme's paper brought out the most discussion and of the points made by him the one which attracted the most attention was his plea for more mathematics, a better teaching of mathematics, and a more real and horse-sense type of mathematics. From the discussion it may be accepted as the general opinion that mathematics is not only one of the fundamentals of engineering, but the most important fundamental.

Other pleas were made for physics, chemistry and English but these were not so generally stressed as fundamentals. In third place of importance were mentioned: special engineering applications, economics, business and foreign languages. It would seem that we have in this list not only the essentials of a good engineering curriculum but also the relative importance of the subjects.

President Howe made an important point in the interest of co-operation between the practicing engineer and the educator for the improvement of engineering education. He asked that the practicing engineer, when recommending what should be included in the curriculum would also recommend what, of that which is already there, should be stricken out to make room for the new. Educators face the problem that most engineering curricula are already too full and a suggestion to add a new topic is not possible of acceptance but a suggestion for a substitution is practical and also puts on the proposer the necessity of proving that the subject suggested is not only important, which is usually acknowledged, but that it is more important than something already being given. This would bring about a careful study of relative values.

Nobody can disagree with Mr. Lamme's plea that mathematics be taught in a practical manner, emphasizing its useful applications rather than its possibilities for mental gymnastics. Mathematics teaches how to formulate general statements in a concise manner and how to pass directly from cause to effect. It is an accurate and rigid method of reasoning from one physical fact to another related one.

There has been a very noticeable increase in the appreciation of the practical side of mathematics in the last few years, particularly since the war and the publication of some books on practical mathematics for engineers by engineers. Closer co-operation between the departments of pure mathematics and of engineering is the solution of the problem.

Mr. Lamme and Mr. Hering pointed out a very common weakness of students. their lack of a quantitative sense or mathematical horse-sense. This is most shockingly shown in the student's carelessness with the decimal point. This lack may be inherent in the individual student's make-up, in which case he should be directed away from engineering, or it may be merely a lack of experience, as it is experience which gives us that judgment or perspective which enables us to tell at a glance whether a result is reasonable or ridiculous. There are many mature engineers who would have difficulty with their decimal points if they worked with ergs instead of kilowatt-hours, merely because they have not been trained to a sense of proportions in ergs.

President McClellan put two very important questions to the gathering: How are we going to sift those adapted to engineering from those not so adapted and how are we going to prevent the graduate from getting into a narrow professional rut in feeling that, because he took an electrical engineering course, he must confine his future activities to electrical engineering and not branch out into other channels?

These questions open up a very broad discussion. First: to what extent should a technical school coerce those, deemed ill-adapted, to drop out or change their course, for many will not change unless dropped and yet some of the ill-adapted are able by a hard struggle to keep above the academic dead-line. It is a shameful waste of the time of all of the students to have these unfit ones dragging down the class and the practice lowers the standards of the school. This adaptability to engineering is an inherent trait and the college cannot create it but only bring it out and develop it.

One solution of this problem is to devise the course so that, after a trial period of two or three years and before real specialization begins, a student may transfer to a general course which will give him a good all-around education and some recognition in the form of a degree, for we must consider the students' desire for tangible proof of work accomplished.

The psychologists promise us a means of classifying the natural bents of our youths early in their educational careers and before specialization, and this scheme is being tried in some of our institutions. If it succeeds it will prevent a great waste of the time of our students and of our instructors

The answer to the second question is being sought in different ways in different institutions and among educators the discussion is known in its extreme form as the demand for the "one course one degree" policy versus the multiplicity of courses and degrees. Some meet the problem by requiring a fifth year for real specialization and the professional degree, and others by requiring a certain amount of college preparation before starting the professional courses. In all cases the principle is that of giving the student a broader education and thus a broader point of view and more general fitness and aspirations.

The time has come when all those interested in engineering education must face the question of how much time a student can afford to devote to his education. In other words, how old may he be when he finishes without handicapping himself. All engineers expect more in the curriculum than it is possible to cover and do justice to in four years. There have been lately many criticisms that the education given in our technical schools is superficial, that the students learn a smattering of many specialties but cannot think out a new problem logically. Prof. C. A. Adams of Harvard has touched upon this many times in public discussions in the last few years. Either we shall have to confine the course to a few important fundamentals taught thoroughly or extend the length of the course to five or six years and include both the fundamentals and specialties.

We like to think of engineering as one of the learned professions rather than as a trade or a craft, yet all the high grade professional schools of Law, Medicine and Religion require a longer period of education than four years. Can engineering stand on a professional par with these others without setting as high an educational standard?

Very few will deny that a man well trained in mathematics, physics and chemistry has a better chance of ultimate success than one who has had a lot of shop-work, armature winding, etc. At present, there is a general feeling that if the recent graduate is adept at some specialty he has a better chance of immediate employment, that is, the boy who is well acquainted with the latest practice of the business has a greater immediate market value than the deeper man with more fundamental knowledge.

The law of supply and demand has been largely instrumental in determining the contents of most of the present day curricula. There is a natural tendency of instructors to emphasize a subject which has been of assistance to a large percentage of former graduates and to bear less emphatically upon subjects which have been of use to only a few. The educator tries to visualize a composite picture of his previous graduates and to reproduce that man with improvements. Chance has such a large part to play in determining the careers of all men that few can know in advance what line of work they will eventually follow.

At present the schools are trying to educate a composite engineer, giving all students in electrical engineering a training which will suit the most probable future lines of activity as estimated by the instructing staffs. Each class contains a certain percentage of potential scientists, executives, salesmen and operators, and also a certain percentage of those who will never follow any line related to engineering, so the design of the course is a difficult compromise.

There are many boys who are not qualified to achieve success in the purely scientific or technical line but who will make good salesmen, operators or calculators. This type of man does not require the longer course of training and yet these men are as essential to the industry as the more scientific and the industry needs a greater number of them.

To solve this difficulty it would be desirable to have our technical schools grouped into different classes according to the training they give and have this classification widely recognized so that as soon as a boy shows his bent he might be transferred to a school best fitted to develop that bent. The proper way to accomplish this would be to give every student a good fundamental and general training first and then let him specialize, if he is qualified for it, afterwards according to his particular bent. Few courses afford the time for this procedure.

There is a new tendency similar to this in a number of institutions at the present time, a grouping of all engineering students together for a longer time than formerly, and before allowing them to choose their particular branch of engineering, giving them information not only upon the possibilities of each profession but also the qualities required to achieve success in each line of activity. Concretely, this means giving only the bachelor's degree after four years and holding the professional degree for those who remain an additional year or two.

Naturally the question of character and personality came up for discussion. The traits of character of the student which were most prominently demanded were tenacity of purpose, desire to render service and a recognition of the philosophy that "whatever is worth doing at all is worth doing well." Mr. Torchio pointed out that any course that disciplines the mind is beneficial but anything that is easy does not discipline Mr. Hering stated that an engineering training is ethical in effect as its laws are strict and inexorable. The successful engineer must have an objective mind so as never to distort facts to fit a theory but base his theory upon indisputable facts.

It was recognized by the speakers that the college cannot create these traits but only cultivate them, and here again the important factor is selection, selection for character as well as for engineering suitability. The process of developing the selected men must take into account the fact that each has a different individuality and a different future career. One speaker put this very tritely by saying: "We must build to order and not manufacture in lots."

While one or two individuals spoke for the introduction of particular specialties into the curriculum, the majority of opinion seemed to be in favor of a broad training in the fundamentals and less specialization, leaving specialization to come after graduation.

Mr. Hering made this point picturesquely by saying: "The college education of an engineer should be like the foundations of a building upon which a superstructure is to be erected. If the foundation is on bed-rock it will support any superstructure that may be later decided upon."

There is an almost unanimous sentiment among the leaders of the engineering profession that the young engineer should have a good training in the use of the English language, be able to write a good letter or report and be able to express his ideas lucidly by word of mouth. To obtain this training it is almost essential that the student spend a part of his time in an academic college course and lengthen his total period of training accordingly. The requirement of a good command of English is common with the profession of law, and most law schools require a certain amount of college preparation before entering upon the study of law proper.

It was conceded that the personality and individuality of the instructor was a very important factor in the development of the embryo engineer. He must instill the fundamentals of character as well as of engineering. Every teacher in teaching a subject is teaching more than that subject, perception, efficiency and decision. To succeed the instructor must be sure that the building of men is the greatest profession in the world. It was interesting to note that, a number of the practicing engineers put in a plea for the instructor by urging that the educational institutions should pay salaries which will prevent commercial corporations from tempting good men away from the teaching field.

Mr. Doane made a very interesting suggestion that the commercial companies establish a definite policy of giving a year's employment to engineering instructors at their regular salaries and at stated periods, for instance, every three years, arranging that the individual go to a different place each period.

Summed up in a few words the verdict of the meeting seemed to be that: there should be a more careful sifting out of those not suited to the work and the selected group should be thoroughly drilled in applied mathematics and physics, specialization should be secondary to fundamentals and if necessary specialization may well be left until after graduation or at least until late in the course.

A Review of the Report of the Lamp Committee of the National Electric Light Association

By George F. Morrison

Vice-President, General Electric Company

The Lamp Committee Report of the National Electric Light Association is always an interesting document. The present article is a review of the latest report. The data and curves in this report show the almost unbelievable progress made in the art of artificial illumination owing to the introduction of the tungsten filament lamp.—Editor.

The reports of the Lamp Committee of the National Electric Light Association have been a series of interesting documents that have given a wealth of information showing the growth of the use of electric light in recent years. The following article gives some of the more interesting data from the latest report.

Numbers of Lamps Sold

The chart, Fig. 1, prepared from data in the reports, shows graphically the number of lamps sold. It will be seen that in 1921 a little over 2½ times the number were purchased as compared with the sales fifteen years ago.

This chart also shows the extent to which the modern tungsten filament lamp has replaced the carbon filament lamp, the latter now being but 3½ per cent of the total. If this continues, it is apparent that in a year or two the carbon lamp will be a thing of the past. The Gem lamp, which had a metallized carbon filament, and which disappeared from the market in 1918, is included with the carbon filament lamps.

Aggregate Wattage of Lamps Sold

To indicate the revenue obtained by central stations from the sale of current used for light, a chart, Fig. 2, has been prepared to show the aggregate wattage of lamps sold each year. The total in 1921 is 2¾ times that in 1907, the average lamp wattage having increased from about 53 to nearly 55 watts. This has been due to the increased use of gas-filled tungsten filament lamps. Their high average wattage is shown by the fact that while about one fifth of the total number of lamps sold in 1921 were of the gas-filled type, they were over 40 per cent of the total wattage and gave over 50 per cent of the aggregate candle-power of all lamps sold. In 1913, when these lamps were first put on the market, the average lamp wattage reached its lowest point, less than 49 watts. Thus the displacement of the carbon lamp was started in 1907 by the use of somewhat lower average wattage (but much higher candle-power) tungsten filament lamps. Later, as the advantages of the use of more light became established, the average wattage of the tungsten filament lamp increased until it is now greater than the carbon lamp.

Total Light Given by Lamps Sold

That the consumer has realized the value of the tungsten filament lamp is shown by the chart, Fig. 3, illustrating the total lumens of lamps sold during the years 1907-1921. In the latter year the total was eight and three-quarter times that of fifteen years ago, so that the consumer in 1921 got nearly 3½ times as much light for the wattage consumed as was obtained in 1907.

Demand of Lamps by Voltage

The most important lamps have always been those in the 115-volt range, that is, lamps of voltages between 100 and 130, they aggregating about seven-eighths of the total. High voltage lamps (200 to 260 volts), so generally used in England, constitute in this country less than 5 per cent of the total. They are less efficient than the 115-volt lamps. The demand in the various voltage ranges, which has not materially changed in recent years, is given in the table below:

Voltage Range	Per Cent 1921 Demand
115	85.8
230...	4.3
30 and 60 ..	4.7
Street Railway	2.6
Street Series ..	1.9
Miscellaneous	0.7
Total .	100.0

Standard Voltages

It was impossible, with the carbon filament lamp, to manufacture all lamps for a predetermined voltage. About 50 per cent of those manufactured would come out at the voltage for which the lamps were designed, the balance coming out one, two, three and occasionally more volts above and below the designed voltage. It became necessary for the economical manufacture of lamps that some central stations should operate their lighting service mains at a voltage other than the popular 110 volts. A demand was thereby created for lamps of individual voltages from 100 to 130 volts.

With the advent of the drawn tungsten filament it became possible to exactly predetermine the voltage of a lamp. The advantages of having lamps of a lesser number of voltages in use is so obvious that the various electrical societies advocated the adoption of three standard voltages: 110, 115 and 120. In 1913 the demand for lamps of these three voltages was less than half the total of the 100 to 130-volt group of lamps. Many central stations then increased the voltage of their circuits from an odd to a standard voltage as is indicated by the fact that in 1913 the average lamp voltage was 112.9 and in 1921 it was 114.2 when over seven-eighths of all lamps sold were for the three standard voltages. These data are shown in the chart, Fig. 4.

It will be noted that about 5 per cent of the 1921 demand was for lamps of from 121 to 130 volts, practically all of which is for 125-volt lamps. The remaining 8 per cent, covering non-standard voltage lamp demand, can be economically changed to a standard by raising the circuit voltage. However, most of this 8 per cent demand is for 112-volt lamps, probably caused by a continuation of the early practice, when tungsten filament lamps were fragile, of using 112-volt lamps on 110-volt circuits to obtain longer life. This is no longer desirable with the present day rugged Mazda lamp as it is done at a sacrifice of candle-power and efficiency, and hence 110-volt lamps could be used in these cases without increasing the circuit voltage.

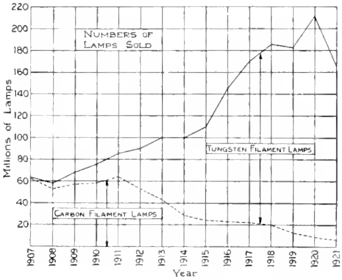

Fig. 1. Numbers of Lamps Sold, 1907-1921

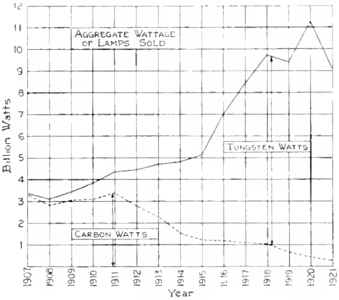

Fig. 2. Total Wattage of Lamps Sold, 1907-1921

Demand of Lamps by Sizes

In 1921, the relative demand of lamps by sizes was as follows:

Size	Per Cent 1921 Demand
40-watt (vacuum) .	20.2
25-watt (vacuum)	17.7
50-watt (vacuum)	14.7
60-watt (vacuum) . .	13.1
75-watt (gas filled) .	6.6
100-watt (gas filled) .	6.5
15-watt (vacuum) . .	3.5
200-watt (gas filled)	2.2
50-watt (gas filled)	1.4
All Sign Lamps . . .	6.1
All Street Railway Lamps . .	2.6
All Street Series Lamps . .	1.9
300-1000-watt (gas filled)	0.9
Miscellaneous (vacuum) .	1.5
Miscellaneous (gas filled)	1.1
Total	100.0

The 40-watt lamp has for several years been the most popular size, with the 25-watt lamp second in demand. The vacuum types cover 79.4 per cent and the gas filled 20.6 per cent of the demand in numbers of lamps. The latter have been increasing in percentage each year (they were first put on the market in 1913) and, as previously mentioned, on account of their high efficiency and high average wattage, they represent a much larger proportion of the aggregate candle-power and wattage of lamps sold.

Price Changes

The reports have shown a chart illustrating the changes in list prices of the more important lamps. A computation made of the list prices in effect during the years 1914-1921 of the average size of Mazda lamp sold in 1921 shows that the present list price is less than that in 1914. In other words, the improvements in methods of production have enabled the manufacturers to keep their price to the consumer below pre-war prices. This is graphically shown in Fig. 5.

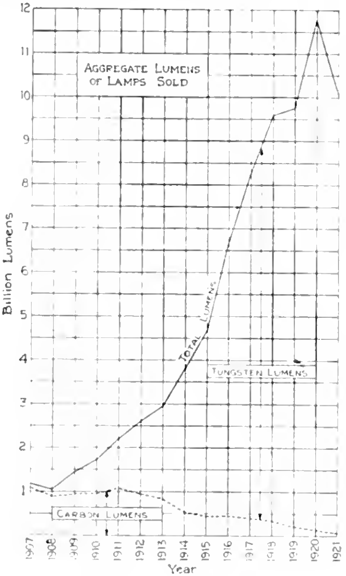

Fig. 3. Total Lumens of Lamps Sold, 1907-1921

Incandescent Lamp Developments

The tungsten filament lamp which appeared in 1907 was first made in the 100-watt size for 115-volt circuits. The filament was made by mixing finely powdered tungsten with a binder, the resulting paste being squirted under hydraulic pressure through a hole drilled in a diamond. The thread formed was cut in short lengths, bent in the form of a hairpin, and the binder removed by passing current through it in the presence of nascent hydrogen. This also sintered the tungsten particles together and made a hairpin shaped tungsten filament, several of which were mounted in a lamp, being connected in series to get the requisite resistance.

Tungsten filaments of this kind are quite brittle so the lamp was very fragile. Later 60-watt, then 40-watt and 25-watt lamps were made for 115-volt circuits. Lamps for series circuits were developed, and the 6.6-ampere lamp soon became standard. Carbon and Gem series lamps, usually made for 3½ and 5½-ampere circuits, as higher current lamps were inefficient, soon disappeared from the market. On account of the high efficiency of the tungsten filament, series lamps up to 400 candle-power were made and they soon drove the carbon arc lamp, which gave about 200 candle-power, out of the market.

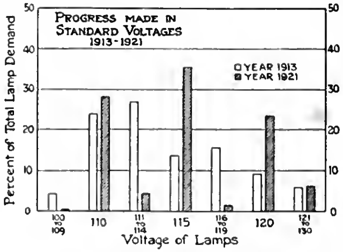

Fig. 4. Demand for Standard Voltage Lamps, 1913 and 1921

Tungsten filament lamps for other voltage circuits were soon developed; 30 volts for train lighting; 60 volts for use on compensators; 12 volts for use in signs in order to get small units; 230 volts for high voltage circuits, etc.

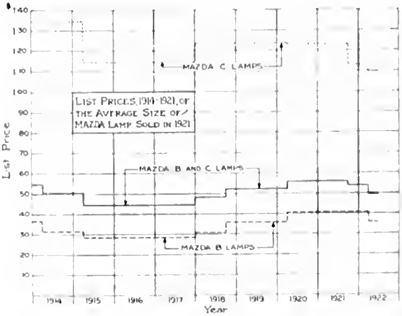

Fig. 5. List Prices, 1914-1921, of the average size of lamp sold in 1921

In 1911, the advent of ductile drawn tungsten wire greatly improved the ruggedness of the lamp and accordingly broadened its use. This made it possible to entirely displace the carbon and Gem lamps whose sales then began to decline rapidly. It also became possible to make smaller as well as larger sizes of lamps, the larger sizes being impractical with the carbon filament. The tungsten filament lamp being more efficient than the carbon arc lamp, the latter rapidly began to disappear from commercial as well as street lighting service.

In 1913, the advent of the gas-filled lamp with its even higher efficiency greatly stimulated the use of electric light. These were at first available only in the larger sizes, 750 and 1000 watts for 115-volt circuits. Later it became possible to make 500-watt lamps and in six years lamps as low as 50 watts for 115-volt circuits had been developed.

The street series lamps were soon made only in the gas-filled type and lamps of larger sizes developed up to 2500 candle-power. In the early eighties, only lamps up to 50 candle-power were available and practical; now 60 candle-power is the smallest regularly made.

Motion-picture Lamp

Other uses for lamps were being found and many hundreds of different sizes developed. One of the most interesting has been the 30-ampere 30-volt lamp for the projection of motion pictures to be used in place of the arc lamp. This lamp has been thoroughly tested in hundreds of installations for over a year, and an active campaign has been started to sell them. A complete incandescent lamp housing with prismatic condensing lens and a current regulator is necessary in place of the arc lamp housing on the projection machine. A $2\frac{1}{2}$-inch diameter objective lens, known in the trade as No. 2 should be used in place of the ordinary $1\frac{1}{2}$-inch lens No. 1, which will thereby double the light that would otherwise be thrown on the screen.

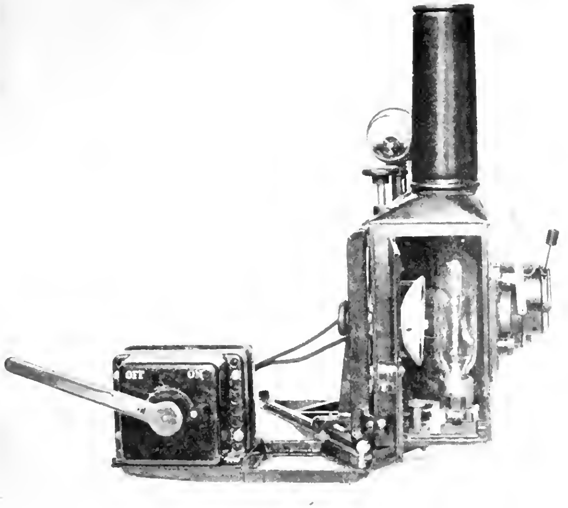

Fig. 6. Motion-picture Equipment for Operating 900-watt Mazda Motion-picture Lamp Equipped with Universal Bracket Regulator

Spare lamps are mounted in removable sockets. Lamps can be adjusted in these sockets by a prefocusing device, known as a lamp setter, so that when the lamp, once adjusted in the socket, is inserted in the lamp housing the filament will be in the proper optical position.

The incandescent lamp has many advantages over the arc, such as lesser consumption of current, freedom of flicker, no ash dust to mar the film, cooler booth, healthier conditions for the projectionist, etc. Fig. 6 illustrates a motion picture equipment.

Water Power Possibilities in the Middle West

By C. W. Place

Chicago Office, General Electric Company

Hydro-electric developments in different parts of the country have very different physical characteristics. The author shows some aspects of the service requirements peculiar to the Middle West and then discusses the form of hydro-electric development best suited to meet the conditions.—Editor.

In the development of our hydro-electric resources each section of the country has its own problem, and that of the Middle West is just as important to those living in the Middle West as the problem of the super-power zone along the Atlantic Coast and that of California along the Pacific Coast are to those communities.

From the very nature of things the development which may be found the most advantageous for the so-called "Super-power Zone" will not be the same as that which would be best for the Middle West. This territory is made up of wide areas of individual farms where the electrical power used at present is comparatively small, and where the main power is about equally supplied by internal combustion engines and animals. Interspersed through this farming territory are villages and towns with occasional large city centers. Without question, the prosperity of this territory depends upon that of the farming interests, modified but slightly by the mines and the manufacturing establishments of the cities and large towns. The development of this power supply has just about reached the point where the best interests of the territory are beginning to be served. Practically all sections are now served electrically. The present development largely consists of connecting up the main centers by transmission lines; thus enabling the generator stations of lower efficiency to be shut down and the load to be carried by the more economical stations. This has resulted in a more or less complete network of transmission lines almost covering the territory.

Fig. 1, which is a reprint of an illustration used in a paper before the American Society of Mechanical Engineers in May, 1921, shows the Middle West with the streams shown on a Government map emphasized. The corresponding map of this territory for transmission lines would look very much like the map of Illinois which is illustrated in Fig. 2. The streams shown vary all the way from those having a flow of 100 sec. ft. to the Mississippi River with its enormous capacity.

At the present time there are two conditions in the Middle West which emphasize the importance of bringing the distribution of streams, as illustrated, into the question of power supply and transmission, namely, the coal strike and the flood conditions in the Mississippi Valley.

The next step in the development of power supply and transmission is the development of these streams in such a way as to benefit the farming population, and incidentally to benefit the mining and city population. The flood condition and the fuel situation should be relieved at the same time.

The farmers now are not being served as efficiently as they might be because of the nature of their load and the difficulty of reaching them. If, however, the innumerable streams draining this farming territory are developed in the natural way, the immediate neighborhood supplied by low-tension lines, at generator voltage, from each, and the bulk of the power thrown into the network of transmission lines, this result can be accomplished. The voltage of these various transmission lines average about 33,000 volts, the lines are not particularly heavy, and they cover long distances. Therefore, the connection of a comparatively small installation does not involve high priced switching equipment, but only a small equipment which can be financed as part of such a development. This type of application of development is going on in various sections of the territory. By following this scheme a large number of streams are being used which by themselves would not warrant development from a financial standpoint.

The line along which these applications appear profitable is as follows:

The head selected must keep the flooded area within the river bottom and not require the purchase of any second bottom land. This second bottom land is the best corn and wheat land and is held at a high price. This means that to get the benefit of pondage, a succession of dams, each with its power development, must be used. This necessity has its compensating features. It means the spread of generating capacity near the load which it is felt will give the greatest benefit to the territory served. It further means a big step in flood control, in that this succession of ponds can be called upon to very largely equalize the flashy flow of many of these streams. The use of a large number of developments to meet these land conditions is made possible by the successful application of automatic control to the hydro-electric stations.

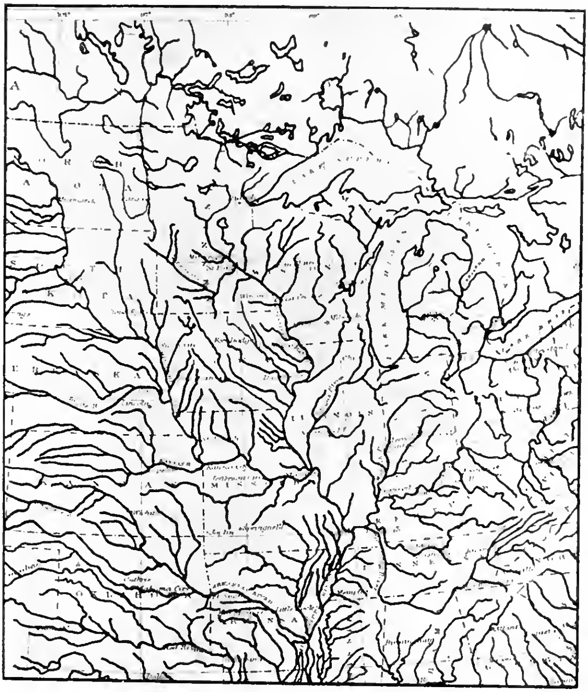

Fig. 1. Streams of the Middle West as Shown on a Government Map (Emphasized)

One of the early stations of 1500 kw. capacity has been supplying in the neighborhood of 7,000,000 kw-hr. per year, or at a load factor of 53 per cent; another of 240 kv-a., or about 100,000 kw-hr. per month on a load factor of 57 per cent. Each station is in territory where the bank and flood conditions are not particularly favorable.

The added possibility of the use of the flow available on these streams during high water time, thus maintaining the head, results from the possibility of locating wheels and generators wherever wanted because of now being able to control them automatically. This is recommended for a consideration where the river rises are severe, and where the nature of the surroundings forestalls a great rise in the pond level. It is to be pointed out that recent investigations have indicated power possibilities on streams which did not previously show very much potential power, and certain streams are being developed where it had previously been thought impossible to make a profit on the development. This has come about because of the network of transmission lines and the fact that enough pondage can be obtained so that the station capacity can be thrown into the transmission

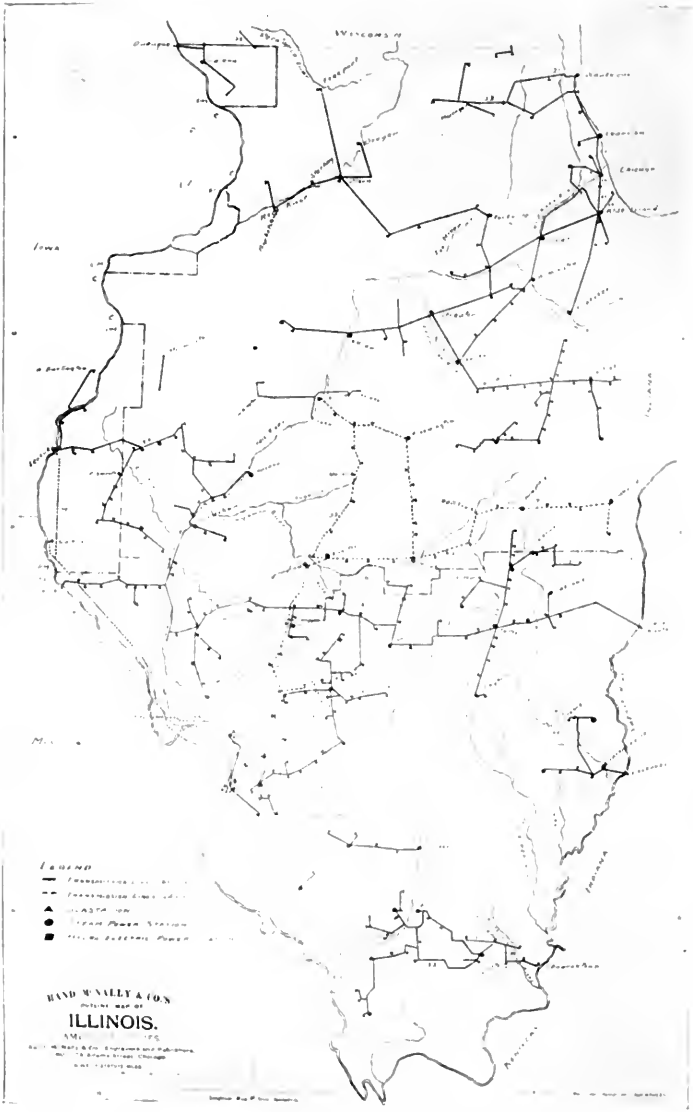

Fig. 2. Map of Illinois showing Power Stations, Substations, and Transmission Lines

Fig 4

Fig 3

Fig 6

Fig 5

Abandoned Mill Sites Offer Many Possibilities line during the peak of the load, thus partly exhausting the pond, and after the pond is restored run along at reduced capacity on the stream flow.

This application during the peak is made more effective due to the short time required by an automatically controlled generator to come on the line. For instance, a 2000 kw. machine, automatically controlled, is now coming on the line in 16½ to 18 seconds. It is felt that this peak operation of waterwheel-driven generators can not be too strongly recommended.

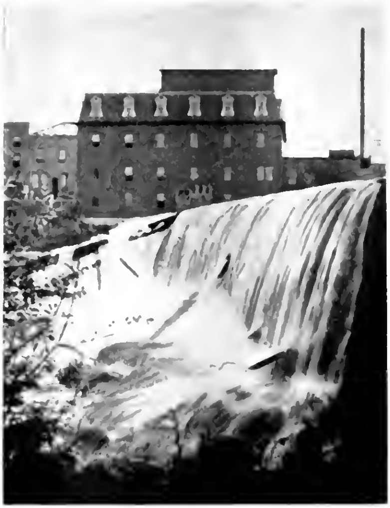

Fig. 7. A Water Power Site Partially Utilized by Mill and Local Electric Light Plant

The development of the number of sites along the stream, the pond of one running out at the tail water of the one above, withdraws all the objection to this method of operation. Now when a succession of such streams are joined up into the same network we have a condition where the stream reserve necessary to carry the load covered by this network is cut down enormously.

To check this the flow conditions of a number of rivers in Iowa were taken and the accompanying Table I illustrates the date of the highest water during storms as shown on the Government reports on these various rivers, both at different points on the same river and on adjoining rivers. This diversity factor, together with the method of backwater control mentioned above means a very sure power supply when such connections and developments are completed.

The over-development of such sites is the cheapest form of reserve generator capacity for peak load supply, and no transmission company with hydro-electric stations or sites available should overlook this reserve. This is particularly true since during the periods of low water the over-lap of the lighting and power loads has disappeared so the slack water is not of nearly as much importance as might at first be thought.

Propositions under active consideration have indicated complete equalization of the stream flow, even where there are extreme differences between the maximum and minimum flow, so the carrying out of such developments on the smaller streams means still greater equalization of flow on the larger streams. Each pond from the source down improves the prospects of larger development below. This application is being very actively studied by state organizations in the Middle West, and certainly should receive the support of the public utilities as well as the civic and technical organizations. Such improvements would mean that light-weight medium-voltage interconnecting transmission lines will do away with the necessity of high capacity power zone busses, the storing of quantities of coal under unfavorable conditions in the yards of many local generating stations, will mean the equalization of the hour-to-hour load on large central stations, and consequently their operation under more efficient conditions. Figs. 3, 4, 5, 6, 7 and 8 illustrate the type of sites subject to such development, and will, no doubt, be suggestive of similar sites.

Most central station companies have filed away reports on hydraulic prospects which for various reasons have been abandoned. It is recommended that such files be taken out to see if the reason they were not acted on was not due to the degree of development suggested, and to study over the situation with a view to putting the proposition on a basis in keeping with the banks and nature of the river valley, using present available means of control. If this were done a great many useful sites in the Middle West should be available to the people who most need the power.

TABLE I

CREST OF RISES IN IOWA RIVERS

Year	Des Moines at Keosauqua	Des Moines at Ft. Dodge	Des Moines at Jackson, Minn.	Iowa at Iowa Falls	Iowa at Iowa City	Cedar at Austin, Minn.	Cedar at Cedar Rapids	Wapsi. at Stone City	Maquo. at Maquoketa
1905	Mar. 1	...			Mar. 4		Mar. 11-23	Mar. 23	
	May 15	May 18			May 24		May 20	May 18	
	June 10	June 2			June 10		June 2	June 26	
	Aug. 25	Aug. 24			None		None	Aug. 28	
	Oct. 19	None			Oct. 18		None	Oct. 21	
1906	Mar. 30	Mar. 26			Mar. 26		Mar. 30		
	April 17	April 15			None		April 18		
	May 4	May 2		......	None		May 20 and May 31	......	
1912	April 4	(April 10)	April 3	April 9-17		.....	April 1	April 2	
	May 11	May 11	April 21	May 12		May 24	(May 27)	None	
	June 17	May 31	None	May 30		June 25	June 15	....	
	Aug. 22	Aug. 21	None	July 15		July 10	Aug. 20	....	
	Oct. 11	None	None	None		None	None	Oct. 13	
1913	May 21	May 16	May 27	(May 15)		May 18	May 26	May 25	
	June 26	June 8	None	June 26		June 26	June 15	None	
	Aug. 18	Aug. 26	Aug. 31 and Sept. 3	None		Aug. 24	Aug. 14	Aug. 15	
	Sept. 13	Sept 13 and Sept. 19	None	None		None	None	None	
1914	May 14	At Kalo None		May 1	May 11	April 29 and May 25	May 4 and May 27	None	May 11 and May 28
	June 29	June 20		June 19	June 18	June 15	June 19	None	June 25,
	Sept. 18	None		Sept. 16	Sept.15	Sept. 17	Sept. 15	Sept. 15	None
	Sept. 24	Sept. 18		Sept. 23	Sept. 21	Sept. 22	Sept. 22	Sept. 22	Sept. 15

None—Means no rise—steady flow. —Means no record in reports.

Potential Power Site for Hydro-electric Station

Utilization of Surplus Flood Water to Suppress Backwater Upon Water Power Developments

By Prof. Floyd A. Nagler

In Charge of Hydraulic Laboratory, State University of Iowa

Casual consideration of the effect of stream flow upon the load capacity of an ordinary low-head hydro-electric plant indicates that the available output should increase with the volume of flow up to the maximum rating of the equipment and there remain uninfluenced by any further increase in the volume of flow because the surplus water goes to waste. Unfortunately, it would be an exceptional low-head plant that could maintain its maximum output as the stream flow approaches that of a flood. To sustain plant capacity under such conditions is a problem which may find its practical solution in the backwater suppressor scheme described in the following article.

Just before going to press the author has informed us that the University's experimental work on this device has been completed, about 100 additional experiments having been made, and by means of diagonal and arched spillways and contractions in the channel downstream from the power house, the effectiveness has been increased about 20 per cent beyond that shown in Figs. 6 and 7 of the article.—Editor.

One of the problems encountered by many water power developments has been that during flood stages of the stream the tail water rises faster than the head water; in fact, it is not at all uncommon to find cases where the tail water rises at a rate more than three times that of the head water. Due to the limitations in the flowage rights of other developments the pond water surface is never allowed to exceed a maximum elevation, while the water surface below the development may vary as it naturally would with change in discharge. Thus the head available for power purposes is often diminished to the extent that, if the plant is able to operate at all, its power output represents only a small fraction of the normal rated capacity although the units may be operating under full water capacity under the existing head. Many plants are forced to cease operation entirely during flood stages, either because the units are unable to operate up to synchronous speed under the reduced head or because the head created at the site may be wiped out entirely. The power output is further decreased during these abnormal times by reason of the fact that water turbines themselves are inherently less efficient when operated at their usual speed under any other than normal head.

Not only is the bulk of the possible power output of a project decreased by this phenomenon, but a great portion of that power which is generated under normal conditions is at once rendered less valuable because it can no longer be classed as firm or continuous power but must be sold as surplus or secondary power. Many projects which are uneconomical to develop at present might be able to show profitable returns if during high water they could operate more nearly up to their normal output capacity.

Several methods have been suggested for the solution of this problem, all based upon the utilization of the energy which the surplus

Fig. 1. Hydraulic Laboratory of the State University of Iowa where the tests described in this article were conducted

flood water possesses by reason of the remaining head which still exists during high water. There is usually water enough at these times certainly; and, unless the development is drowned out entirely, there is a great amount of energy which is not being utilized.

An increase in the turbine capacity of the plant itself is a most obvious solution of this problem. At best this is expensive and its economy is especially doubtful on projects which have already been developed up to a reasonable water capacity. In any event, however, other methods for the utilization of the flood water must not prove more expensive than the generation of the same amount of additional power by this method.

The Herchel Fall Increaser,* invented by Clemens Herschel in 1907 is a device which discharges the waste water through a Venturi tube located at the end of the draft tube, the turbine discharge being drawn through apertures into the throat of the Venturi tube. In small scale tests of this device at the Holyoke Testing Flume the ordinary head was increased ninety per cent when the draft tube discharge was twenty-three per cent of the waste water used. The practical limitations in the quantities of water which can be economically handled through this fall increaser have prevented its extensive commercial application.

A device patented by W. W. Tefft has been installed at the Mio Development, Mio, Michigan, in which waste water is discharged through a gate at the elbow of a quarter-turn draft tube. A gain in head of 1.5 feet was realized when the waste water discharge was about one-third of the discharge through the water turbines.

In May, 1921, the Iowa Railway and Light Company of Cedar Rapids, Iowa, requested the staff of the State University of Iowa Hydraulic Laboratory to make a series of tests upon a scheme for using a high-velocity discharge of head water over a spillway or through gates to depress the water surface at the mouth of the draft tube, the water level later rising to the elevation of the river at a point farther downstream. In other words, surplus head water was to be utilized to suppress the backwater by the production of a more or less imperfect form of hydraulic jump.

The Hydraulic Laboratory at the State University of Iowa is admirably adapted for the performance of such tests. A view of the laboratory is shown in Fig. 1. The laboratory is located on its own dam site on the Iowa River at Iowa City, Iowa. There is a drainage area of 3140 square miles tributary to the river at this point making available almost unlimited quantities of water with a gravity head of eight to ten feet.

An experimental model of a development of about 30-ft. head on the scale of 1 to 10 was proposed, in which the water would discharge over spillways on either side of a power house section, and, surrounding the water coming from the draft tube while producing the hydraulic jump, would carry this discharge water with it downstream. The draft tube would at all times be discharging into the depression ahead of the jump. Each spillway on either side of the power house was equal in length to the width of the power house section.

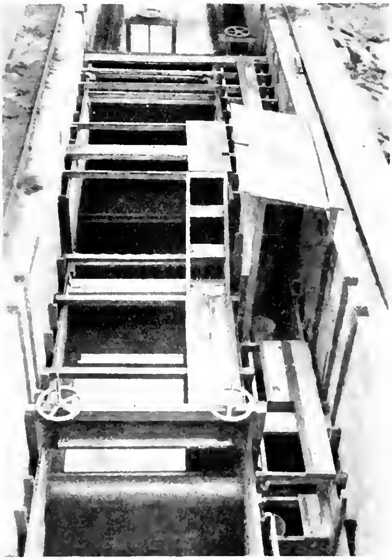

Fig. 2. General Arrangement of the Test Apparatus. The standard weirs are shown in the upper part of the illustration while the model dam (with no power-house section) can be seen in the foreground

The experimental apparatus set up in the long concrete flume approaching the laboratory building provided for sharp crested weirs for measuring both the quantity of water discharged through the draft tube and that discharged over the spillways. Six hook gages operating in stilling wells, and ten or more

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* Engineering News, Vol. 59, p. 635.

staff gages for observing water surface elevations were also installed. The general set up of the apparatus can be seen in Fig. 2, the standard weirs being in the upper part of the picture while the model dam (with no power house section) can be seen in the foreground.

Fig. 3. A View of the Model in Operation showing the draft tube in the center at the end of the section

A sketch of the model with water surface elevations which were actually observed in one of the experiments is shown in Fig. 5. The draft tube discharged between two spillway sections such as those shown in the illustration, and a gain in head which amounted to *J* was realized on the draft tube.

During 1921 over 350 experiments were performed upon this model with varying quantities of water discharging over the spillway and through the draft tube. The length and form of spillway was modified and the character of the toe and draft tube exit was experimented upon to a considerable extent. These experiments will be continued during 1922 in an effort to make an exhaustive investigation of all the problems involved.

The operation of the model can be observed in Figs. 3 and 4. These pictures were taken during an experiment in which 21.56 cu. ft. of water per sec. was discharged over the two spillways while 3.01 cu. ft. per sec. was being discharged through the draft tube at the end of the section shown in the center of Fig. 3. The amount of backwater being held back, or gain in head *J*, was 1.06 ft. when the actual head would have been but 2.38 ft. if no hydraulic jump had been produced below the dam. The rise in the water surface as one proceeds downstream can be seen more clearly in Fig. 4. Downstream from the crest of the hydraulic jump the water flows in a relatively undisturbed manner and with low velocity, although the action of this part of the model cannot be seen in Figs. 3 and 4.

In extending the values obtained with these models to the proportions of actual developments, linear dimensions need only be multiplied by the scale ratio, and discharge quantities by the square root of the fifth power of this scale ratio. Thus, if a development ten times the size of the model shown in Figs. 3 and 4 were proposed, it would be possible to secure a gain in head of 10.6 ft. when back water had reduced the normal head to 23.8 ft. making an effective head of 34.4 ft. The discharge through the draft tube would in this case equal $3.01 \times 10 = 952$ cu. ft. per sec. and the spillway discharge required would be $21.56 \times 10^{5/2} = 6817$ cu. ft. per sec.

The average results of the experiments are shown graphically in Fig. 6, and for representation on this diagram have been multiplied by a scale ratio of 9.4. Curve *A* is a line drawn at an angle of 45 deg. with the axes showing that with waste water producing no hydraulic jump a normal head of 24 ft. (for example) would mean an effective head of 24 ft. upon the turbines as well. But reading from Curve *B* with the hydraulic jump pro-

Fig 4. A View showing the Rise in Surface Water as one proceeds downstream

duced downstream from the power house by 5700 cu. ft. per sec. of water discharging over spillways, this effective head may be increased to 32.9 ft. (gaining 8.9 ft.) at the same time taking care of 670 cu. ft. per sec. of water from the draft tube which is discharging into the depression ahead of the hydraulic jump. The horizontal distance between Curves *A* and *B* represents the amount of jump *J* or head which can be gained for any particular value of difference in elevation between head water and tail water in the river downstream from the jump. The entire diagram is based upon only those results in which a constant quantity of water is discharged over the spillway and through the draft tube. The normal head, or amount of backwater on the development caused by high water was varied while the elevation of the head water was held constant.

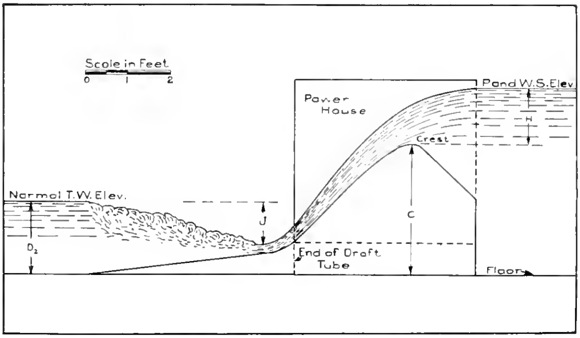

Fig. 5. A Sketch of the Model with Water Surface Elevations actually observed in one of the experiments

The diagram shown in Fig. 7 indicates the results which may be anticipated in a development 9.4 times the size of the experimental model. It is assumed that the water surface in the pond is held at a constant elevation 40 ft. above the river bottom in the tail race, as is shown by the scale at the left of the diagram. Various quantities which may be discharged over a spillway with a bear trap crest (a crest of variable elevation) are shown by the scale at the bottom of the drawing, whereas the elevation of this crest 42 ft. long (21 ft. on each side of the power house) is shown by Curve *C*. The depth of water discharging over this crest is shown graphically by the vertical distance from this curve to the top of the chart.

Assuming 670 cu. ft. per sec. discharge through the draft tube, and also assuming that the water surface in the depression upstream from the jump must never become lower than the top of the end of the draft tube, Curve *J* has been drawn from theoretical considerations to indicate the maximum height of jump or gain in head which may be expected. Curve D_2 shows the corresponding elevation of the water surface downstream from the jump. The top of the end of the draft tube is in this case assumed to be 7 ft. above the bed of the river. The broken line just underneath Curve *J* shows the range and location of the average experiments upon the model. The fact that these values are not quite the same as those obtained by theory is easily accounted for by the effect which friction on the crest of the Ogee model was proven to have upon the water that passed over it, this effect being of more significant consideration when small quantities of water discharged over the dam. If this fact is taken into consideration, the broken line checks the theoretical computations very well indeed. Some experiments with improved forms of aprons and draft tube outlets were found to check the theoretical curve with remarkable precision.

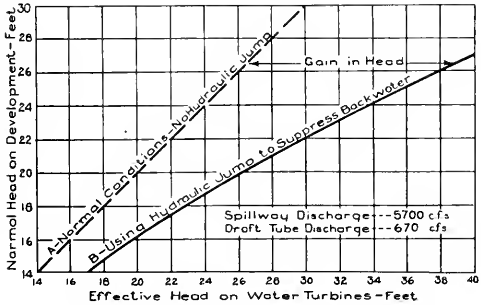

Fig. 6. Diagram showing Average Results of the Experiments Multiplied by a Scale Ratio of 9.4

It should also be observed that under these conditions the amount of head which can be gained J becomes a maximum when the discharge over the spillway is about 15,000 cu. ft. per sec. The depth of water flowing over the crest is then as great as 21.5 ft., and the normal head on the development is but 15.5 ft.; and the gain in head J is a maximum of 16.5 ft., making a total effective head of 32 ft. Under this condition, however, the jump is only 65 per cent higher than that which is obtained with 6000 cu. ft. per sec. although 2½ times the quantity of water is required to produce it. The economical point for operation is approximately at 6000 cu. ft. per sec., when an increase of a given percentage of the amount of water required to produce the maximum jump is effective in producing the same increase in height of jump expressed as a percentage of its maximum value.

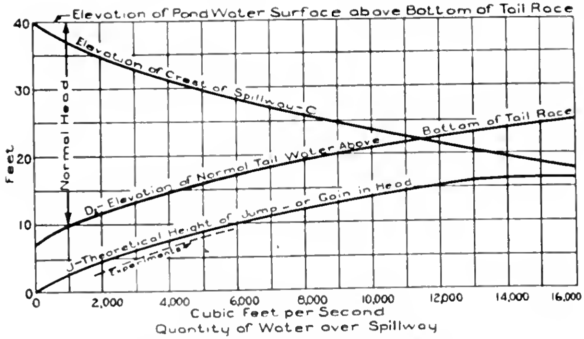

Fig. 7. Diagram Indicating Results Anticipated in a Development 9.4 times the Size of the Experimental Model

A study of Fig. 6 in connection with Fig. 7 will reveal the fact that if the depth of water downstream from the jump D_2 is greater than that indicated by the Curve in Fig. 7 with a given discharge over the spillway, the gain in head J will not be as great as that shown by the Curve J in this same diagram. On the other hand, if the water surface elevation D_2 is less than that shown by Curve D_2 greater values of height of jump J may be expected, but the draft tube will no longer remain submerged. This latter fact suggests that if the draft tube exit were placed below the bed of the river, discharging upward to some extent, greater values than those shown by Curve J can be obtained. Experiments have verified this fact.

Experiments also demonstrate that the quantity of water discharged through the draft tube has but little effect upon the amount of the jump J. The turbine discharge may be increased to four times the quantity designated in Figs. 6 and 7 without affecting the gain in head more than 2 per cent, if 6000 cu. ft. per sec. is discharging over the spillway.

The installation of this type of head increaser should involve very little expense in addition to that required for development without this device. The power house should be isolated in individual units between spillway sections in the main stream channel. The spillway itself may be made up of large head gates, or be constructed of an overflow type with large Taintor gates or bear trap crest. The toe of the dam should be extended somewhat farther downstream than is the usual practice with dams on soil foundations, and each individual set of spillways with their own power house should be separated by river walls as high and extending downstream as far as the crest of the jump if each unit is to be operated separately during flood stages. A full description and discussion of the experimental data and the theory involved is being prepared by the laboratory staff, copies of which may be had upon application at a later date.

Commercial Radio Telephone and Telegraph Transmitting Equipment

PART I

By W. R. G. Baker and B. R. Cummings

Radio Engineering Department, General Electric Company

Radio was initially developed for the purpose of safeguarding life at sea, and the success attained was so pronounced that commercial applications soon followed. The invention of the two-element and the three-element vacuum tubes made radio telephony possible, and gave birth to the broadcasting of instructive and entertaining radio programs. In the field of commercial radio, these versatile tubes are already supplanting the quenched-gap or spark type of transmitter. The following installment of the present article explains the advantages of continuous-wave and interrupted-continuous-wave transmission, describes the essential elements of a standardized commercial type of radio transmitter for telephony, continuous-wave and interrupted-continuous-wave telegraphy, and briefly analyzes the circuits utilized in a 200-watt and a 1000-watt equipment.—Editor.

A radio transmitter is primarily an alternator. Instead of generating the usual commercial frequencies, however, radio transmitters generate frequencies in the order of 100,000 to 1,000,000 or 2,000,000 cycles. Obviously the usual form of alternator cannot be employed for this purpose, and the system used must be one which is not dependent on moving mechanical parts. The function of a radio transmitting equipment is to generate alternating current at these frequencies and transfer this energy to the antenna system. The antenna system consisting of ærial wires, inductance units, and a ground system forms a series alternating-current circuit which represents the load on the transmitter. Frequencies of this magnitude (so-called "radio frequencies") are essential in order that efficient radiation of energy be obtained from the antenna. Of the total power in the antenna, the percentage that is radiated decreases very rapidly as the frequency is lowered, or (which is the same thing) as the wave length is increased.

Radio transmitters differ from usual electrical equipments in that instead of avoiding resonance this phenomenon is utilized in practically all radio-frequency circuits. The fundamental fact that a circuit consisting of inductance and capacity has a natural period is utilized in establishing the frequency required.

Radio transmitters in order to be applicable for commercial use must be capable of generating any one of a number of frequencies, and in many cases must be so designed that the frequency of its output can be changed by throwing a single switch. This requirement is brought about by the fact that, in commercial traffic, it is customary to use one wave length for calling purposes and then to transfer to a second wave length for communication.

Developments in the radio field in the last few years have resulted in the gradual substitution of continuous-wave transmitting equipment to replace quenched-gap or spark transmitters. Continuous-wave transmitters possess several inherent advantages which are of considerable importance. For example, continuous-wave telegraphy permits of greater selectivity. The energy radiated by a spark transmitter is sent out in damped wave trains hence the selectivity of reception depends not only on the decrement of the receiving circuit but also upon the decrement of the wave train itself, which in turn depends upon the decrement of the transmitting station. Continuous-wave transmitters give an increased range of transmission due partly to the greater sensitivity of the receiving apparatus. With continuous-wave telegraphy, the signal note can be adjusted to the pitch or tone most suitable for reading through static or interference. With damped-wave transmission, the signal note is fixed by the transmitter group frequency. With continuous-wave transmitters, since the energy is radiated in a continuous stream when the signal is being sent out, and not in groups, it follows that for a given power in the antenna the amplitude of the oscillations need not be so great. Obviously, if much power is to be radiated by the damped-wave transmitter, comparatively high oscillation amplitude must be used; that is, the energy associated with a group of waves, for a given amount of energy radiated per second, must be high since energy is radiated only during a small fraction of the time. Thus a given antenna will have a greater possible energy radiation with continuous waves since the energy may be radiated continuously. An advantage of thus decreasing the required amplitude of oscillation for a given radiation is the reduction in required voltage, thus decreasing the use of extremely high-voltage apparatus and antennas.

Continuous-wave transmitters also provide a means for obtaining radio telephone communication, which is not possible with the usual form of spark transmitter.

The foregoing advantages combine to give to the continuous-wave transmitter a degree of selectivity and efficiency of transmission very much higher than could be obtained with the damped-wave type.

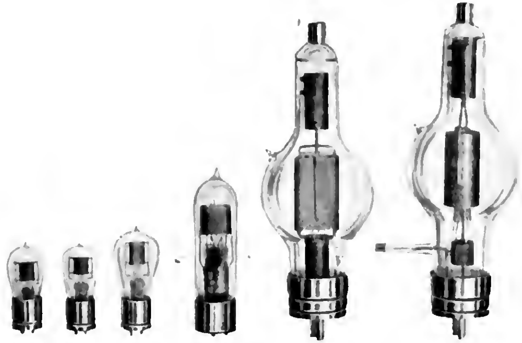

Fig 1. Group of Radiotrons Used as Power Oscillators and Amplifiers in Radio Transmission and as Detectors, Oscillators, and Amplifiers in Radio Reception

The heart of the continuous-wave transmitter is the type of vacuum tube called the "radiotron." A group of these tubes which have been developed by the Research Laboratory of the General Electric Co. and which are used in the equipments to be considered is shown in Fig. 1. A complete description of these radiotrons has been published.* In general a radiotron consists of three elements: filament (cathode), grid, and plate (anode) mounted in a highly evacuated glass vessel. As applied to radio these tubes may be used as detectors, oscillators and amplifiers for receiving purposes. In transmitting equipments radiotrons are used primarily as power oscillators and amplifiers.

A second group of tubes called kenotrons is shown in Fig. 2. Kenotrons are used chiefly in radio work as power rectifiers in order to obtain a source of high-voltage direct current. The direct application of the various types of radiotrons and kenotrons will become evident when the various equipments are considered.

A continuous-wave radio telegraph transmitter may be roughly divided into the following units:

The power supply which must provide a source of high-voltage direct current for the plate circuit and a low-voltage alternating current supply for filament excitation. In addition either an alternating-current or a direct-current supply must be available for the operation of auxiliary apparatus such as relays, controls, etc.

The radio-frequency generator or transmitter proper must provide means for transforming the high-voltage direct current into radio-frequency current. This unit in addition usually contains all the apparatus necessary to control the radio-frequency output such as when telegraphing.

The antenna equipment is not ordinarily considered a part of the transmitter equipment. Regardless of whether such is the case, the antenna consists of an elevated capacity area composed of a number of wires usually suspended horizontally from 75 to 300 ft. above the earth. Depending upon local conditions—

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* Articles by W. C. White: GENERAL ELECTRIC REVIEW, Oct., 1920, and Journal of Franklin Institute, April, 1921.

the earth may be directly connected to the antenna through the transmitter unit or a metallic network may be buried in or suspended a few feet above the ground. This metallic network is called a counterpoise.

When the continuous-wave transmitter is used for telephony or interrupted-continuous-wave telegraphy, a modulation system is incorporated in the radio transmitter proper. For telephony this modulation or control system consists of a group of radiotrons termed modulators. The function of the modulators is to vary the amplitude of the radio-frequency alternating current in the antenna circuit in such a manner that the envelop of the maximum amplitudes of the radio-frequency alternations reproduces the wave form of the voice. One method of providing interrupted-continuous-wave telegraphy is by using a motor-driven commutator which chops up the radio-frequency energy so that a group frequency of about 1000 cycles is obtained.

The following is a brief description of two types of radio telegraph and telephone transmitters recently developed, designed, and built by the General Electric Co., including a brief analysis of the circuits utilized, together with a description of the controls provided and the method of operation.

It should be borne in mind that it is comparatively simple to sketch a circuit which will provide radio telegraph and telephone communication. The more difficult problems arise when quantitative specifications are prepared for the component units; and when suitable materials, designs, controls, and protective devices are selected to insure a transmitter which will give the service required under all conditions imposed upon it. These problems are particularly difficult due to the high frequencies and high potentials which are inherently associated with radio transmitting equipment.

The two transmitters* referred to have ratings of 200 and 1000 watts respectively. The circuits utilized in the two equipments are identical and the equipments themselves are very similar in appearance.

The rating of all vacuum-tube transmitters built by the General Electric Co. is based on the number and kind of tubes which are used for telegraphy. If a transmitter utilizes four radiotrons (UV-204) as oscillators, each radiotron having a capacity of 250 watts, the transmitter is rated at 1000 watts. The transmitter may put slightly more or slightly less than this amount of power into the antenna circuit, depending on the wave length used, the characteristics of the antenna, etc. This point should be remembered in comparing the output of vacuum-tube transmitters with that of spark transmitters, since the latter are almost universally rated on the output of the power equipment; i.e., the input to the radio transmitter proper. Since the average efficiency of commercial spark transmitters is approximately 50 per cent, the output of a one-kilowatt tube transmitter is approximately equal to that of a two-kilowatt spark transmitter. Furthermore, the effective range of a vacuum-tube transmitter is much greater for the reasons given previously.

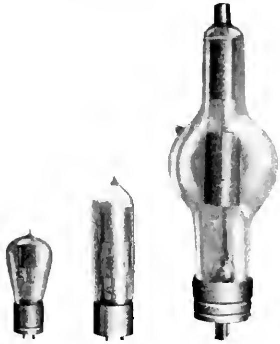

Fig. 2. Group of Kenotrons Used as Power Rectifiers to Obtain High-voltage Direct Current for Radio Transmission

These transmitters are designed to provide communication by continuous-wave telegraphy, interrupted-continuous-wave telegraphy and telephony. The provision for transmitting interrupted-continuous waves is made in order that communication may be carried on with stations not equipped for the reception of continuous-wave signals. The wave form radiated on interrupted-continuous-wave transmission has characteristics sufficiently close to those of a spark transmitter that stations which can receive the latter (and this includes practically all stations) can also receive the former. Transmission by continuous waves is so much more effective than that by interrupted continuous waves and by spark signals that it is only a matter of time before all receiving stations will be equipped to receive continuous waves. When that time comes, the provision in tube transmitters

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* Known as Models ET-3602 and ET-3608.

for interrupted-continuous-wave telegraphy can be omitted.

The 200-watt transmitter utilizes four 50-watt radiotrons (UV-203) as oscillators when transmitting continuous waves or interrupted continuous waves (hence the 200-watt rating) and five for telephony (two as oscillators, two as modulators, and one as a speech amplifier). The last radiotron amplifies the output of the microphone transformer before it is impressed on the grids of the modulating tubes, since the transformer alone has not sufficient capacity to modulate the output of the oscillators efficiently.

The 1000-watt transmitter utilizes four 250-watt radiotrons (UV-204) as oscillators when transmitting continuous waves or interrupted continuous waves, and four for telephony (two as oscillators and two as modulators). In this set also, a 50-watt radiotron is used as a speech amplifier for telephony.

While the number of oscillators is halved when telephony is used, the plate system of modulation which is utilized in these transmitters gives so-called "positive modulation," i.e., the modulator tubes contribute power to the output of the oscillator so that, when telephoning, the power in the antenna will be appreciably more than the output of the oscillators. For the 1000-watt set, the output will be between 500 and 1000 watts; and for the 200-watt set, between 100 and 200 watts.

The sets have a wave-length range, on an average ship's antenna, of from 300 to 800 meters, and the three methods of communication are provided for throughout this range. The sets can also be supplied for a wave-length range of 600 to 2000 meters. Under these conditions, continuous-wave and interrupted-continuous-wave telegraphy are provided for throughout the entire range, but telephony is available only up to 1000 meters.

For transmitting with interrupted continuous waves, use is made of a motor-driven interrupter mounted within the confines of the transmitter structure. This interrupter functions the same as the transmitting key on the continuous-wave position, except that the oscillations are started and stopped at an audio frequency. This system of modulation has the following inherent advantages over the so-called "buzzer modulation" method:

(a) It is more positive in action because it is designed to give the equivalent of a 500-cycle spark note, which it will do consistently without re-adjustment.

(b) The modulation is inherently 100 per cent.

The filaments of all tubes are illuminated by alternating current, which increases the filament life from 50 to 100 per cent over the life obtainable by direct-current illumination. This is due to the fact that when direct current is used one side of the filament is at higher potential, with respect to the plate, than the other. This condition causes more rapid evaporation of one half of the filament than the other. When alternating current is used each half of the filament is alternately at higher and lower potential with respect to the plate, thereby equalizing the evaporation of the two halves of the filament.

Negative bias for the grids of the modulator and speech amplifier tubes is obtained by a potentiometer connected across the 125-volt direct-current exciter forming one unit of the power equipment. The bias is increased with increase in power.

The wave length of the transmitters is established by the antenna circuit, including the loading inductance and "generating" coil in the transmitter. Series antenna condensers are used to obtain the lower wave lengths.

When the set is installed, adjustments of plate and grid coupling are made for each wave length which the set will utilize. These adjustments, once made, need not be changed thereafter. They cannot be made before installation, because they are dependent on the constants of the antenna on which the set operates.

All oscillator and all modulator tubes are connected in parallel. The same plate voltage supply is utilized for all tubes in each set, except the 50-watt speech amplifier in the 1000-watt set. The plate voltage for this tube is 1000 volts, while that for the remaining 250-watt tubes is 2000 volts. The 1000 volts is obtained from one of the 1000-volt commutators of the power equipment, two of these commutators being connected in series to obtain 2000 volts.

A small radio choke coil is included in the plate lead of both oscillator and modulator tubes to eliminate parasitic oscillations, which are otherwise apt to be generated when operating tubes in parallel.

(To be Continued)

Noiseless Automatic Substation for Los Angeles Railway

By Clark E. Baker

Railway Engineering Department, General Electric Company

The building boom, temporarily interrupted by the war, is again resulting in such rapid expansion and development of outlying residential districts that more and more railway companies are finding it no longer economically possible to supply the increasing load demands direct from their power houses through feeders at trolley voltage. If the problem were one of engineering alone, it could easily be solved by determining the location of the new load centers and there installing substations of the requisite capacity. However, a human element enters in the form of bitter objections by property owners at the proposal of a substation being located in their midst. To the Los Angeles Railway Corporation belongs the credit of attacking the problem and solving it in a manner satisfactory to all concerned by utilizing automatic substation equipment housed in an ingeniously-constructed sound-proof building of architectural beauty.—Editor.

Automatic control in its application to noiseless substations promises to solve one of the problems of economic load distribution in city service. With the constant extension of residential districts many railway operators have been confronted with the necessity of locating substations at load centers falling in restricted residential districts. The condition of existing substations, many of which were built with little thought as to appearance and no precautions for eliminating noise, has resulted in a more or less antagonistic attitude on the part of residents in the vicinity of proposed new locations.

The Los Angeles Railway Corporation, Los Angeles, Cal., recently encountered this situation to such an extent that attempts to acquire property for new substations in residential districts were blocked by the residents in several instances. It was only after the Railway Corporation had agreed to erect a building of sufficient architectural beauty to harmonize with the surrounding residences and with provision for the elimination of noise that approval for the Garvanza substation was obtained from the City Council.

It being practically impossible to build the modern high-speed rotating machinery to operate noiselessly, it was necessary to resort to a building designed to absorb the noise. Since very little work had been done to obtain noiseless operation to the extent required in this type of service, it was necessary for the Engineering Department of the Corporation to do some original work in this field.

The first of the attractive noiseless substations, known as Garvanza Substation, was recently put into operation and has been passed by the City Council and pronounced both attractive and noiseless. The success of this installation has resulted in permission being granted the Corporation to erect additional substations of this type, the electrical equipment for two of which is now being built by the General Electric Company.

The equipment in the Garvanza substation consists of a 1000-kw., 6-phase, 600-volt synchronous converter, a 3-phase 6-phase oil-insulated self-cooled 16,500-volt transformer, and complete automatic control equipment with four 600-volt direct-current automatic feeders. The synchronous converter and switchboard are installed in a large totally enclosed room ventilated by means of blowers and designed to prevent sound penetrating the walls and ceiling. The lightning arrester, oil circuit breaker, and transformer are installed on one side of the building in separate compartments ventilated by means of louvres and roof vent.

The inside of the substation is 42 by 44½ ft. floor plan and the ceiling is 20 ft. above the floor at the lowest point, the roof being flat and sloped to drain in one direction. The foundations are extra heavy concrete as a part of the noise-proof design and reinforced with old 60-lb. rails thoroughly cleaned to facilitate adhesion to the cement.

The exterior walls are well burned common brick 13 inches thick and laid in cement mortar. The upper portion of the exterior walls is reinforced concrete to act as a bond to tie the building together and to facilitate the placing of tile and anchors where required.

The exterior walls have large buttresses of brick laid up solidly, and timbers 8 by 8 in. in size project out beyond the cornice line. The walls are coated with cement plaster, tinted a deep green and applied with a circular sweep producing a highly pleasing effect. A number of blind windows covered with heavy black grilles serve to break up the flatness of the wall and improve the appearance from the architectural standpoint. Each pilaster is ornamented by a large black iron lantern especially designed for the substation.

The interior walls consist of 4 by 12 by 12-in. hollow building tiles laid in lime and cement mortar and secured to the brick walls by 60 d. spikes bent down to each third tile.

Between the exterior and interior walls ½-in. "Flaxlinum" was placed between two thicknesses of building paper to insulate the walls against noise.

The roof is 4-in. concrete reinforced with square twisted bars and is carried on steel girders and beams. The concrete is covered with "Flaxlinum" laid between building paper and a layer of 4-in. hollow tile. The roofing consists of two layers of 15-lb. roofing felt and a layer of three-ply standard cap sheet, all thoroughly coated with tar.

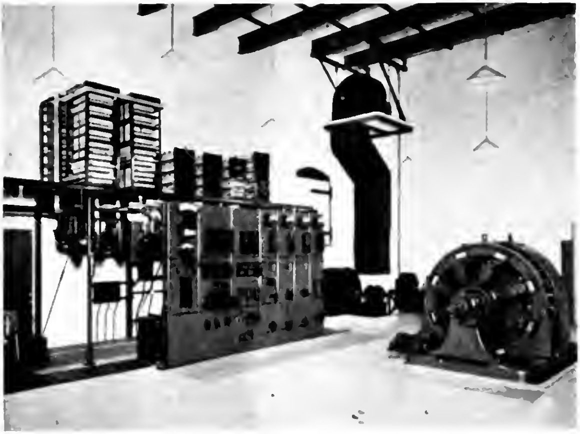


Fig. 1. Interior of Noiseless Substation showing 1000-kw. Synchronous Converter, Automatic Switchboard, Load-limiting Resistances, and Ventilating Blowers

All doors into the main room are designed to be sound-proof and are provided with special fastenings to permit tight closing. The main door, located in the rear of the building, is 10 by 14 ft. made in two pieces and is large enough to allow the removal of the largest piece of apparatus in the building. A small door is provided in the front of the building for general use. The lightning arrester, oil circuit breaker, and transformer compartments each have doors opening into the main room.

The doors are made of three thicknesses of tongue and grooved lumber laid diagonally with "Flaxlinum" between layers and framed into solid timber. The door frames are heavy timber secured to the walls by long bolts built into the brick work. The doors and jambs are beveled on all sides similar to refrigerator doors to assure a tight fit.

The air intake for ventilation of the main room was originally through metal louvres located in the wall near the top of an intake shaft. The air in passing through the metal louvres produced a shrill whistling sound and it was found necessary to board up the louvres. A hole of equal area was cut in the roof and covered with a pent house hidden behind the parapet walls. The air is drawn through this hole down the intake shaft by a 2-h.p., 3-phase induction motor driven No. 6½ Sturtevant, 375-r.p.m. multivane fan located outside the shaft on the floor of the main room.

From the intake fan the air passes through a duct under the floor to the converter pit and rises to the ceiling by convection. A second fan, similar to the intake fan, mounted on a suspended platform near the ceiling, draws the warm air into a metal duct down to the floor and through a 180-degree bend to the exhaust shaft. The metal duct is wrapped with cotton bandage and thoroughly coated with tar to eliminate vibration. The exhaust shaft extends from the floor to the ceiling and is open to the air, which arrangement necessitates a drain at the bottom of the shaft. By thus interrupting the path of both the intake and exhaust air, the noise produced by the synchronous converter is absorbed within the building and is not transmitted to the outside air.

The general appearance of the building and grounds is most attractive and is a credit to the community. The presence of unsightly transmission lines and feeder cables has been eliminated as far as possible by making entrance at the rear of the building from towers located on the alley at the rear. The direct-current feeder cables are brought out underground to the base of the tower. A generous lawn with vines and shrubbery complete the harmony with the neighborhood. An automatic sprinkling system has been installed to keep the lawns in condition. The exterior illumination of the building between sundown and 2 a.m. is controlled by an automatic time switch.

Automatic control is particularly applicable to this type of an installation. The operation of a substation totally enclosed and so isolated from the outside is by no means attractive or desirable from an attendant's standpoint. By using automatic control all attendance, except for inspection and cleaning, is eliminated.

Detailed descriptions of automatic substations have appeared in the technical press and bulletins from time to time; therefore only a brief description of the outstanding features of this control equipment is given here.

The substation was installed essentially to take care of morning and evening peak loads in the Garvanza section. and is started by low trolley voltage and shut down automatically when the load supplied by it decreases and remains for a given time below a value at which it is not economical to continue operation. An automatic time switch prevents the station from being started unnecessarily due to temporary low voltage during the night hours.

A notable feature in the layout of the equipment in the substation is the isolation of the transformer, oil circuit breaker, and lightning arrester in separate compartments and the simple high-tension bus construction. The compartments are on one side of the building and the apparatus is so arranged in the compartments that it was possible to bring the high-tension line in through the rear wall and continue through the compartments in a straight line to the transformer.

The high-tension oil circuit breaker is provided with a single-phase, 220-volt, one-horse power motor operating mechanism to close the breaker each time before the station starts, thus eliminating the transformer no-load losses. The operating mechanism is mounted on the steel framework supporting the oil circuit breaker making a complete unit which was assembled, adjusted, and tested at the factory and shipped without disassembling.

The operation of the blowers as well as the remainder of the equipment is completely automatic. The blowers start when the station starts and continue to operate 10 to 15 minutes after the station shuts down. The blower motors are equipped with speed limit switches, the contacts of which are closed when the blowers are operating. If the blowers fail to start or shut down for any reason while the station is running, the contacts of the speed limit switch open and de-energize a time delay stopping relay which in turn operates to shut down the station. A throwover switch connected in the blower motor control circuit makes it possible to operate the station without the blowers when the temperature permits.

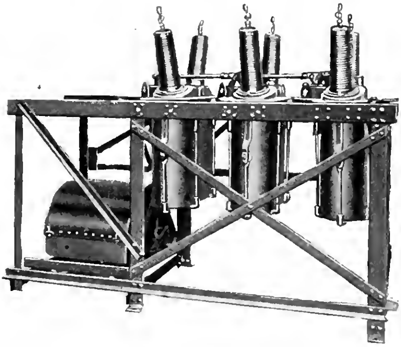
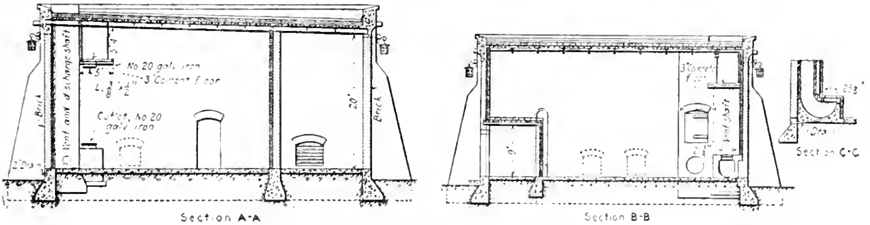


Fig. 2. 35,000-volt, 3-phase, Oil Circuit Breaker and 220-volt Single-phase, Alternating-current, Motor-operating Mechanism Assembled in Steel Framework

The equipment includes four 600-volt automatic feeders, three of which are multiple-end feed and one stub-end feed. Each feeder is protected by a load limiting resistance which is normally short circuited by a contactor. In case of an overload on a feeder, a shunt type overload relay operates to open the resistance short circuiting contactor inserting the resistance into the feeder circuit. If the overload continues a sufficient time to heat up the resistance beyond a safe temperature, a thermostat mounted over the resistance operates to open a feeder contactor



Section A-A

Section B-B

Section C-C

Fig. 3. Cross Sections of Noiseless Substation showing Construction of Walls and Roof

disconnecting the feeder from the bus until the resistances cool off at which time the thermostat operates to reclose the feeder isolating contactor. The resistance thermostats have a temperature adjustment and the reset time interval may be varied by varying the location of the thermostat above the resistance.

Two of the multiple-end feeders are equipped with suitable control to provide for reclosing the feeder from either the station bus or the feeder depending on which receives voltage first. Thus provision is made for reclosing the multiple feeders from the adjacent station and feeding through the substation bus to the stub-end feeder even though the automatic station is inoperative due to loss of high-tension voltage or other cause.

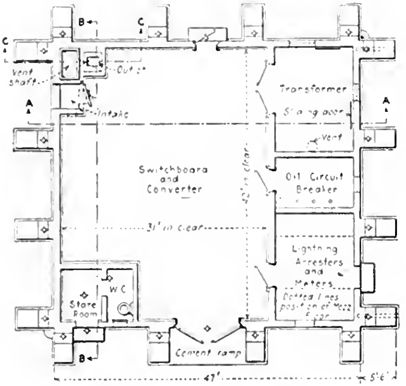


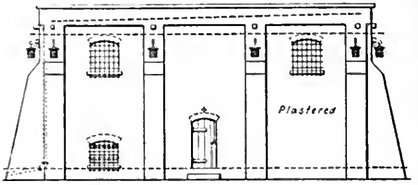
Fig. 4. Plan of Noiseless Substation

The remaining multiple-end feeder is provided with reverse-current protection to disconnect the feeder from the station bus in case a reverse feed occurs. The feeder remains disconnected from the bus until the conditions are such that the trolley voltage is below that of the station bus.

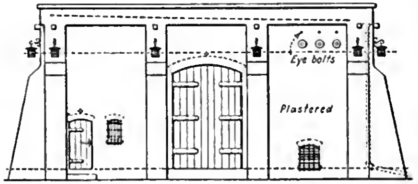
No provision has been made for directly circulating air through the load limiting resistances for cooling because the heating of resistances is too infrequent to necessitate special precautions. The exhaust fan is, however, located near the resistances and the exhaust intake is so located that it draws directly on the warm air above the resistances.

The switchboard and starting and running contactor panel were completely assembled, wired, and all equipment except the synchronous converter and transformer was assembled and tested at the factory. The small wiring on all panels was brought to terminals at the bottom or top of the panels; and the terminals on the panels, as well as the terminals on the drum controller, brush raising device, and oil circuit breaker operating mechanism, were numbered corresponding to numbering on the wiring diagram to facilitate installation.

An important feature, too often considered unnecessary in an automatic substation, is the installation of a compressor for blowing out the machine and other equipment.



Front Elevation



Rear Elevation

Fig. 5. Elevations of Noiseless Substation showing Heavy Buttresses and Doors

While this installation represents a greater expenditure than some operators find necessary, it is an excellent example of what may be accomplished. In some cases where substations can be installed on the rear of lots in business sections, only the noiseless feature is necessary. It must be remembered, however, that in some cases operators are forced to proceed in this manner and much credit is due the Los Angeles Railway Corporation for the success of this installation both as to noise elimination and architectural beauty.

The design of this substation, the drawing of plans, and the entire supervision of erection of both the building and the electrical machinery are the work of the Engineering Department of the Los Angeles Railway Corporation under the direction of P. B. Harris and the Supervision of L. J. Turley and G. E. Campbell.

Steel Mill Auxiliary Drives

FACTORS AFFECTING THE SELECTION OF ELECTRIC MOTORS

PART I

By L. A. Umansky

Power and Mining Engineering Department, General Electric Company

To make the motor fit the drive is very desirable in all industrial applications of the electric motor. It is especially essential in steel mill work. The author's analysis of the method of determining the correct motor to use with each steel mill auxiliary should find a broad field of usefulness in the steel industry.—Editor.

General

The electric motor has won its fight to become *the* drive for steel mill auxiliaries. At every up-to-date steel plant it drives the mill table carrying the hot ingot to and from the blooming mill; it tilts the ingot from side to side between two rolling passes; it operates the screw-downs bringing the rolls together or moving them apart; it opens and closes the furnace doors, pushes the billets into the reheating furnace and out of it—to mention only a few of its many applications. In fact, the electric motor does almost everything that was previously done—slowly and inefficiently—by hand and does many other things besides; only through its agency the output of the mills was brought to the up-to-date high standard, which could not be duplicated if the motor were substituted by any other drive.

But the position won by the electric motor in the steel plant is not only honorable: it is just as responsible. If the electric drive insures the high mill tonnage, every failure in the chain of electric apparatus means a more or less considerable but irreparable loss of time and money. In case of any failure, the delay and loss are charged against the electrical equipment and are charged in terms of lost tonnage, figured of course at the rate obtainable with the electric drive. Thus, the very advantages of the electric drive are turned against it when it fails to function uninterruptingly.

One will readily see how important it is to have a reliable, rugged and correct size motor for each of these steel mill auxiliary drives.

During the early years of the motor application in steel mills many failures were readily traceable to the attempts to use industrial type motors for steel mill service. In the greatest majority of cases this will not do; good as the standard motor may be, it will not stand the severe strain of mill duty. Mechanical shocks; high temperature due to the nearness of the furnaces and of the hot metal; frequent starting, contributing to the heating from internal, electrical source, and tending to shorten the life of the insulation; and last, but not least, the ever-present dirt and water combine in causing many accidents so familiar to the mill electricians.

Not before the motor manufacturers, co-operating with the steel mill men had developed a new line of machines, especially adapted for the service, could the electrically operated auxiliary drives become a success.

Fig. 1 shows a typical steel mill motor. Large size bearings, strong shaft, rigid frame with sturdy feet—give the required mechanical strength. The armature, with diameter reduced at the expense of increase of its length, has a comparatively low inertia—the feature so essential for quick reversals. The motors are either totally enclosed, as shown in Fig. 1, or are of the open type, as illustrated in Fig. 2. The former type gives complete protection against dirt and water, but its heat dissipating capacity is limited; it is especially adapted for intermittent service, i.e., where the load imposed on the motor is heavy, but of short duration and occurs with considerable time intervals. The open type motors have a superior capacity for carrying continuous load.

Electrically these machines have a well defined series characteristic Their duty requires high starting torque with minimum current drawn from the line. The series-wound motor fits these requirements nicely, just as it fits the street car service. Where it is expected that for part of the time the motor will carry very little load, the plain series motor might overspeed beyond safe limits; in this case the motor is furnished with an additional shunt field winding which limits the no-load speed to say 150 per cent or 200 per cent of the full load speed. Fig. 3 gives the typical characteristics of a series-wound mill type motor.

A line of such motors, ranging in capacity from 4 h.p. to over 200 h.p., has been developed, and the steel mill engineers have a number of standardized machines to choose from for their requirements.

Selection of Motors

It is here where the real story begins. It will not be stretching the point too far to say that no less failures were due to the misapplication of a given motor to a particular drive, than to the unsuitable design of the original motors.

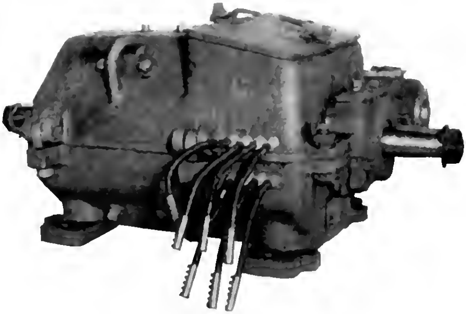


Fig. 1. 30-h.p., 625-r.p.m., 230 volt, Series-wound, Mill-type Totally Enclosed Motor

In a number of cases the drives were undermotored; after several machines were burnt out in this way, it was natural for the operators to go to the other extreme and to install motors of the capacity about double of what would apparently do the work. But, strange as it may seem, this over-motoring did not always solve the problem; quite frequently, a larger motor would overheat just as badly as the smaller one, although, to all appearances, the performance of the drive was not changed. It seemed as if the engineers could not figure out beforehand the load conditions of these motors.

In the first place, all these drives are of intermittent duty type. It was necessary to foresee with sufficient accuracy the expected time schedule of the drive; but this part of the engineering work, although important, needed but the general knowledge of steel mill operations, a stop-watch and a few minutes of the engineer's time in making observation. Thus the intermittency of duty can be determined as follows: The furnace door motor should open and close the door in, say, three seconds, every 40 seconds; or, the reversing mill table will carry the hot ingot over an average travel of, say, five feet 15 times during the rolling of one ingot, and the ingots are rolled at the rate of, say, one every minute. This or similar schedule is sufficient to estimate the intermittency of the duty.

Thus we know what percentage of the time the motors will be busy. But *how busy* are they when they are working? It was lack of knowledge on this point that caused most of the failures, and this was plainly a failure of the engineers and not of the motors.

When a motor drive is selected for, say, a pump, or a compressor, it is a matter of everyday practice to figure out accurately the required capacity of the drive. Take for instance a pump delivering 20,000 gallons of water per minute against a 30-ft. head; we know that the net work of doing this is: $20{,}000 \times 8.35 \times 30 = 5{,}000{,}000$ lb.-ft. per minute or 152 h.p. (1 gal. = 8.35 lb.). Say, the pump efficiency is 80 per cent; then the motor should deliver to the pump $152 \div 0.8 = 192$ h.p. A 200-h.p. motor, as the next larger standard size, will probably be selected.

Why cannot the same method so successfully used elsewhere be applied to calculating the power requirements for the steel mill auxiliaries? Why not express the work they have to perform in terms of horse power or otherwise—just as we did with the water pump?

Let us consider, for instance, a reversing mill table. It consists, see Fig. 4, of several rollers, gear-driven by an electric motor; it starts, rotates the rollers in one direction and brings the ingot to the mill; then the table is stopped and started in the opposite direction. The table does not do any "useful work," i.e., it does not lift the ingot, nor

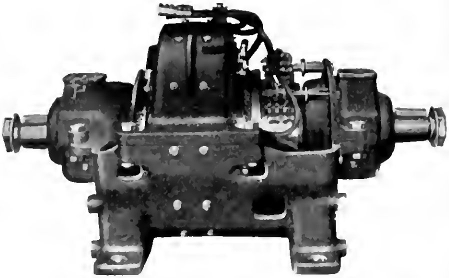


Fig. 2. 140-h.p., 450-r.p.m., 230-volt, Series-wound, Open Construction, Mill-type Motor

does it change the shape of the ingot as the main rolls do. If the table should be left running free for some time, giving the motor only friction load to overcome, we could see, by observing the ammeter that this load is very light, certainly not much over, say, 50 h.p. for even a large table of this kind. On the other hand, we know that quite frequently two 100-h.p. motors are kept very busy to drive the same table under normal operating conditions, i.e., "start-stop-reverse" and so on. We see offhand where the real problem is: the motors are not doing the readily calculated "useful work"—they merely work against the forces of inertia. In estimating the value of these forces is the crux of our problem, and it is here that most of our engineering mistakes were made.

We know that the forces of inertia and therefore the inertia load on the motor appear only when the speed of the drive changes; at a constant speed—the inertia load disappears, and, in case of our mill table, only friction load remains. And here also comes into play and apparently further complicates the problem the series characteristic of our motors: their speed has a fixed relation to their load. Thus we have a vicious circle: in order to know the load of the motors we must know their speed at various instants, but we do not know this speed unless we know the load.

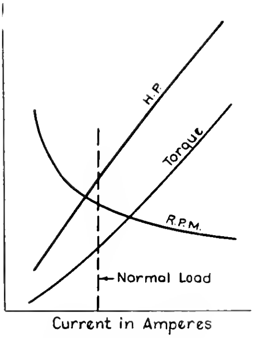


Fig. 3. Typical Characteristic Curves of a Series-wound, Mill-type Motor

As a matter of fact our problem is a very simple one. There is nothing mysterious in the calculations of forces of inertia; all these forces obey one single law, readily comprehended by everyone; the application of this law to various problems may be called mathematics, but we may call it just as well simple logic and common sense.

The Nature of Inertia Forces

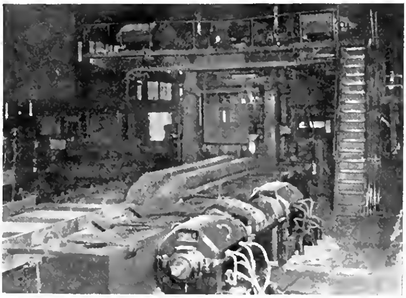


Fig. 4. Mill-type Motors Operating Live Tables and Screw Down of the Reversing Blooming Mill

This simple rule reads: if you have a body with a mass "M" and desire to accelerate it, i.e., to increase its speed by "a" feet per second every second, then you have to apply to this body a force "F_a," which should be the larger, the larger is the mass of the body M, and the higher is the rate of acceleration "a." If F_a is to be expressed in pounds, then

$$F_a = M \times a \tag{1}$$

Everyone knows this law by meeting it in everyday life: when you accelerate your automobile you know that it must do more work than when going at constant speed, and naturally you give "more gas" to the engine; or, when you watch the ammeter in the motor circuit while it starts, you see that the meter hand goes up during the acceleration and then drops down after the motor reaches the constant speed. The rule (1) simply states in writing these basic and well known facts.

Naturally, when you have two bodies, one twice the weight of the other, and apply equal forces F_a to them, then the smaller body will accelerate at a rate twice as high as the larger one. Or, if both bodies should be accelerated at the same rate, then the larger body will require a proportionally larger accelerating force, so that the force per unit of mass will be the same in either case.

Now, the force of gravity, or the weight of the body is of just the same nature as any other force, i.e., it is also capable of accelerating the body, when the latter is free to move in its direction. We know that all falling bodies (neglecting air resistance) accelerate at the same rate which is 32.2 ft. per sec. per second. It is customary to call this gravity acceleration by letter "g." Thus the weight:

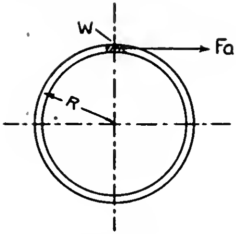


Fig. 5. Acceleration of a Heavy Rim

$$W = M \times g = M \times 32.2 \text{ lb.} \qquad (2)$$

This gives us a convenient means of finding the value of the mass of a body, when its weight is known:

$$M = \frac{W}{g} = \frac{W}{32.2} \qquad (3)$$

and the rule (1) may be rewritten as

$$F_a = W \times \frac{a}{g} = W \times \frac{a}{32.2} \qquad (4)$$

$$\text{Accelerating force} = (\text{weight}) \times \frac{(\text{rate of accleration})}{(\text{gravity acceleration})}$$

Now, if the speed changes from V_1 ft. per sec. to V_2 ft. per sec. in "t" seconds at a uniform rate of acceleration "a," then

$$a = \frac{V_2 - V_1}{t} \qquad (4a)$$

and

$$F_a = \frac{W}{32.2} \times \frac{V_2 - V_1}{t} \qquad (4b)$$

It is obvious that the force F_a, calculated as outlined, is the force required for acceleration only. If it is necessary to overcome the friction (F_f) in moving the body, or to do some "useful work," such as lifting the body, requiring an application of force (F_w), then the total force (F) to be applied to the body will be:

$$F = F_a + F_f + F_w \qquad (5)$$

If we apply a smaller total force than F, then the friction force and the force required for the "useful work" will still take their share of it, and less force will be left available for accelerating the body, so that the rate of acceleration will be smaller.

Rotating Motion

It can be readily shown that exactly the same rule applies to rotating bodies.

Let us take a wheel of weight W lb. and of radius R ft. Suppose it is running at the speed of N_1 r.p.m. and it is desired to increase this speed to N_2 r.p.m. in t seconds.

Now, let our wheel consist of a heavy rim and of comparatively light spokes. It is fairly accurate to assume that its whole weight is at the rim, and then we may say that the wheel is equivalent to a body with weight W lb. moving with the speed equal to the rim speed.

When the wheel runs at N_1 r.p.m. or $n_1 = \frac{N_1}{60}$ rev. per sec., the rim speed is

$$V_1 = 2\pi R \times n_1 \text{ ft. per sec.} \qquad (6)$$

Similarly, at

$$N_2 \text{ r.p.m. or } n_2 = \frac{N_2}{60} \text{ rev. per sec.}$$

$$V_2 = 2\pi R \times n_2 \text{ ft. per sec.} \qquad (7)$$

Thus, if the increase of speed was done at a constant rate in t seconds, the rim acceleration is

$$a = \frac{V_2 - V_1}{t} \text{ ft. per sec. per sec.} \qquad (8)$$

or

$$a = 2\pi R \times \left(\frac{n_2 - n_1}{t}\right) \text{ ft. per sec. per sec.} \qquad (9)$$

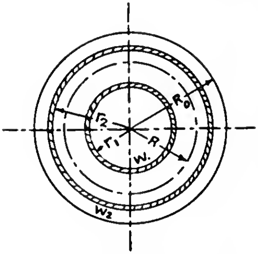


Fig. 6. Inertia of a Disc Wheel

In other words, the weight W lb. should be accelerated at the rate of a ft. per sec. per sec. We know that in order to do this a force F_a should be applied to the rim which is (see rule 4):

$$F_a = W \times \frac{a}{32.2} = \frac{W}{32.2} \times 2\pi R \times \frac{n_2 - n_1}{t} \qquad (10)$$

This force will be applied of course in the direction of the desired motion, that is, tangentially, as shown in Fig. 5.

Now, instead of dealing with the force F_a applied to the rim we may consider the torque (T_a) that it produces at the wheel shaft. This torque

$$T_a=F_a\times R \text{ lb.-ft.} \qquad (11)$$

Substitute for F_a its value from (10) and obtain:

$$T_a=WR^2\times\frac{2\,\pi}{32.2}\times\frac{n_2-n_1}{t} \qquad (12)$$

or

$$T_a=0.195\times WR^2\times\frac{n_2-n_1}{t} \qquad (13)$$

Remember, n_1 and n_2 are expressed in rev. per sec. If the speeds are given in r.p.m., then

$$T_a=\frac{WR^2}{308}\times\frac{N_2-N_1}{t} \qquad (14)$$

But the expression

$$\frac{N_2-N_1}{t}=a_0 \qquad (15)$$

is the rate of change of wheel speed in r.p.m. per sec., or rate of wheel acceleration. Thus

$$T_a=\frac{WR^2}{308}\times a_0 \qquad (16)$$

Now, let us compare the two equations: (4b) and (14). The first expresses the accelerating force for straight line motion; the second the accelerating torque for rotating motion; instead of weight of body (W) we use the value WR^2, which we call the "flywheel effect"; instead of rate of linear acceleration, $\left(\frac{V_2-V_1}{t}\right)$, we use the rate of rotating acceleration $\left(\frac{N_2-N_1}{t}\right)$. The similarity is striking, which is not at all surprising, as both rules are merely different expressions of the same basic but simple law of inertia, which was given in the beginning of this part of the article.

The "flywheel effect," or the WR^2, which is identical to the weight in the linear motion, as can be readily seen, is proportional to the weight of the wheel and the second power of its radius. In other words, if we have two wheels (heavy rims) of equal weight, but one having its diameter twice that of the second, then the WR^2 of the first wheel will be four times greater than the flywheel effect of the second wheel. If the accelerating torques are the same in either case, then the second wheel will accelerate four times faster than the first. If instead of the wheel, consisting of a heavy rim with light spokes, we have a disk wheel, as in Fig. 6, then we may conceive it consisting of many concentric rims, each having its flywheel effect $w_1\ r_1^2$, $w_2\ r_2^2$, etc. The total flywheel effect is, naturally, the sum of $w_1\ r_2^2+w_2\ r_2^2+$, etc. We may substitute such disk, as far as its flywheel effect goes, by a heavy rim with the same weight W as our disk, and of such radius R, that its flywheel effect WR^2 will equal the sum of $w_1\ r_1^2+w_2\ r_2^2$, etc. The radius of such an imaginary or equivalent wheel is called the radius of gyration of the rotating body. In case of a disk, with an outside radius R_0 it can be substituted by a rim with the same weight W and radius $R=0.707\ R_0$.

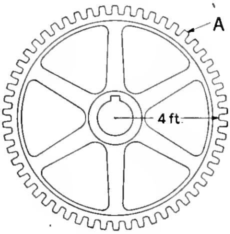


Fig. 7. Single Gear

Example

A simple example will illustrate all the above rules.

Let us assume a heavy gear wheel A, see Fig. 7, having a weight of 10,000 lb. and a radius of 4 ft. What will be the torque required to accelerate it from 100 to 150 r.p.m. in five seconds?

It is easy to calculate that the wheel has an approximate $WR_A{}^2 = 10{,}000 \times 4^2 = 160{,}000$ lb.-ft.². Use equation (14) and obtain:

$$T_{A_a}=\frac{WR_A{}^2}{308}\times\frac{N_{A2}-N_{A1}}{t}=$$

$$\frac{160{,}000}{308}\times\frac{150-100}{5}=5200 \text{ lb.-ft.} \qquad (17)$$

Suppose, then, that the same wheel runs at 100 r.p.m. and that it is desired to bring it to a full stop in eight seconds. What retarding torque should be applied to the wheel to accomplish this?

Now, the retarding or braking torque is calculated exactly in the same way as the accelerating torque; use (14):

$$T_{A,r}=\frac{WR_A^2}{308}\times\frac{N_{A2}-N_{A1}}{t}=$$

$$\frac{160,000}{308}\times\frac{0-100}{8}=-6500 \text{ lb.}$$

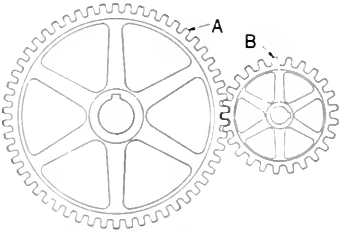


Fig. 8 Simple Geared Mechanism

The sign $(-)$ is used, because the braking torque is applied *against* the direction of rotation; the retardation is, after all, a negative acceleration.

The presence of friction, as was shown, increases the total required torque for acceleration. For retardation the friction obviously contributes to the braking effort.

Now, very frequently the mechanisms to be considered are not as simple as one single gear or wheel. In most cases we have several gears, meshed together, running at different speeds and therefore accelerating at different rates. How shall the accelerating forces be calculated in such case? Another example will make this clear

The same large wheel A that we have considered before is now geared to, and is driven by, the smaller gear B, see Fig. 8. The gear ratio is "k," that is, the gear B runs k-times faster than the gear A. Say, this ratio is $k=2:1$.

It was already figured out that the wheel A has $WR_A^2=160,000$ lb.-ft.^{2} Assume that the flywheel effect of the wheel B was figured in the same way and is: $WR_B^2=20,000$ lb.-ft.^{2}

The torque required to accelerate A from 100 r.p.m. to 150 r.p.m. in five seconds was figured out as $T_{A,a}=5200$ ft-lb. *at the shaft A*.

Due to the gear ratio $k=2:1$ between the two gears, any torque to be produced at shaft A requires half that torque at shaft B This general well known rule is as applicable to accelerating torques as to any other. Thus the torque at shaft B, required to accelerate the gear A, is:

$$T_{B,A}=\frac{T_A}{k}=\frac{5200}{2}=2600 \text{ lb.-ft.} \qquad (18)$$

Besides this, the gear B should also be accelerated. While A changes its speed from 100 to 150 r.p.m., B speeds up from 200 to 300 r.p.m.

The corresponding torque, at shaft B, is:

$$T_B=\frac{WR_B^2}{308}\times\frac{N_{B2}-N_{B1}}{t}=$$

$$\frac{20,000}{308}\times\frac{300-200}{5}=1300 \text{ lb.-ft.} \qquad (19)$$

Altogether the required accelerating torque is $2600+1300=3900$ lb.-ft. This is a simple way of figuring, but when there are many gears, wheels, etc., in the mechanism, it is rather tedious to calculate separately the accelerating torques for each wheel and then reduce them to the driving shaft in proper ratio.

Equivalent Inertia Load

We shall outline a method by means of which the calculation of the inertia of almost any mechanism can be reduced to consideration of a single wheel, as in our first example. This can be done in the following simple way:

Let us consider again our two wheels, A and B, see Fig. 8. We have found out that when it takes torque T_A on shaft A to accelerate the wheel A, it will take the torque of only $T_{B,A}=\frac{T_A}{k}$ at the shaft B to accelerate the same wheel A. Now we can imagine that the wheels A and B are disengaged, but that another wheel C, see Fig. 9, is mounted on shaft B as a substitute inertia load of wheel A. This wheel, in order to be a substitute, should require the same torque $T_{B,A}$ to accelerate it, as the wheel A required from

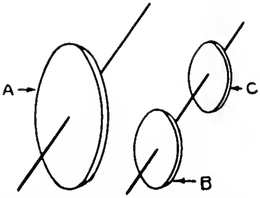


Fig. 9. Transfer of the Inertia Load from One Shaft to the Other of a Geared Mechanism

shaft B. What should be the WR_c^2 of the wheel C?

Suppose this wheel is properly selected; then, as per equation (14)

$$T_c = T_{B,A} = \frac{T_A}{k} = \frac{WR_c^2}{308} \times \frac{N_{B2}-N_{B1}}{t} \qquad (20)$$

Hence

$$WR_c^2 = \frac{308 \times T_A \times t}{k \times (N_{B2}-N_{B1})} \qquad (21)$$

But we have already found out that (see 17)

$$T_A = \frac{WR_A^2}{308} \times \frac{(N_{A2}-N_{A1})}{t} \qquad (22)$$

Insert the value of T_A in (21) and obtain:

$$WR_c^2 = \frac{WR_A^2}{k} \times \frac{(N_{A2}-N_{A1})}{(N_{B2}-N_{B1})} \qquad (23)$$

Now, the shaft B with all the wheels on it runs always at a speed "k" times higher than the shaft A. Therefore

$$\frac{N_{A2}-N_{A1}}{N_{B2}-N_{B1}} = \frac{1}{k} \qquad (24)$$

and, finally

$$\boldsymbol{WR_c^2 = \frac{WR_A^2}{k^2}} \qquad (25)$$

This rule (25) means that the equivalent wheel C, running at the speed "k" times higher than the wheel A (which it should substitute) should have a flywheel effect k^2 times smaller than that of wheel A.

Thus we may forget about wheel A and merely consider the shaft B with two wheels: B and C. Their total flywheel effect is:

$$WR_B^2 + \frac{WR_A^2}{k^2} \qquad (26)$$

With this rule in mind we can reduce a good many mechanisms to the simplest, but equivalent form.

Take for instance the several gears and shafts shown in Fig. 10. Assume the following values for WR^2 and speed ratios:

$WR_A^2 = 250$ lb.-ft.²
$WR_B^2 = 2000$ lb.-ft.²
$WR_c^2 = 800$ lb.-ft.²
$WR_D^2 = 21000$ lb.-ft.²

Ratio between shafts:

(1) and (2)........ $k_2 = 2{:}1$
(2) and (3)......... $k_{2.3} = 3{:}1$
(1) and (3)......... $k_3 = 6{:}1$

Reduce all the wheels to shaft (1), following the rule (25). Denote all reduced values of WR^2's by the mark (1), which stands for the shaft of that number.

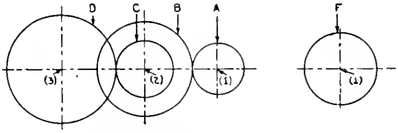


Fig. 10. Substitute Inertia Load of a Mechanism Consisting of Several Gears

$$WR_{A_1}^2 = WR_A^2 = \qquad 250 \text{ lb.-ft.}^2$$

$$WR_{B_1}^2 = \frac{WR_B^2}{k_2^2} = \frac{2000}{2^2} = \qquad 500 \text{ lb.-ft.}^2$$

$$WR_{c_1}^2 = \frac{WR_c}{k_2^2} = \frac{800}{2^2} = \qquad 200 \text{ lb.-ft.}^2$$

$$WR_{D_1}^2 = \frac{WR_D^2}{k_3^2} = \frac{21{,}000}{6^2} = \qquad 584 \text{ lb.-ft.}^2$$

Total WR^2 on shaft (1) = 1534 ft.-lb.²

Thus for all inertia calculations the mechanism shown in Fig. 10 can be replaced by a single wheel (F) on shaft (1) having $WR_F^2 =$ 1534 lb.-ft.²

Practically all the mechanisms of the steel mill auxiliary drives can be substituted for calculation purposes by such simple elementary forms. The inertia force can then be readily figured out and the resultant load on the motor will then be calculated exactly in the same way as the load produced by any other force, such as gravity, friction, etc.

We shall select an existing auxiliary drive (reversing mill table, with motors, gears, etc.), and shall study a few operations of this drive step by step. This will show the reader how the simple inertia laws should be actually applied.

(To be Continued)

Electric Drive in Tanneries

By J. A. Horne

Publication Bureau, General Electric Company

In our July, 1922, issue (page 441) there appeared an article which briefly reviewed some of the historical accomplishments in the art of tanning leather and which gave general information regarding the advance that has been made in the electrification of the modern tannery. The following article describes in detail the electric drive of two tanneries, one operating by the vegetable process and the other by the chrome process. A consideration of the facts which are presented amply demonstrates the electric motor to be: (a) readily adaptable to drive the variety of machines that have been used in tanneries; (b) a desirable substitute for manual labor in many divisions of the process; and (c) a more productive, more reliable, and yet cheaper motive power than has hitherto been used in this industry.—Editor.

Introduction

Leather is as old as trade and its manufacture is a part of the industrial activity of practically every people. The United States leads all other countries in the production of leather; while the import of hides and skins, amounting to approximately $270,000,000 for the year 1920, is one of the greatest items of our import trade. An idea of the importance of the industry may be gained from reports received from 681 tanning establishments for the year 1919, which indicate a total output of leather products amounting to $929,000,000. A report of similar nature for 1914 from 767 tanneries placed the value of product at $367,000,000.

Despite the tremendous growth of the tanning industry, the archaic methods still pursued are a sad commentary on American enterprise. Within the past few years, however, successful applications have demonstrated beyond doubt that electricity affords a ready solution to many of the vexatious problems confronting the industry today.

In general the application of electric drive to tannery machinery offers the same advantages as in other industries with the distinctly important feature of decreased power consumption and increased production for a given equipment.

Owing to the extended areas over which power must be transmitted, the losses incurred in steam-driven plants due to friction and belt transmission are sometimes greater than the actual amount of energy expended in doing useful work. In addition to these losses several engines and isolated boiler equipments are usually necessary and incur high cost for attendance and maintenance. The major portion of this power cost may be eliminated by applying the motive power directly to the various machines. The cost of energy in a plant operated in this manner becomes very nearly proportional to the work done.

Existing installations of electrically operated tanning machinery have proved beyond question that a given equipment will do more work at lower cost when electrically driven, due mainly to the greater uniformity of speed obtained and to improved control. Other advantages of motor drive that indirectly lower the cost and improve the quality of the product are: greater cleanliness, which materially reduces the percentage of damaged leather; more convenient and logical arrangement of machines, which insures quick and economical handling of hides from one machine to another; greater reliability of operation, since the failure of any driving motor can affect only a small part of the plant machinery. This last factor is of vital importance in a tannery since the failure of power at certain stages of the process will frequently entail a heavy loss.

VEGETABLE TANNING PROCESS

Motor Drive at the Plant of J. Paskus & Son, Inc.

The utilization of electric energy contributes in no small measure to the reputation enjoyed by the firm of J. Paskus & Son, Inc., Middleburg, Pa., as tanners of an especially fine grade of sole leather. The product of this plant is extensively used in the manufacture of fine custom-made shoes. The tannery under normal operating conditions has a capacity of 700 sides per day and uses a mixed oak and hemlock tannage, the complete process from receipt of raw hides to the finished leather requiring 120 days.

The electrical equipment includes 25 polyphase induction motors ranging in size from 2 to 50 h.p. with a combined rating of 260 h.p. All motors are equipped with hand-operated starting compensators, and in addition each motor has an individual overload circuit breaker conveniently located on the nearest distribution switchboard. Average load conditions at this plant approximate 50 kw., while at times 100 kw. is required for peak operation.

The old power station was equipped with one 200-h.p., two 100-h.p., and two 125-h.p. return tubular boilers which furnished steam for the operation of four reciprocating engines, two of which were rated 75 h.p., one 100 h.p., and the fourth 125 h.p. These engines were belt-connected to line shafts and under normal operation were all overloaded, resulting in low speed on all the plant machinery and a consequent lowering of production.

The new equipment consists of one 120-kw. 900-r.p.m. 240-volt 60-cycle 3-phase alternator belt-driven by a 150-h.p. Corliss engine. Excitation for the alternator is furnished by a 5-kw. 125-volt chain-driven generator. Steam at 125 lb. pressure is delivered to the engine by two 200-h.p. return tubular boilers, one of which has ample capacity for all except extreme load conditions. Exhaust steam is used for heating the buildings, and for the various drying and leaching processes about the plant.

Arrangements have been made for the exchange of energy with a local public utility which is of mutual advantage. At times a considerable portion of the plant machinery is not required to operate and energy is needed only in emergency to prevent possible spoilage. For such operation the power supply is received from the lines of the Juniata Public Service Corporation through a 60-kw. 2300/220-volt transformer. A similar amount of energy may be fed back into the high-tension line in case of emergency.

Bark Mill and Leach House

The bark mill for grinding and shredding the bark preparatory to the extraction of the tannic acid is bevel-geared to a line shaft which in turn is chain-driven by a 50-h.p. motor. From this line shaft is operated a blower which forces the ground bark into a separator. The bark is then conveyed to the leaching vats by a revolving screw driven by a 15-h.p. slip-ring induction motor. The vat pumps are operated by compressed air, the compressor being belt-driven by a 7½-h.p. motor. After the bark has been leached, it is conveyed by an endless chain drag and dumped direct into cars for shipment and sale as a by-product. This drag is operated by a 5-h.p. motor.

Beam House

The mechanical equipment of the beam house consists of two washing mills, a portable reel for transferring the hides from the vats through the successive stages of soaking, liming, and washing, an unhairing machine, a fleshing machine, a working-out machine, and a hair washer. With the exception of the unhairing machine and the hair washer, which are group-driven from a line shaft by a 10-h.p. motor, the remainder of these machines have individual motors. The washing mills are each belt-connected to a 10-h.p. motor located in the sorting room directly over the beam house. The fleshing and working-out machines are driven by 15 and 10-h.p. motors respectively, and the portable reel is belt-driven by a 2-h.p. motor.

Rocker, Handler, and Layer Vats

In this plant there is a total of 95 rocker vats, these being operated in groups by four motors two of which are of 2 h.p., one of 3 h.p., and one of 5 h.p. Since the "rockers" are best operated very slowly, back-geared motors are employed with a speed reduction from 1800 r.p.m. at the motor to 15 r.p.m. at the line shafting. Prior to electrification this room was a maze of shafts and belts which not only rendered expeditious handling of hides an impossibility, but was an ever-present source of possible injury to operatives.

Adjacent to the rockers are the "handlers" and "layaways," a total of 142 such pits being necessary when the plant is operating at capacity. Because of the low ceilings, the transfer of hides to and from these pits is accomplished manually, although in an establishment of this size having sufficient head room the economies afforded by the use of electrically-operated overhead cranes would easily justify such an installation.

From the layaways the hides are passed through a wringer which is belt-driven by a 5-h.p. motor.

Extract Milling and Oiling

The extract mill with a capacity of 75 to 80 sides is vertically belted to a 10-h.p. motor, while the two oil mills are group-driven by a 15-h.p. motor. These mills are of the hollow-axle feed type and are raised so as to extend through the floor above in order to permit loading of the hides from either floor. A belt-tightener attachment is utilized whereby the load fluctuations caused by the mass-tumbling of hides in the mills are smoothed out to a considerable degree before reaching the motor.

Dry Room

In the dry room the hides are dried, dipped, sponged, and rolled, all of these operations with the exception of the last being performed manually. The rolling machines, six in number, are arranged in groups of two, each group belt-driven by a 10-h.p. motor.

Before sorting and baling the leather for shipment, it is passed through a buffing

Fig 1 Small Continuous Drier Operated by a 10-h p , 1200 r p m , 440 volt Induction Motor. John R Evans Co , Camden, N J

Fig 2. Color Drums Driven by Three 15 h p., 1200 r p m , 440 volt Induction Motors Controlled by hand starting compensators. John R. Evans Co.

Fig. 3. Shaving Machines. Each driven by a 5-h p , 1200-r p m., 440-volt induction motor. Controlled by hand starting compensators John R. Evans Co.

Fig. 4 One 750-kw., 3600 r.p.m., 480-volt Curtis Condensing Steam Turbine Arranged for Automatic Steam Extraction, and one 100-kw., 3600-r p.m., 480-volt Curtis Steam Turbine at the Plant of John R. Evans Co. (An additional 750-kw. unit will soon be installed)

machine which polishes the grain side. This machine is belt-driven by a 10-h.p. motor.

Results of Electrification

As a direct result of electric drive, production at this plant has been increased 100 percent. At the same time the former 14,000-lb. daily coal consumption has decreased to 3500 lb. However, a considerable portion of the saving in coal is due to the present method of utilizing exhaust steam for heating and drying. Prior to electrification all of the reciprocating engines exhausted into the atmosphere and live steam was used for drying the hides and for heating the buildings.

CHROME TANNING PROCESS

Motor Drive at the Plant of John R. Evans & Co.

The new Ruby plant of the John R. Evans & Co. at Camden, N. J., affords a striking example of the modern electrically operated tannery. This firm, one of the largest in the United States, utilizes the two-bath chrome tanning process and produces a high-grade glazed kid in blacks and colors, calf side leather, and patent sides. For manufacturing convenience and because of the diversified product, the establishment is divided into three distinct plants, one of which, the Ruby, is now completely electrified, while the remaining plants are rapidly being changed over from mechanical to electric drive.

The original power station equipment consisted of eight 250-h.p. hand-stoked return tubular boilers which delivered steam to one 100-kw. steam-engine-driven generator and to ten 200-h.p. Corliss engines, belt-connected to line shafts. This equipment, however, was of insufficient capacity and it was necessary to purchase energy for a motor load of approximately 150 h.p. and a lighting load of 130 kw.

The new equipment consists of two 937-kv-a. 0.8 p-f. 3600-r.p.m. 480-volt Curtis steam turbines arranged for automatic steam extraction, one 25-kw. motor-generator exciter set, one 125-kv-a. 0.8 p-f. 3600-r.p.m. 480-volt Curtis turbine with direct-connected exciter, and one 10-kw. turbine-driven exciter set. The two large turbines, only one of which is installed at this time, will furnish energy for all three plants, will replace the ten reciprocating engines, and will obviate the necessity for purchasing energy. Operating statistics obtainable thus far indicate that but four of the eight boilers previously mentioned will be required for operating the turbines.

The 100-kw. turbine is used for plant lighting and for power requirements occasioned by night operation, while the small 10-kw. steam driven exciter provides starting excitation for the two main units and also emergency lighting for the boiler room and for the generating station.

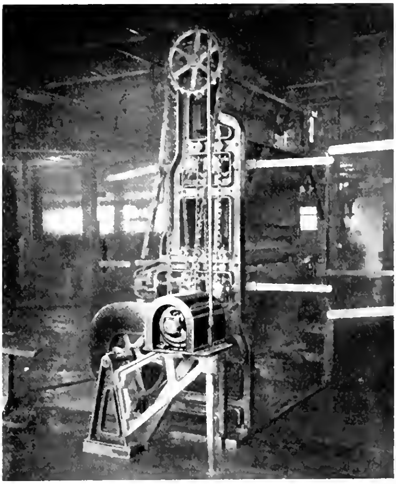


Fig. 5. A Five-table Serial Putting Out Machine Chain driven by an individual 1200-r.p.m., 440-volt motor. Twenty-two such machines are installed and controlled by hand-starting compensators. John R. Evans Co.

Energy is transmitted from the main switchboard in the generating station through iron conduit to distribution centers carefully located with respect to power requirements in each of the three plants.

Under normal operating conditions, the three plants require approximately 2000 gallons of water per minute. The supply is taken from the Delaware River and is delivered to the plants by a 2500-g.p.m. centrifugal pump direct connected to a 60-h.p. motor. A duplicate set is installed thus providing an emergency equipment.

In the Ruby plant, the buildings are heated by exhaust steam from the large turbine. The so called "unit system" of heating is utilized wherein the heat is distributed and proper circulation maintained by motor-driven blowers. Exhaust steam is also utilized for heating the

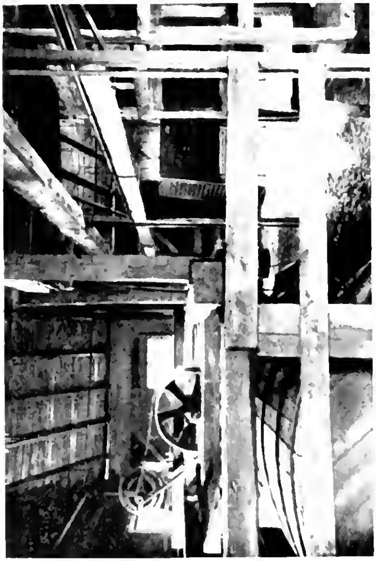


Fig. 6. Two Oil Mills driven by a 15-h.p., 3-phase, 60 cycle, 220 volt induction motor. J. Paskus & Son, Inc., Middleburg, Pa.

Fig. 7. Unhairing, Fleshing, and Working Out Machines driven by individual three phase motors. J. Paskus & Son, Inc.

Fig. 8. View of a lime yard in which there are 164 lime reels group-driven by twelve $7\frac{1}{2}$-h.p. motors. John R. Evans Co.

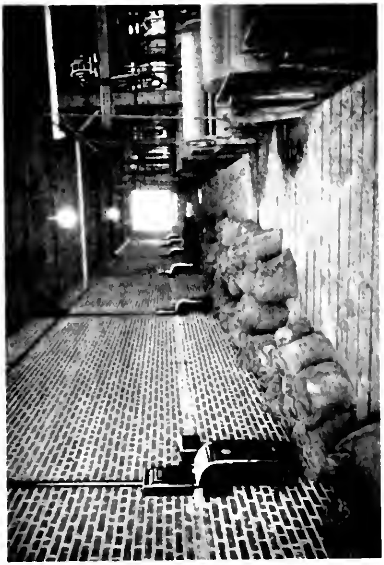


Fig. 9. End view of the lime yard showing the location of the hand-starting compensators, reversing switches, and safety switches controlling the motors that drive the lime reels

high temperature process water, large quantities of which are necessary in the chrome tanning process. The low temperature process water is taken directly from the condensers.

An accurate record of the consumption of steam and water is obtained by the use of water and steam flow meters. Such records are essential to the efficient and economical operation of a plant.

Motor Drive

A careful survey was first made of the power requirements of the various machines in this plant in order to determine the drive best suited to each operation. In general, the group system of drive was adopted, since many of the machines used in the manufacture of leather are best adapted to this form of drive because of the intermittent power requirements. This feature is especially notable on the heavy staking and glazing machines, these having a reciprocating motion with the load applied only during a portion of the stroke. On the other hand such machines as the striking out, putting out, and shaving machines are fitted with individual motors, these where possible being mounted directly on and forming an integral part of the driven machine.

To equip the Ruby plant properly a total of 92 motors with a combined rating of 855 h.p. was required. All motors are of the polyphase induction type, wound for 440 volts, and operate at 1200 r.p.m.; the equipment is thus standardized so that a very few spare motors and supply parts will insure prompt replacement in the event of injury to any motor in the plant, and will minimize interruptions to the power service. Each motor is equipped with reliable control and protective devices; motors of a rating 3 h.p. and less are thrown directly on the line by oil circuit breakers with double overload trip coils. For the larger motors a hand-starting compensator, affording under-voltage and overload protection, is employed.

Lime Yard

This yard, a model of its kind and perhaps one of the largest in the industry, contains 164 liming paddle-vats arranged in groups, each group being chain driven from a line shaft to which is connected a 7½-h.p. motor. By means of a clutch in the line shaft, each vat may be operated independently. Each motor is equipped with a reversing switch so that the vats may be rotated in either direction. Prior to electrification still vats were used, necessitating a considerable amount of manual labor for agitating the contents of the vats and for the periodic handling and draining of the skins. Located in this same room and adjacent to the lime vats are the soaking vats and mill drums. There are four mill drums in all, operated in groups of two from a line shaft, each group requiring a 20-h.p. motor.

Beam House

In the beam house are located the unhairing, fleshing, and slating machines, the washing and pureing reels, the large washing tumblers, and the neutralizing vats. Here, group drive is exclusively employed, and with the exception of the tumblers and neutralizing vats which require 10-h.p. and 5-h.p. motors respectively, all motors are of 7½-h.p. capacity.

Wet Room

The machines in the wet room consist of chrome reels, striking-out and putting-out machines, shaving machines, and color drums. Both group and individual drive find application here. The chrome reels are very similar to the lime vats, and a group of ten is chain driven from a line shaft to which is connected a 7½-h.p. motor. Clutches on the line shaft make possible the independent operation of any reel. The striking-out and putting-out operation is accomplished on a five-table serial striking-out machine. There are 22 of these machines, each independently driven by a direct-connected 5-h.p. motor. The shaving machines, of which there are seven, are individually driven by a 5-h.p. motor, through a chain. The shaving machine should be driven at an absolutely constant speed if a perfect product is to be obtained; and with individual motor drive "wash boarding" of the skins, a common occurrence with the old belt drive, no longer takes place.

The color drums are group driven, each group requiring a 15-h.p. motor which drives a line shaft. The line shaft in turn drives the drums through a floating chain which engages with teeth on the outer periphery of the drum. Provision is made for the independent operation of each drum.

Glazing and Seasoning Room

In the glazing and seasoning room, the skins are oiled, dried, staked, seasoned, and glazed. The oiling machines are group driven by a 5-h.p. motor.

The drying operation which was formerly accomplished by storing the skins in a steam heated loft, requiring from 24 to 36 hours, depending somewhat upon atmospheric conditions, is now done in a continuous drying machine, driven by two motors, one rated 15 h.p. and the other 40 h.p. The heat for the drier is supplied by steam from the power house conducted through steam coils in the drier and is controlled thermostatically. It requires approximately three hours for a wet skin to become thoroughly dried by this process.

The staking machines are group driven from a line shaft to which is connected a 15-h.p. motor. There are 33 such machines in all, arranged in groups of 11 each.

The glazing jacks are group driven by a 10-h.p. motor. Each group consists of ten jacks, there being six groups in all.

Measuring and Sorting Room

With the exception of the measuring machines, the labor in this room is manual since the sorting is best performed by hand. The measuring machines, eight in number, are belt-driven from a line shaft to which is connected a 2-h.p. motor. These machines will later be arranged for individual motor drive, each machine requiring a ¼-h.p. motor.

Results of Electrification

The Ruby plant has now been electrically operated for ten months, but since operating statistics are being compiled on an annual basis it is still too early to present figures covering the operation of the entire plant for such a period.

There is, however, a sharp line of demarcation between several of the manufacturing steps and it has been possible to determine accurately what the intelligent utilization of the electric motor has accomplished. In the new lime yard, for instance, statistics available at the end of nine months clearly indicate a saving of two-thirds the cost of the manually operated yard. In the shaving operation, with the same equipment, production has been increased 100 per cent. Moreover, the constant speed at which the shaving machines are now driven has resulted in a tremendous decrease in spoilage. The motor-driven continuous drier accomplishes in four hours the work for which the old steam-heated loft required two or three days.

That the results at the Ruby plant have exceeded expectations is best attested by the fact that the officials of the John R. Evans Co. some months ago decided to electrify their other plants: Peerless Leather and Jersey Kid. This work is now under way and is rapidly being pushed to completion.

Water Power Resources of Montana

By H. H. Cochrane

Chief Engineer, The Montana Power Company

With her many developed and undeveloped natural resources Montana is fortunate in having such a wealth of water power. Montana uses more power per capita than any other state in the Union and the author shows how great are the possibilities for future hydro-electric power developments.—Editor.

The main range of the Rocky Mountains cuts across the western part of Montana, forming the Continental Divide, and gives the state two principal watersheds. The eastern slope is drained by the Missouri River and its tributary, the Yellowstone; the western slope by the Clark's Fork and Kootenai rivers, which combine to form the Columbia. Although the western watershed comprises only about 15 per cent of the area of the state, yet the runoff from this 15 per cent is greater than from the remaining 85 per cent. In fact, the Clark's Fork is the largest river in the state, followed in order by the Missouri, Kootenai and Yellowstone.

The most important developments which have been made up to the present time are those on the Missouri River, including the Madison, its principal tributary. This is clearly indicated in the following list of developed water powers.

DEVELOPED WATER POWERS IN MONTANA

Name	River	Kilowatts
Madison	Madison	12,000
Big Hole	Big Hole	3,000
Canyon Ferry	Missouri	7,500
Hauser Lake	Missouri	18,000
Holter	Missouri	40,000
Black Eagle	Missouri	3,000
Rainbow	Missouri	35,000
Volta	Missouri	60,000
Livingston	Yellowstone	1,500
Billings	Yellowstone	1,000
Thompson Falls	Clark's Fork	30,000
Bonner	Missoula	2,400
Big Fork	Swan	1,600
Flint Creek	Flint Creek	1,200
Total		216,200

There is one important development on the Clark's Fork. This is at the town of Thompson Falls from which the plant takes its name. This plant, together with those on the Madison and Missouri rivers, are tied together with a high voltage network and form the system of The Montana Power Company.

Various estimates have been made, from time to time, by Government officials and others, of the total undeveloped water power of the state, some estimates running into millions of kilowatts. A very good summing up of possibilities was made by E. W. Kramer, Hydro-electric Engineer, United States Forest Service, in the *Electrical World* of July 16, 1921.

Estimates based on total river flow and total fall within any given region naturally lead to very large figures of possible power. Such figures are liable to be misleading, due to the fact that only in rare instances can the entire fall of a river be economically utilized. To develop head with a dam requires a reasonably narrow channel and high banks. To develop it with a pipe line or other conduit requires a river slope of about 50 feet or more to the mile. Where neither of these conditions exist a development will ordinarily be uneconomical. There are other things which may spoil an otherwise good power site, such, for example, as the existence of a town or railroad which would be flooded by back water from the dam.

The present estimate of possible power developments is therefore limited to really good sites which may be reasonably developed as soon as there is a market for the power.

The Mystic Lake site, on the West Rosebud River, is of importance on account of its location, being well toward the eastern part of the state, where the country is mostly flat and good power sites are scarce. Preliminary development work is now being done by The Montana Power Company on this site, with the idea of amplifying the amount of power available in the eastern end of its transmission system. The development will utilize a head of 1100 feet, which will be the highest head yet developed in Montana.

The Big Horn Canyon site is also in eastern Montana and apparently offers an opportunity to develop a large amount of power economically. The canyon is deep, narrow and long, and power can be developed either in small units with a number of low dams or in larger units with high dams. The total available head is about 450 feet, which must all be developed by dams.

The Madison No. 3 site is located at the lower end of the Lower Madison Canyon, about four miles from the present Madison No. 2 plant of The Montana Power Company; 175 feet head is available, which can probably be developed most advantageously by means of a low dam and tunnel. The Giant Spring, Great Falls and Sheep Creek sites on the

Fig. 1. Hauser Lake Development of the Montana Power Company, on Missouri River, 18,000 kw., 65-ft. head

UNDEVELOPED WATER POWER SITES IN MONTANA

Name	River	Kilowatts
Mystic Lake	West Rosebud	10,000
Stillwater No. 1	Stillwater	5,000
Yankee Jim Canyon	Yellowstone	5,000
Buffalo Rapids	Yellowstone	5,000
Big Horn Canyon	Big Horn	75,000
Madison No. 3	Madison	20,000
Black Eagle	Missouri	10,000
Giant Spring	Missouri	10,000
Great Falls C	Missouri	28,000
Sheep Creek	Missouri	28,000
Missouri No. 8	Missouri	50,000
Missouri No. 9	Missouri	50,000
North Fork	Flathead	25,000
Coram	Flathead	9,000
Polson	Flathead	100,000
Flathead No. 2	Flathead	50,000
Fish Creek	Missoula	13,000
Donlan	Clark's Fork	40,000
Rock Island	Clark's Fork	50,000
Cabinet Gorge	Clark's Fork	65,000
Kootenai Falls	Kootenai	15,000
Total		663,000

Fig. 2. Holter Plant of the Montana Power Company, on Missouri River, 40,000 kw., 105-ft. head

Fig. 3. Dam at Thompson Falls, on the Clark's Fork River

Fig. 4. The Montana Power Company's Dam on Yellowstone River, at Billings

Fig. 5. Volta Plant of Great Falls Power Company, at Great Falls, 60,000 kw., 150-ft. head

Missouri River are all near Great Falls, and will complete a series of possible developments at Great Falls, six in number, of which three, having a total capacity of 98,000 kilowatts, have already been developed. These additional developments will all be made very simple, with the dam and power house built practically as one unit.

The largest single power site in the state is at Polson, on the Flathead River, just below the outlet of Flathead Lake. There is available a head of 186 feet, and with the storage made available by the lake, a flow of about 8000 second-feet can be depended upon. With the exception of the Great Lakes, Flathead Lake is the largest body of fresh water in the United States, and forms a very remarkable natural storage reservoir.

The development of the Polson site will result in increasing the minimum flow of the Flathead River, and will thereby increase the value of all the power sites on the Flathead below Polson, as well as the sites on the Clark's Fork, of which the Flathead River is the principal tributary. The estimated capacities of the so-called Flathead No. 2 site and the three sites listed on the Clark's Fork are based on the river flow which will be available after the Polson site has been developed as, in the natural order of things, Polson will doubtless be developed before anything is done on the lower sites.

In the development of water power, reservoir capacity is a very important matter. A large storage capacity on a stream makes the operation of plants largely independent of the variations caused by nature in the flow of the average river. At the head of the Madison and Missouri rivers, The Montana Power Company has provided, by means of the Hebgen Dam, a storage of 340,000 acre feet. This dam backs the water of the Madison River up to the border of Yellowstone Park and forms a lake having a shore line sixty-five miles long. This storage is available for use at present in seven plants, operating in series on the Madison and Missouri rivers, each plant having a small local storage reservoir of its own, the aggregate capacity of which, together with Hebgen Reservoir, being sufficient to more than double the minimum flow of the Missouri at Great Falls. Each additional site developed in this series will add its local storage to the present total and thereby increase the capacity of all the sites below the one developed.

Fig. 6. Thompson Falls Power House and Tailrace of Thompson Falls Power Company, 30,000 kw., 55-ft. head

On the Flathead and Clark's Fork the same condition will exist to even a greater extent on account of the even greater storage capacity of the Flathead Lake.

In conclusion, it may be said that the power resources of Montana are sufficient to supply all probable requirements for a long time to come. There are no developments with enormously high heads and no developments which have to handle enormous quantities of water. The sites are so located with reference to present and probable future markets that no unusually long transmissions will be required. The present system of developments is dependable, well-balanced and easy to operate. As new developments are added and the system grows, these conditions will still obtain.

Montana is rich in natural resources and uses more power per capita than any other state in the Union, and the amount of economical water power still available is sufficient to allow in the future a very large industrial growth.

Present Status of High Voltage Transmission of Power

PART I

By W. W. Lewis

Lighting Department, General Electric Company

This general review of the present status of high-voltage power transmission will, we believe, be appreciated by a large number of our readers. The author goes into considerable detail where necessary. He discusses line insulation, corona, grounded neutral, protection, and charging the line in this installment and in the next will treat of synchronous condensers, the characteristics of long lines, transformers, oil circuit breakers and bushings.—Editor.

The purpose of this article is to discuss the present status of high voltage transmission, with especial reference to practice in America, with which the author is most familiar.

Present Limit of Transmission Voltage

In Table I is a list of the principal transmission systems and their normal system or circuit voltages including those of 66,000 volts and above. The "normal voltage" is defined as the highest rated secondary voltage of the step-up transformers supplying the system. It is now the practice to insulate all apparatus for the normal voltage, even though the apparatus is to be applied on a part of the system which ordinarily operates below the normal voltage. This is logical because at times of light load or no load, the apparatus at the end of the line may be subjected to a voltage even higher than normal.

It will be noted that there are thirty separate voltages represented in this list, some not differing very much from one another. It is obviously a hardship on the manufacturer to be compelled to develop lines of apparatus for all these voltages, and of course the cost of so doing must be borne by the electrical industry and ultimately by the public. It has happened usually that a voltage was selected strictly with regard to local conditions, whereas the nearest standard voltage would have been equally suitable and had it been adopted, fully developed and standardized apparatus would have been available.

In order to reduce the burden on the industry, simplify the practice, encourage the development of standard apparatus and facilitate interconnection of systems, the following voltages have been adopted as standard by organizations representing the power industry and the manufacturer:

33,000, 44,000, 66,000, 88,000, 110,000, 132,000, 154,000, 220,000 volts.

Above 44,000 volts, it will be noted, there are now six standard voltages as contrasted with the thirty voltages shown in Table I, and it is believed that these six steps will fit all the usual requirements of present day operation.

For a number of years 150,000 volts has represented the highest transmission voltage in commercial use. Apparatus has now been built for 154,000, 165,000 and 220,000 volts, but has not yet been placed in regular operation.

The Great Western Power Company will operate their new Caribou system for the present at 110,000 volts by auto-transformer connection, and go to 165,000 volts when the receiving station is finished. The Southern California Edison Company are converting their present 150,000-volt lines from Big Creek for 220,000-volt operation. A portion of one line has been operated experimentally at 280,000 and 240,000 volts. The Pacific Gas & Electric Company are building a transmission line and installing apparatus for transmitting at 220,000 volts. Operation will be commenced at 165,000 volts by auto-transformer connection and be extended to 220,000 volts when the load demands.

Other 220,000 to 250,000-volt systems have been proposed by the Lehigh Electric and Navigation Company, the New England Power Company and the Superpower System in the United States, the Hydroelectric Power Commission of Ontario, Canada, the Government of Sweden and the Government of Argentine. Thus it will be seen that the old limit of 150,000 volts has been definitely left behind and that 250,000 volts is the present prospective limit. It is probable that such extremely high voltages will pay only where there are large amounts of power available for transmission and where the demand extends over the greater part of the day. Under any other conditions the cost per kilowatt-hour would be prohibitive.

TABLE I

PRINCIPAL SYSTEMS AND THEIR "NORMAL SYSTEM OR CIRCUIT VOLTAGES" 66,000 VOLTS AND ABOVE

These "Normal System or Circuit Voltages" are on the basis of the highest rated *Secondary* Voltage of Transformers supplying these systems or circuits

No.	Normal System or Circuit Voltage	Altitude of Stations in Feet	Frequency in Cycles per Sec.	Neutral Ground	Operating Company	Beginning of Operation
1	66000	4000-6000	60		Montana Power Co.	
2	66000				Parr Shoals Pr. Co.—S. Carolina	
3	66000	600-1000	60		Central Pr. Co.—Ohio	
4	66000	600-1000	60		Central Pr. Co.—Wellsburgh, W. Va.	
5	66000	350- 950	60		Columbus Pr. Co.—Georgia	
6	66000				Indiana General Service Co.	
7	66000	1200	60	Dir.	San Joaquin Lt. & Pr. Co.—Calif.	
8	66000	350	60		Central Georgia Pr. Co.	
9	66000	100- 250	60	Dir.	Turners Fall Pr. & Elec. Co.	
10	66000	500	60		Keene Gas & Elec. Co.—N. H.	
11	66000		60		Pacific Pr. & Lt. Co.—Oregon	
12	66000		60		Tennessee Pr. Company	
13	66000	100	60		Eastern Connecticut Pr. Co.	
14	66000	100	60	Dir.	Connecticut Lt. & Pr. Co.	
15	66000	200	60		Connecticut Power Co.	
16	66000	200	60		Fall River Elec. Lt. Co.	
17	66000	500	60		Narragansett Elec. Lt. Co.	
18	66000	850	60		Wisconsin-Minnesota Lt. & Pr. Co.	
19	66000	1200	25-60	No	Great Northern Pr. Co.—Minnesota	
20	66000				American Falls Pr. Co.—Idaho	
22	66000		60		New Hampshire Water & Elec. Lt. Co.	
23	66000		60		Northwestern Elec. Co.—Oregon	
24	66000		60		North Coast Pr. Co.—Oregon	
25	66000				Wisconsin Pr. & Lt. Co.	
26	66000		60		Idaho Pr. Co.	
27	66000		60		San Diego Gas & Elec. Co.	
28	66000		25		N. Y., N. H. & H. R. R.	
29	66000		60		Duquesne Lt. Co.	
30	66000				Wisconsin River Pr. Co.	
31	66000				Steubenville & E. Liverpool Rwys. Co.	
32	66000				Monongahela Valley Traction Co.	
33	66000				Philadelphia Electric Co.	
34	67560		60		Braden Copper Co.	
35	69000				Albany & Southern Railroad	
36	69000				Kingston Gas & Elec. Co.	
37	69000				Central Rudson Gas & Elec. Co.	
38	70000	100	50	Res.	Royal Water Falls Adm. Alfkarleby Development—Sweden	1915
39	70000	1000-2000	25	No	Loussavaarda Kirunvaara Aktiebalag—Sweden	
40	70000	1000-2000	25	No	Swedish State Rwys. Projus Dev.	1914
41	70000	1000-3000	50	No	Guadalajara—Mexico	1911
42	70000	0- 500	25	Res.	Penn Water & Pr. Co.	1910
43	70000	0-1000	50	Res.	Societa Electrica Rivera Di Ponente—Spain	1911
44	70000	0-1000	50	No	Hydroelectrica Espanola Molinar—Spain	1910
45	72000		60		Peninsular Pr. Co.	
46	72000	600	30		Consumers Pr. Co.	1906
47	72000		60		City of Winnipeg	1911
48	72000	500-2000	42	No	Societa Generale Electrica Del 'Adamella—Italy	1910
49	72000	500-1000	42	Res.	City of Milan—Italy	1910
50	72000	0- 500	60	Dir.	New England Power Co.	1909
51	72000	200	50	Dir.	So. Cal. Ed. Co. (Los Angeles Dist.)	1905
52	75000	2700	50-60	Dir.	So. Cal. Ed. Co. (Kern River 3 Dev.)	1921
53	75000	2700	50-60	Dir.	So. Cal. Ed. Co. (Kern River 1 Dev.)	1907
54	76200	600	25		Milwaukee Elec. Rwy. & Lt. Co.	1909

Dir. = Direct. Res. = Resistance.

TABLE I—Continued

No.	Normal System or Circuit Voltage	Altitude of Stations in Feet	Frequency in Cycles per Sec.	Neutral Ground	Operating Company	Beginning of Operation
55	77000				Monviso Calcinere—Italy	
56	77000		60		Nagoya Elec. Lt. Co.—Japan	
57	77000	0-1000	50	Res.	Katsuragawa Hydro-Elec. Co.—Japan	1912
58	77000	Below 4000	60	Res.	Kiso Denki Kogyo K.K.—Japan (Daido Denryoku)	
59	80000	3100	25	No	Govt. of Mysore—India	1921
60	80000	1000-2000	15	Res.	Swedish State Rwys. Projus Dev.	1915
61	80000		60		St. Lawrence Trans. Co.	1915
62	80000	300	60	No	Northern Pr. Co. (N. Y.)	
63	80000	300	60	No	Hannawa Falls Pr. Co.	
64	80000	300	60	No	Racquette River Paper Co.	
65	80000		60		Ogdensburgh Paper Mills, Inc.	
66	80000		60		Remington Paper Co.	
67	80000		60		De Grasse Paper Co.	
68	85000	2250-10000	50	Dir.	Mexican Lt. & Pr. Co.	1910
69	86500	300- 750	25	No	Toronto Pr. Co.	1914
70	87000	1000-4500	60	No	Southern Sierras Pr. Co.	1915
71	88000	1000	50	Res.	Victoria Falls & Transvaal Pr. Co.—South Africa	1913
72	88000		50	Dir.	Tasmania Hydro-Elect. & Metal Co.	
73	88000	2180	60	No	Cia. Paulista de Estradas de Ferro—Brazil (Paulista Rwys)	1921
74	88000	0-1000	60	No	Sao Paulo Elec. Co.—Brazil	1914
75	88000	0-1000	50	No	Rio Janeiro T. L. & Pr. Co.—Brazil	1913
76	88000	1000-2500	60	No	Appalachian Power Co.	1912
77	88000	0- 500	42	No	Societa Italiana di Elettrochimica—Italy	1912
78	88000	1000-2500	60	Dir.	Ky. & W. Va. Pr. Co.	1920
79	88000	1000-2500	60	No	Lynchburg Trac. Co.	1920
80	90000	0-1000	50	No	Energia Electrica De Cataluna—Spain	1914
81	100000	100	25	Res.	City of Stockholm Electricity Works—Sweden, Untra Development	1917
82	100000	2750-7500	60	Dir.	Pueblo Tramways Lt. & Pr.—Mexico	
83	100000	100- 300	60	Dir.	Shawenegan Water & Pr. Co.	1912
84	100000	0-1000	50	No	Tata Hydro Elec. Pr. Co.—India	1914
85	100000	0-1000	50	Dir.	Andhra Val. Elec. Pr. Supply Co.—India	1921
86	100000	5000-10500	60	No	Colorado Power Co.	1909
87	100000	0- 500	60	No	Great Western Power Co.	1909
88	102000	4000-6000	50	Dir.	Montana Pr. Co.	1910
89	102000	3300-5500	60	Dir.	Great Falls Pr. Co.	
90	102000	3300-5500	60	Dir.	Anaconda Copper Mining Co.	
91	102000	4000-6000	60	Dir.	Thompson Falls Pr. Co.	
92	102000	5000	60	Dir.	C. M. & St. P. R. R. (Eastern Electrification)	1915
93	103900	100- 400	60	Dir.	Yadkin River Pr. Co.	1912
94	103900	100- 500	60	Dir.	Carolina Pr. & Lt. Co.	
95	103900	100- 400	60	Dir.	Palmetto Pr. & Lt. Co.	
96	104000	0-2000	60	Dir.	Sierra & San Francisco Pr. Co. (Oper. by P. G. & E. Co.)	1916
97	104000	4000-6000	60	No	Truckee River G. E. Co.	
98	110000	200-2100	50	Dir.	City of Los Angeles	1914
99	110000	400- 850	60	Dir.	Southern Power Co.	1909
100	110000	0-4000	60	Dir.	C. M. & St. P. R. R. (Western Elec.)	1920
101	110000	0- 600	60	Dir.	Puget Sound T. Lt. & Pr. Co.	1920
102	110000	2000-4000	60	Dir.	Washington Water Pr. Co.	1920
103	110000	0- 500	60	Dir.	New England Pr. Co.	Not Yet
104	110000	0-9000	50	Dir.	Chile Exploration Co.	1915
105	110000	0-4000	50	Dir.	Compania Nacional De Fuerza—Chile	
106	110000	0-6000	50	Dir.	Chilian El. Tram. Lt. & Pr. Co.	
107	110000	0-3000	50	Dir.	Ebro Irrigation & Pr. Co.—Spain	1914
108	110000	5500	60		Cia. Agricolo y Fuerza Electrico del Rio Conchas—Mexico	
109	110000	2000-3000	60	Res.	Mexican Northern Pr. Co.	1914
110	110000	0- 100	60	Dir.	Virginia Rwy. & Pr. Co.	1919

Dir. = Direct. Res. = Resistance.

TABLE I—Continued

No.	Normal System or Circuit Voltage	Altitude of Stations in Feet	Frequency in Cycles per Sec.	Neutral Ground	Operating Company	Beginning of Operation
111	110000	300	60	No	Aluminum Co. of Amer. (Massena Development)	1914
112	110000	300	60	No	Cedar Rapids Mfg. & Pr. Co.	1914
113	110000	1000	25	Res.	Lehigh Navigation Elec. Co.	1914
114	110000	500	25	Dir.	Union Elect. Lt. & Pr. Co. St. Louis	1913
115	110000	460- 530	25	Dir.	Mississippi River Pr. Co.	1913
116	110000	500- 600	60	Dir.	Air Nitrates Corp.—Govt. Plant No. 2	1918
117	110000	200- 800	60	Dir.	Alabama Power Company	1913
118	110000	600-1600	60	Res.	Georgia Rwy. & Pr. Co.	1912
119	110000	500	50	No.	Lauchhammer A. G.—Germany	1911
120	110000	600	25	Res.	Hamilton Hydro Elec. System	1910
121	110000	600	25	Res.	Hydro Elect. Pr. Comm. of Ontario	1910
122	115000	0-2500	50	No	Inawashiro Hydro Elec. Pr. Co.	1914
123	115000	350- 900	60	No	Columbus Pr. Co.	1913
124	120000	500	60	Dir.	Minneapolis G. E. Co.	1917
125	120000	800	60	Dir.	Wis.-Minn. Lt. & Pr. Co.	1917
126	120000	800	60		Northern States Power Co.	1917
127	120000	500- 900	60	No	Tennessee Power Co.	1914
128	120000	500- 900	60	No	Chattanooga & Tennessee River Power Co.	1914
129	120000	500- 900	60	No	Knoxville Rwy. & Lt. Co.	1921
130	120000	600-1000	60		West Penn Power Co.	
131	120000	100	50	Petersen Reactor	Royal Water Falls Adm. Trollhatten, Sweden (Westeras Tie Line)	1922
132	120000	Below 4000	50	Dir.	Basse Isere—France	
133	120000	3300	50	Dir.	Compagnie des Chemins de Fer du Midi —France	
134	125000	0-4500	60	Dir.	Pacific Gas & Electric Co.	1920
135	127000	665	60	Dir.	San Joaquin Lt. & Pr. Corp.	1920
136	130000	4000-6000	60	Dir.	Utah Pr. & Lt. Co.	1914
137	130000	0-3000	50	Petersen Reactor	Catalana de Gas y Electricidad Cia—Spain	
138	130000	0-2000	50	Dir.	Sociedad Anonima Electra del Lima —Portugal	
139	132000	2000	50	Dir.	Hidroelectrica Espagnola Salto dos Aguas Rio Jugas—Spain	
140	132000	0-3000	50	Dir.	Soc. Anonima Hydro. Iberica—Spain	
141	132000	600	25	Res.	Hydro-Elec. Pr. Com. Ont. (Queenston Development)	1923
142	132000	Below 4000	50	Dir.	Victorian Electricity Comm., Melbourne —Australia	1922
143	132000	600-1000	60	Dir.	Amer. Gas & Electric Co.	1917
144	132000	600-1000	60	Dir.	Northern Ohio Pr. & Lt. Co.	
145	132000	600-1000	60	Dir.	Ohio Power Co.	
146	132000	600-1000	60	Dir.	West Penn Power Co.	
147	140000	5000	60	No	Nevada-Calif. Pr. Co.	Not Yet
148	140000	750	30 60	No	Consumers Power Co.	1918 1912
149	150000	1000-4500	60	No	Southern Sierras Power Co.	Not Yet
150	150000	0-5000	50	Dir.	Southern Calif. Edison Co.	1913
151	150000	1000	60	Dir.	Aluminum Co. of America (Tallassee Development)	1919
152	154000	Below 4000	60	Res.	Taiwan Denryoku K K.—Formosa	1924
153	154000	Below 4000	50	Res.	Shinyetsu Denryoku K. K.—Japan	1922
154	154000	Below 5000	50	Res.	Keihin Denryoku K.K.—Japan	1922
155	154000		50	Res.	Tokyo Elec. Lt. Co.—Japan	1922
156	154000	Below 4000	60	Res.	Nippon Elec. Pr. Co.—Japan	1922
157	154000	Below 4000	60	Res.	Daido Denryoku—Japan	1922
158	165000	0-3000	60	Dir.	Great Western Power Co.	1922
159	220000	0-5000	50	Dir.	Southern Calif. Edison Co.	1922
160	220000	0-4500	60	Dir.	Pacific Gas & Electric Co.	1923

Dir. = Direct. Res. = Resistance.

Fig. 1 shows the increase in transmission voltage from 1888 to 1922, as indicated by the orders received by the General Electric Company for transformers. The beginning of operation naturally lags one or two years behind the dates given.

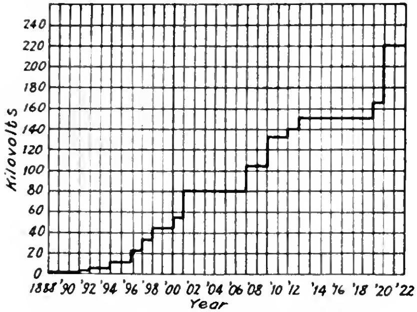


Fig. 1. Maximum Transmission Potentials 1888 to 1922, as Indicated by Transformer Orders Received

Line Insulation

The standard high voltage line insulation is the disk suspension insulator of either the cemented cap or Hewlett type. A limitation in the use of such insulators has arisen due to the unequal manner in which the voltage distributes across the various insulators in the string. Thus for a string of 10 disks, the first disk at the line end takes about 35 per cent of the voltage, while some of the intermediate units take less than 5 per cent of the voltage. In fact on strings of five units or over the insulator next to the line always takes about 30 per cent of the total voltage. This unequal distribution of voltage is caused by the capacitance of the insulator hardware to ground. Such capacitance must be charged through the capacitance of the insulator disks. This is illustrated in Fig. 2. The first disk takes the charging current for all the capacitances to ground, the second disk for all but one, etc., the result being an unequal charging current through the various disks and an unequal distribution of potential across them. One remedy for this condition is to vary the capacitances of the various disks in proportion to the charging current by increasing the size of the disks or by metal caps placed on the upper and lower surfaces of the disks. Another method of remedying the condition is to place alongside the string an antenna charged from the line end. In practice this is done by surrounding the string with a shielding ring at the line end (see Fig. 3). This in effect neutralizes or eliminates the capacitance to ground. Fig. 4 shows diagrammatically the first method and its result and Fig. 5 the second method and its result. Figs. 6 and 7 give the voltage distribution for two strings of insulators graded by the two methods.*

Thus the insulator string of the Southern California Edison Company, which at present operates at 150,000 volts or 87,000 volts to ground, has about 25,000 volts across the first disk. With the grading ring and the system operating at 220,000 volts or 127,000 to ground, the first disk now gets about 14,000 volts. That is, with an increase in voltage of 47 per cent, the strain across the first disk has decreased about 44 per cent.

The grading ring does not appreciably increase the arc over voltage of the string, but it equalizes the stress across the individual disks, eliminates corona and acts as an arcing horn, throwing the arc away from the disks and decreasing the danger of damage due to this cause. The Hewlett insulator, on account of its small amount of hardware, does not have such an uneven distribution of voltage as the cemented cap type, and conversely the grading ring is not so effective in equalizing the potential distribution. During a rain the voltage distribution over a string is more or less automatically graded by the water dripping over the disks, and the grading ring is not essential except as an arcing ring.

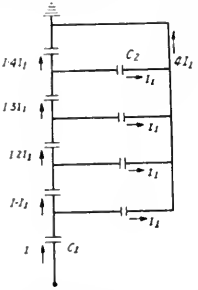


Fig. 2. Illustrating Cause of Uneven Voltage Distribution on Insulator String. The capacitance to ground C_1 causes an uneven distribution of current through insulator capacitance C_1 and consequently an uneven voltage distribution

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* Transmission-line Insulation in America, F. W. Peek, Jr., *Electrical World*, Dec. 4, 1920.

Corona

Aside from insulation, corona is the most important electrical feature of the transmission line.

Corona is calculated by the well-known formula of Peek:

$$p = a\ (f+25)\ (e-e_0)^2 \times 10^{-5} \text{ kw. per mile of single conductor} \quad (1)$$

It has been found in tests on transmission lines by the writer and others that this law is followed very closely above e_v, the visual critical voltage, but not so well below e_v. For small conductors, in general, the loss is less than calculated and for large conductors it is equal to or greater than calculated. This is due mainly to irregularities in the conductors, which have less relative effect on the larger conductors, and even on the smaller conductors are smoothed out at the higher voltages by the corona itself.

Fig. 3. Suspension Insulator String with Antenna or Shielding Ring of the Peek Type for Equalizing the Voltage

The disruptive critical voltage e_0 in formula (1) is found by the following formula:

$$e_0 = 2.303\ g_0\ m_0\ \delta\ r\ \log_{10}\ (s/r) \text{ effective kv. to neutral} \quad (2)$$

In this formula m_0 is a factor to take care of the irregularity of the conductors. Peek gives this factor as 1.0 for polished wires, 0.98 to 0.93 for roughened or weathered wires and 0.87 to 0.83 for seven-strand cable. Mr. Peek is now engaged in further investigation of this factor and although it is too early to draw conclusions, it may be said that he has found values of m_0 varying from 0.7 to 0.9 for new cables depending on the number of strands and the manner of stranding. Certain methods of stranding may be used which increase the diameter of the cable, but may decrease m_0. Thus part of the benefit of the increased diameter may be lost. The main strands are sometimes composed of smaller strands for purposes of flexibility, but these may decrease m_0 on account of local roughness.

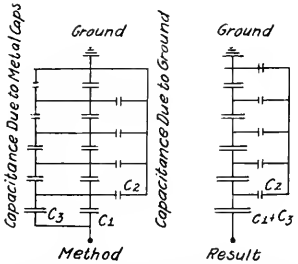

Fig. 4. Grading by Increasing Capacitance C_1 in Proportion to Current Distribution. This may be done by using varying sizes of disks and hardware or by metal caps on the disks, or by a combination of both methods

In some tests made by Mr. Peek at Pittsfield, recently, he checked the corona law up to 1,000,000 volts and found that the law held as well as at the lower voltages. A tubular conductor 5 inches in diameter was necessary in order to have no loss at 1000 kv. under dry conditions, and about 6.5 inches in diameter in order to have only a small loss during storm conditions. Spark-over tests made on sphere gaps, needle gaps

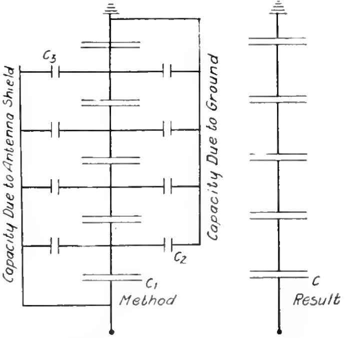

Fig. 5. Shielding by Means of Antenna, Thereby Eliminating the Effect of Capacitance to Ground

and suspension insulators also checked closely the calculated values.

A couple of years ago the writer discovered that on a grounded neutral system corona produced a triple frequency current which passed between conductors and ground and back through the grounded neutral.* This current increased with the voltage, until at 200 kv. on the particular lines under test it amounted to about 40 per cent of the line charging current (see Fig. 8). If the neutral was grounded at both ends of the line, the triple frequency current divided about equally between the two grounded neutrals (Fig. 9). If the neutral at one end was not grounded, a triple frequency voltage appeared between neutral and ground at that end. A comparison of losses showed that the loss with grounded neutral was somewhat greater than with isolated neutral (Figs. 8 and 9) also that the curve of measured losses for grounded neutral deviated from the curve somewhat more than for isolated neutral (see Figs. 10 and 11). This was no doubt due to the effect of the triple frequency current and voltage. There was also a marked difference in the shape of the curve of current, which is a combination of line charging current and transformer exciting current. That for the grounded neutral had a decided upward trend while that for the isolated neutral dropped over at the higher voltages (Figs. 8 and 9). This latter effect was probably

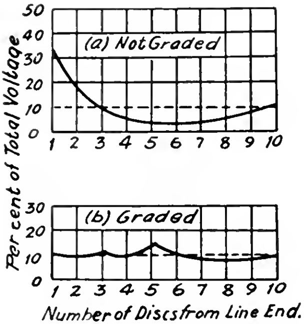

Fig. 6. Distribution of Voltage Over String of 10 Insulator Disks

(a) Not graded; (b) Graded by means of metal caps placed on insulator disks. Dotted line shows even distribution of voltage.

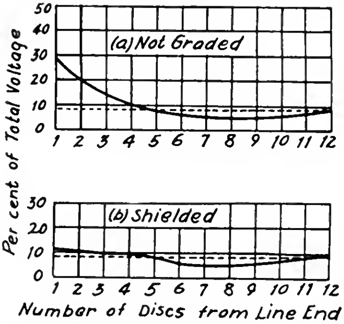

Fig. 7. Distribution of Voltage Over String of 12 Insulator Disks

(a) Not graded; (b) Shielded by antenna or shielding ring. Dotted line shows even distribution of voltage.

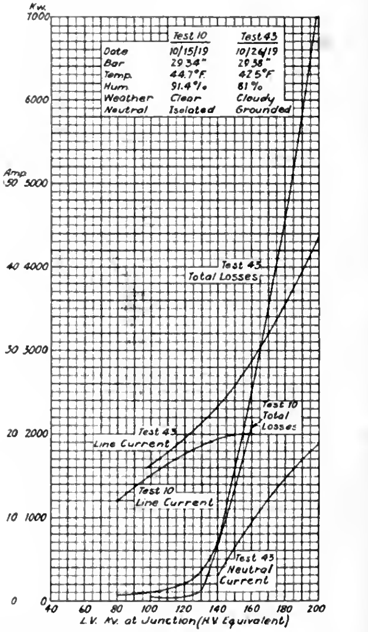

Fig. 8. Comparison of Corona Loss, Isolated Neutral (Test 10) and Grounded Neutral (Test 43). Line from Junction to Grand Rapids. No transformers at Grand Rapids. System of Consumers' Power Company

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*Some Transmission-line Tests, W. W. Lewis, *Journal A.I.E.E.*, June, 1921.

a result of the flattening of voltage by the triple frequency component which in turn peaks the flux wave. This causes an increase in the transformer exciting current, which is lagging, and consequently a decrease in the total current, which is a combination of lagging current and leading line charging current.

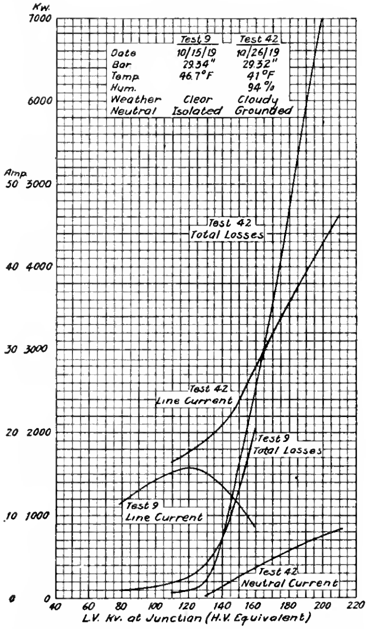

Fig. 9. Comparison of Corona Loss, Isolated Neutral (Test 9) and Grounded Neutral (Test 42). Line from Junction to Grand Rapids. Transformers connected at Grand Rapids and neutral grounded at both ends

Fig. 12 shows the manner in which the triple frequency current is formed by the corona. In this diagram (a) represents the line to neutral or leg voltage of one phase. In each half cycle the shaded portion represents the part of the wave during which corona is formed, or this might be called the corona voltage. In (b) the corona voltage is plotted and analyzed into a fundamental and triple harmonic. Fig. 12(c) shows the leg voltages of the three phases and in Fig. 12(d) are plotted the fundamental and triple harmonic components. It will be noted that the triple harmonic components are all in phase, adding up to give the dotted curve. This total triple frequency voltage exerted between line and ground causes a triple frequency current to flow to ground and back through the grounded neutral.

Now if the neutral is not grounded, current cannot flow. We may consider that this current is neutralized by an equal and opposite current, which is produced by a voltage equal in value to and opposite in phase from the original triple frequency voltage. Fig. 13(a) shows this voltage and how it combines with the fundamental to form a distorted flat-topped wave. Fig. 13(b) shows vectorially how leg voltages 1 and 2 combine to form line voltage 1-2, and in Fig. 13(c) the waves of voltage are combined. It will be noted that the fundamentals add up but the triple harmonics cancel, giving a line voltage of pure fundamental frequency. The triple frequency component, however, will appear between neutral and ground.

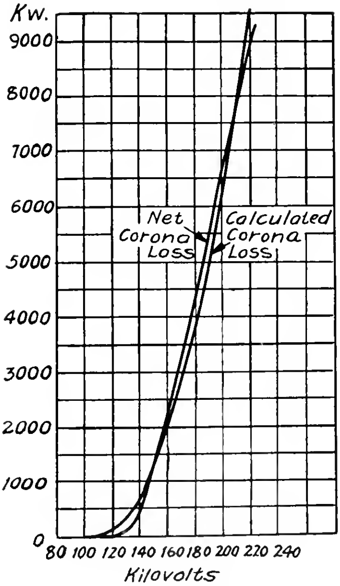

Fig. 10. Comparison of Calculated and Tested Corona Loss (Test 42), neutral grounded at both ends of line

The rise in voltage along the line and the line charging current were greater in these tests than calculated, probably due in part to the harmonics placed in the voltage by corona and in part to the apparent increase in diameter of the conductor due to corona with consequent increase in capacitance.

Grounded Neutral

Of the systems in Table I, the majority of which we have a record have the neutral grounded either directly or through resistance and by far the greater part of these are grounded directly. This is especially the case in America, where the isolated neutral has been tried and found unsatisfactory. As a consequence practically all new systems are going in with grounded neutral and many old systems are changing from isolated to grounded neutral.

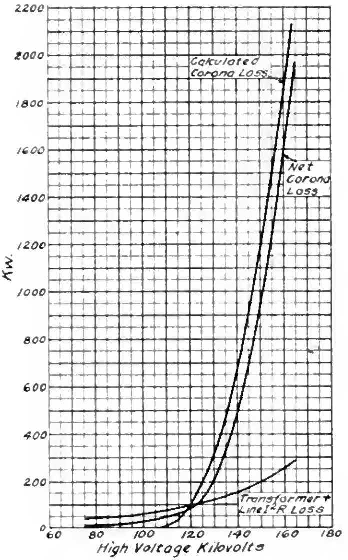

Fig 11. Comparison of Calculated and Tested Corona Loss (Test 10), neutral isolated at both ends of line

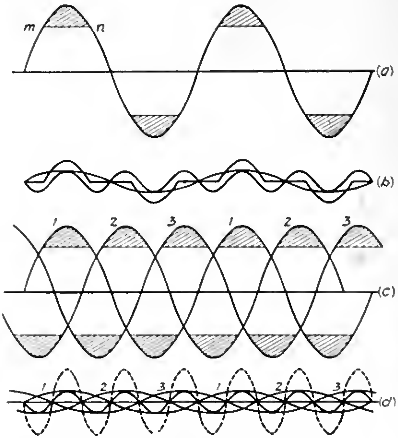

Fig. 12. Illustrating Manner of Formation of Triple Frequency Current due to Corona, Y-connected Grounded Neutral System

The chief argument in favor of the isolated neutral is the possiblity of continuing operation in case one line becomes grounded. That this has been done in some cases is unquestioned. Reports in general, however, indicate that this operation is not practicable on a line of high voltage or great length because of (a) the rise in voltage on the ungrounded lines causing danger of breakdown on these lines; (b) the increased charging current and corona due to the increased voltage of the two lines above ground, and (c) the telephone interference due to the unbalanced electrostatic conditions, which ex-

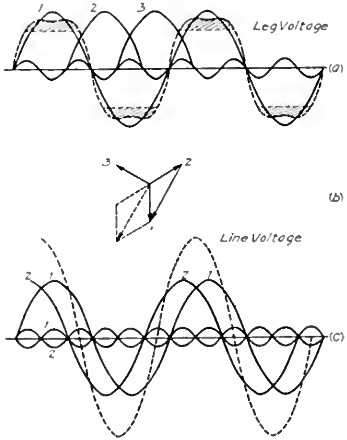

Fig. 13. Illustrating Distortion of Voltage from Neutral to Ground Due to Corona, Isolated Neutral System

perience has demonstrated makes it almost impossible to operate telephone lines in the vicinity of the power lines, especially the power company's own telephone system.

A ground on an isolated neutral system usually results in an arcing ground as the ground originally takes place by arcing over an insulator, the charging current of the line discharging into the ground. The combination here of capacitance, inductance and arc produces an arcing or oscillating ground, which is capable of setting-up very high over voltages on the ungrounded phases. Often this results in breakdowns on several feeders, either simultaneously or successively, and several switches may trip out on different parts of the system, in which case there is no definite manner of quickly selecting the faulty line to clear the cause of the trouble.

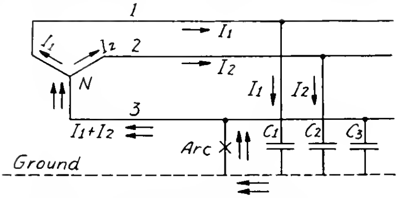

Fig. 14. Flow of Current with Ground on One Conductor of a Three-phase System, Neutral Not Grounded

In the case of a grounded neutral system, there will occur practically as many first cases of line failure, such as breakdown of insulators or other apparatus, but as soon as one phase becomes grounded there is a short circuit on one leg of the grounded neutral transformer and a reduction in voltage on all three phases due to armature reaction in the generators, which causes no over-voltage stress on any part of the system. In consequence, secondary breakdowns are almost unknown on a grounded neutral system. Most of the troubles on a grounded neutral system will be confined to one point and the current in the short circuit flows over definite and known paths, which makes it possible automatically to select the line in trouble and save the service on the remainder of the system. Selective action by relays, therefore, becomes more positive with this connection. For these reasons the grounded neutral system is finding more and more favor with operating companies.

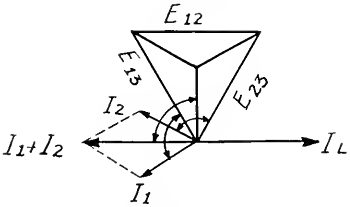

Fig. 16. Vector Relation of Currents in Circuit of Fig. 15, Angles Marked by Arrows=90°

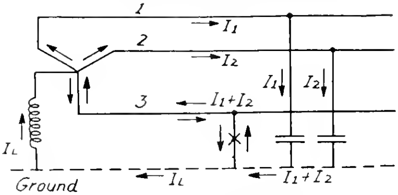

Fig. 15. Flow of Current with Ground on One Conductor, Neutral Grounded Through Reactor

Operation with grounded neutral lends itself most readily to networks where a section of line in trouble may be isolated without cutting off the service from the customers. On single circuit transmission systems it is not desirable to cut off the line every time a ground occurs and for this reason such systems are usually operated with isolated neutral.

Even here, however, the advantages of the isolated neutral are doubtful. Hanging on to a ground in order to avoid interruption to service frequently results in destruction of the insulator or a burned off conductor. This undoubtedly causes a more serious interruption than would be experienced if the line were pulled off at once and then put back into service immediately.

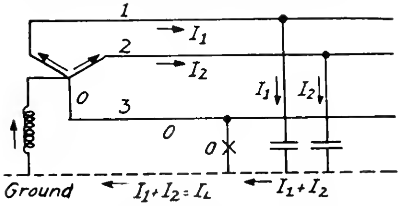

Fig. 17. Final Result When $I_L = I_1 + I_2$ in Circuit of Fig. 15

For the higher voltages there is considerable economy in building the transformers with the neutral connected directly to the core and only one high tension bushing. The high tension lead is brought to the center of the coil stack and progress is made through the winding in both directions to the ends of the windings, which are metallically connected to the core. No core supports are necessary and the bracing of the coils against short circuit is greatly assisted. Such a transformer is insulated for 2.73 times the leg voltage instead of 3.46 times, which is standard for transformers with isolated neutral. The reduced insulation as well as the smaller size permitted by omitting the coil supports results in an appreciable reduction in the price of such transformers. The 220,000-volt transformers built and on order for the Southern California Edison Company and the Pacific Gas & Electric Company are of the reduced insulation type. It is interesting to know that this transformer connection was patented by the General Electric Company in 1907, but it was not until the recent advent of very high voltages that it has found much use.

Grounding the neutral is done with a twofold purpose, namely, to reduce voltage stress and to produce more positive conditions for relay operation than possible on an isolated neutral system. If too high a resistance is used in the neutral, neither of these objects will be accomplished, and probably also telephone interference will not be eliminated. When there is an arc over an insulator, a charging current passes from the two ungrounded conductors and back through the arc, the current in the ungrounded conductors being increased to about 130 per cent of the normal charging current, and the current in the grounded conductor to about 200 per cent of normal charging current. These currents lead their respective voltages. Now sufficient current must pass through the grounded neutral and the arc to counter-balance the leading current and make it predominately lagging, in order to eliminate the danger of arcing grounds and permit the relays to operate. If sufficient current does not flow to accomplish this, then the circuit will not be cleared and the arc may be of the nature of an arcing

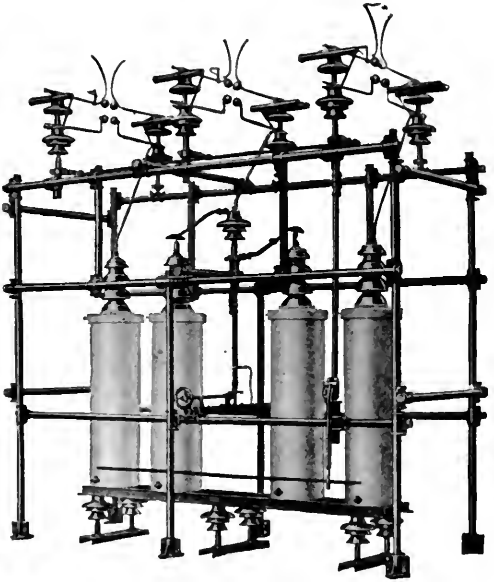

Fig. 18. Aluminum Cell Lightning Arrester

or oscillating ground, with consequent liability of damage to insulation and interference with communication circuits. Thus if the neutral resistance allows only 25 amperes to flow and the charging current in case of a line ground is 200 amperes, then the system is obviously in the class of an isolated neutral system.

It would seem that less trouble would be caused if sufficient current were permitted to pass through the neutral to permit positive and rapid relaying, and this is borne out by the operating experience of many power companies. A number of years' experience with isolated neutral proved conclusively that the extent and disastrous results of transmission line trouble was very largely due to arcing grounds on these systems. There is considerable evidence to show that the chief cause of permanent damage is due to the heat of the arc breaking the porcelain disks, but that a fair amount of time, say several seconds, is required for this damage to occur. It is not uncommon to have an arc occur over a string of insulators due to lightning or other cause, and when tripped off quickly, say in less than one second, to cause no physical damage whatever. The line trips out, is put back into service immediately and operation resumed. This of course is not possible with an isolated neutral system, as a secondary breakdown must occur to cause a short-circuit and in the meantime the original arc has been maintained a considerable length of time, and the system subjected to over-voltage strain.

Arcing ground suppressors have been developed and used to some extent on isolated neutral systems of 88,000 volts and lower. These are of the Creighton and Nicholson types, and operate on the principle that when a ground occurs on a conductor, a voltage unbalance is produced. This operates a potential relay, which in turn grounds the faulty conductor at the station either by means of an oil circuit breaker or a fuse. This drops the potential of the conductor to zero and the arc becomes extinguished.

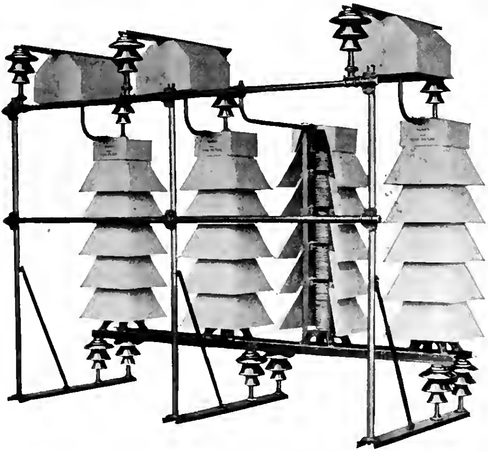

Fig. 19. Oxide Film Lightning Arrester

A new device called the Petersen Earth Coil* has been worked out and used to a considerable extent on European systems. This consists essentially of a reactor, which is placed between neutral and ground. It is so designed that a current passes through the reactor which is equal in value to, and opposite in phase from, the charging current passing through the arc. The current in the arc is thereby reduced to zero and the arc extinguished. Fig. 14 shows the flow of current in a circuit with a ground on one

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* See On the Grounding Reactor, by S. Bekku, *Journal Inst. Elec. Eng. of Japan*, February, 1922.

conductor and without neutral reactor. Fig. 15 shows the same circuit with neutral reactor and Fig. 16 gives the vector relation of the currents. The final result is shown in Fig. 17.

The writer had the pleasure of installing and testing one of these devices on a portion of the 44-kv. system of the Alabama Power Company. About 50 arc-over tests were made and the arcs were extinguished satisfactorily, even with settings of the reactor differing as much as 40 per cent from the value required for a true balance. The device has been in service since October, 1921, but the experience of the present lightning season must be awaited before definite conclusions may be drawn.

This device may find a certain application on systems which are now operating isolated neutral, and on which for some reason connected with the operation or apparatus, it is not wished to go to a solidly grounded neutral. From the writer's study of the device, he is of the opinion that its use will be limited for the present to comparatively low voltage lines of moderate length, that is, perhaps up to 66,000 volts, or in a few cases up to 100,000 volts if the length is short. The reason for this limitation is as follows: The current through the reactor is affected by the line reactance. In the case of a short line or low voltage line, this is comparatively small. For example, the Alabama line we have been considering has about 20 ohms reactance, which added to 982 ohms in the reactor, makes an insignificant change in the reactor current. On the other hand, a typical 154,000-volt line may require 200 ohms in the reactor and the reactance of the line itself may be 150 ohms. It is probable that the residual current in this case would maintain the arc.

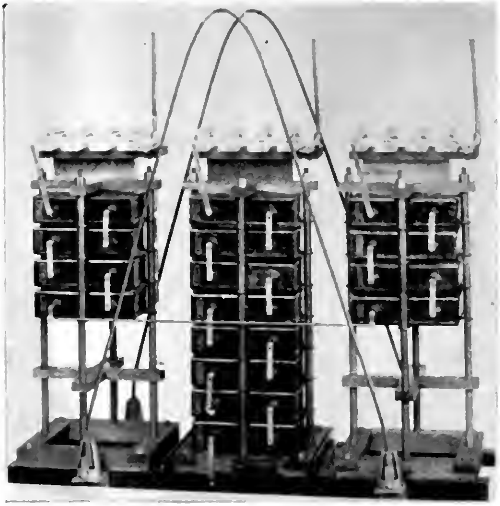

Fig. 20. Interior View of High Frequency Absorber

Protection

The aluminum cell and oxide film lightning arresters (Figs. 18 and 19) are almost universally used for lightning protection on high voltage systems. The aluminum cell arrester has a combination horn and sphere gap, the former taking care of the lower frequencies and the latter of the higher frequencies and impulses. The sphere gap has no time lag when properly set, and therefore this is the fastest possible gap. As the gaps for these arresters are usually out of doors and uncovered, they must be set for wet conditions, which makes the dry arc over considerably greater and the protection therefore not so good.

The oxide film arrester has a number of points of advantage over the aluminum cell, which it is gradually superseding. It has practically the same discharge rate and therefore gives equally good protection from this standpoint. It is permissible with this arrester to cover the gap and therefore the arc-over voltage is the same in dry and wet weather, thus giving better protection in dry weather. The cells do not require charging and the absence of oil reduces the fire hazard. In addition to these advantages the oxide film arrester has a lower shipping weight than the aluminum cell. It is interesting to note that both the aluminum cell and oxide film types of arrester were developed in the laboratories of the General Electric Company.

So-called "static" potential frequently causes breakdown on the low voltage side, either in generating stations or substations. This is potential induced through the electrostatic capacitance of the transformers and results, usually, from an unbalanced condition on the high voltage side, such as a ground on the line, one of three switches closing before or after the others, etc. Such static potential is usually protected against by a combination of an oxide film lightning arrester and a high frequency or surge absorber (see Fig. 20). The latter consists of a condenser in series with a resistance connected directly to the bus without a gap in series. This absorber acts as a constant drain to any static which may appear on the bus, thus preventing the static from gradually eating into and destroying the insulation of the generator windings, etc. If a disturbance or charge of unusually high potential should appear on the busbars, the oxide film arrester would act through its horn gap to reduce the potential. The horns of the arrester also act to limit the voltage that can be impressed across the condenser. Such a combination has also been used to good advantage in substations on cable systems, at the junction of overhead lines and cables, and on busses to which overhead lines are brought directly without transformers intervening. The absorber takes care of low voltage, high frequency disturbances and static and the arrester takes care of low frequency, high voltage disturbances. Such a combination has the advantage that the impedance of the condenser varies inversely as the frequency, so that the higher the frequency the greater the discharge through the absorber.

Standard absorbers have been developed for voltages up to 25,000 volts, and numerous installations of these devices have been made on systems in America.

Every system is more or less subject to short circuits, in fact in installing the grounded neutral it is the deliberate intention to produce a short circuit when an insulator arcs over, and on isolated systems an arc over frequently results in a short circuit before the trouble is cleared. For clearing such short circuits dependence is placed on the short circuit current to operate the line relays and disconnect the circuit in trouble.

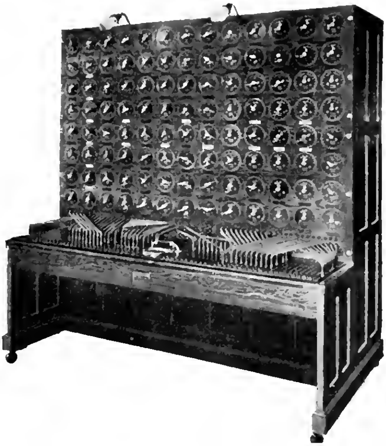

Fig. 21. Short Circuit Calculating Table

Apparatus must be built to stand such short circuits, but where the short circuit exceeds in value a reasonable amount for the transformers and generators and for the oil circuit breakers to interrupt, then it is necessary to split up the circuits so as to reduce the short circuit kv-a. that can be concentrated at one point, or to introduce current limiting reactors for the same purpose. Oil circuit breakers have been developed to take care of 1,500,000 kv-a. in a short circuit, but it is doubtful whether it is advisable to concentrate such an enormous amount of power at one point on account of its effect not only on the circuit breakers but on busses, transformers and other apparatus, as well as on account of the interference to service which such a short circuit represents. Some companies are placing a limit of 500,000 kv-a. on the short circuits which they are willing to permit.

For clearing short circuits dependence is placed to a large extent on the induction type inverse time limit and reverse power relays supplemented by special relays of various kinds. The so-called differential protection for generators and transformers is almost universal. Balanced interconnected protection for two or more lines in multiple is extensively used and is quite successful. This may be accomplished in some cases with reverse power relays and in some cases with mechanically balanced current relays, according to the circumstances. Neutral or ground circuit relays are used to some extent. The success of any relay scheme depends on a thorough short circuit study and the application of the relay scheme best suited to the particular system.

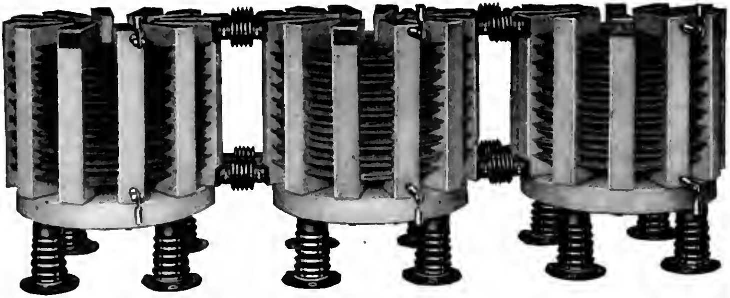

Fig. 22. Current Limiting Reactor of the Cast in Concrete Type

The calculation of short circuits on a power network is usually accomplished by considering that the short circuit is limited only by the reactance of the various elements of the circuit. This reactance, expressed in the form of percentage voltage drop or per cent, IX based on a convenient kv-a. or current, is set up on a short circuit calculating table (Fig. 21) which consists essentially of rheostats calibrated to represent percentage reactance. The various rheostats representing generators, transformers and lines are connected together by means of telephone cords and jacks. The whole is energized by direct current and the currents in the various elements read on a milliammeter. This device was developed by the General Electric Company and has been described in the technical press.*

If resistance predominates in the circuit, as in a cable system or when cables or overhead lines are connected in the same circuit, thus causing considerable difference in the impedance angle, it is still possible to obtain fairly accurate results by using percentage impedance instead of reactance. Single-phase short circuits from line to neutral or from line to line require special and rather laborious treatment, but in general relay settings and switch selections based on three-phase short circuit calculations by the reactance method have proved very satisfactory in practice.

Current limiting reactors are useful in limiting the duty on oil circuit breakers and the stress on transformers, generators and busses, but they may in themselves be a source of danger when in a circuit subjected to external voltage disturbances such as lightning, arcing grounds and switching. To obviate this danger the reactor is shunted by a resistor properly proportioned, and this combination has been found to give excellent results. The reactor built up of coiled cable, embedded in concrete pillars, has been found to be extremely rugged and reliable, and of course is absolutely fireproof (Fig. 22).

Devices are sometimes employed for reducing the generator field temporarily, thus causing the arc to be extinguished, after which the field strength is restored. Short circuit suppressors are also used to some extent, for example, on the Pennsylvania Water and Power system and the Mississippi River Power system. These work on the principle of temporarily grounding the line in trouble through a switch or fuse at the generating station, thus allowing the arc to be extinguished, after which the temporary ground is automatically removed. This scheme has the disadvantage that the max-

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* See a New Short Circuit Calculating Table, W. W. Lewis, General Electric Review, August, 1920.

imum short circuit is placed on the generating station every time an insulator flashes over and the buffer effect of the line reactance is lost.

Charging the Line

Charging a long line is often a problem and a number of schemes are used. In the first place the size of generator should be related to the line charging current if possible so that one generator can pick up or charge the line. This alone, however, is not sufficient and the generator should further be designed so that its saturation characteristic will lie below the line charging characteristic, that is, so that a given voltage will produce less line charging current than the field current required to excite the generator to that voltage. The line charging current will act to magnetize the generator, but additional d-c. field current will need to be supplied to bring the generator up to voltage. On the other hand, if the generator saturation curve lies above the line characteristic, then a given voltage will produce more line charging current than necessary to excite the generator to that voltage, with the result that the generator voltage will build up to a potential corresponding to that field current, thus charging the line at higher current, thereby building up more generator voltage, etc., until a point of stability is reached where the two curves intersect. This building up of voltage takes place very rapidly and the final voltage may be much higher than is safe either for the generator or the line. Fig. 23 illustrates both the stable and unstable conditions.

In case the generator does not have the proper characteristics for the particular line, it may be possible to charge the line with two generators in multiple, thus dividing the line charging current between the two machines and bringing the generator characteristic to a stable position below that of the line. In this case the generators must first be synchronized and excited with sufficient field to hold them in step.

As an alternative to charging the line with two or more generators in multiple, line charging reactors may be installed. These reactors may be placed in service either at the generating station or at the receiving station, thereby drawing lagging current from the generator to offset the leading charging current. If placed at the generating station, the generator is relieved but conditions on the line are not affected, whereas if placed at the end of the line, not only is the generator relieved but there is caused a drop in voltage over the transmission line and the charging current necessary is thereby decreased. Transformers connected to the end of the line assist to a small extent in the same manner.

Where synchronous condensers are available at the end of the line, these may be connected to the circuit without field and brought up to voltage with the line. The condensers will act as induction motors and draw lagging current over the line. Such machines after coming up to speed will require about 150 to 200 per cent normal kv-a. at zero power-factor, and thus are equivalent to adding line charging reactors of that kv-a. as decribed in the previous paragraph.

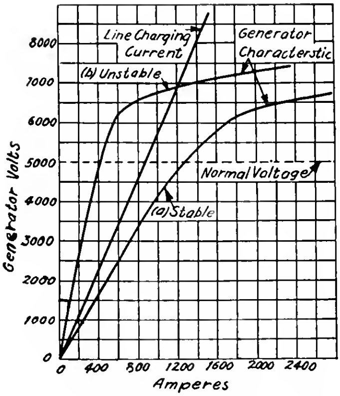


Fig. 23. Illustrating Stable and Unstable Conditions for Line Charging

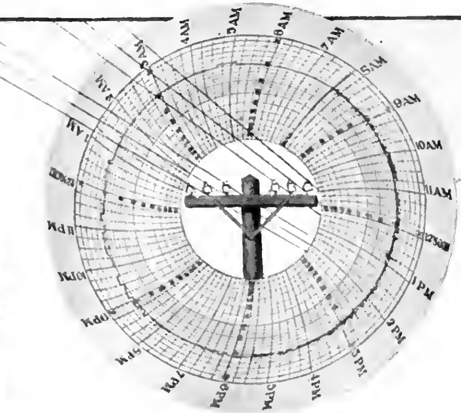
When generator curve falls at (a) then conditions are stable. When generator curve falls at (b) then conditions are not stable, and generator voltage will build up without field to intersection of generator curve and line charging current curve.

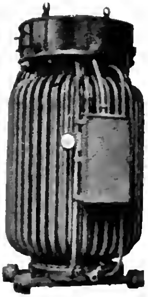
Negative field excitation may be given to the generator by a special scheme, thus preventing the rapid building up of the generator voltage and allowing the slow charging of the transmission line. This scheme among others is used on the Southern California Edison Company's Big Creek system.

Whenever possible the generator voltage is lowered and the generator, line and step-down transformers brought up together. The charging is more easily controlled in this manner and there is not such a shock to the system as would be caused by picking up the line at full voltage.

(To be Continued)

Voltage regulation means not only better service to users of power and lighting current, but more revenue to the central station





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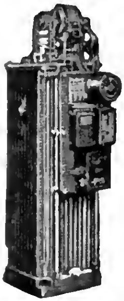

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GENERAL ELECTRIC REVIEW

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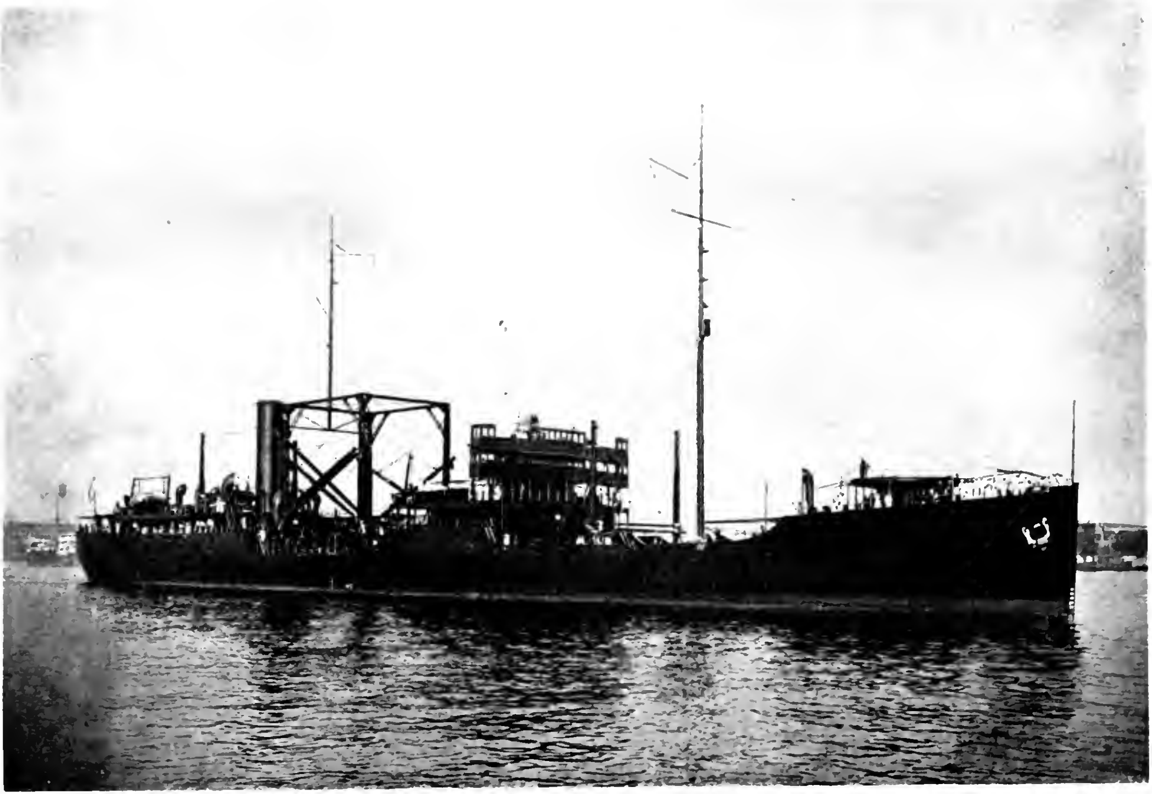

THE ELECTRICALLY PROPELLED FUEL SHIP *KAMOI* OF THE IMPERIAL JAPANESE NAVY

A preliminary description of this ship appears on page 650. A detailed description of the control of its electrical equipment will be given in the December issue of the *Review*

GENERAL ELECTRIC
REVIEW

THE ELECTRIC POWER INDUSTRY

In this issue we publish the first of a series of articles by Dr. Charles P. Steinmetz on the Electric Power Industry. To minds of many engineers this would appear a hackneyed subject but really the reverse is the truth. The kaleidoscopic changes of the past two decades have made such a profound difference in our mode of living that the mind of the engineer and layman alike is still hazy as to where these changes have led us and their probable future trend.

When we look backward on human progress in past ages we always find curious cycles of events—something is built—then over-built—then destroyed to make way for something new. Such changes are always resented and deplored by the pessimistic mind and are always brought about by the optimist. Some people always resent changes and think we are going from bad to worse, and some see our only chance for improvement in change.

It was the discovery of coal and the invention of the steam engine that led to organized industry. Before the adoption of the machine there were, practically speaking, no factories. Industries were home industries. Cloth was weaved in the home, shoes were made in the home and so on. The individual artisan could not afford to buy a steam engine and so hand products could not compete with machine made products. This led to the machine being put in a factory and the worker going to his work each morning rather than the work being carried to the worker. This evolution made a profound change in our mode of living and, by virtue of the fact that the machine could make much more than was required for local use, it also made a profound change in our economic status. The town that produced more than it could use looked for broader markets and the country that produced more than it could consume looked for foreign markets.

It was the introduction of wholesale production in factories that led to a decrease in the population of country districts and an increase in the population of towns.

Up to a certain point these changes were beneficial but carried beyond a certain point they were harmful. Over-congested towns are not conducive to happiness, health or comfort and in some of our manufacturing towns the freest blessings of Nature are denied mankind —fresh air, sunshine and contact with Nature.

So we have built to the stage where we have to pull down something we have built up, but we must pull it down without destruction and must build something better for mankind in its place.

We have been proud and boastful of large cities but now we have reached the stage where they have gotten too large and where life in them has become too complicated.

The solution is reasonably simple—not to keep adding factory upon factory to our large towns but to build large factories in the country and take our workers into the country. Just as the steam engine was the cause for our congested areas so the advent of electric power must be the means of eliminating the attendant evils. With the steam engine and inadequate means of transportation, the towns and factories had to group themselves in areas reasonably close to the source of fuel. With electric power and its inherent advantages, among which is its ability to be produced by coal or water and transmitted over wires for great distances, our choice of town sites and factory sites knows practically no limits. So by the advent of the machine many blessings were secured, but at the same time many attendant evils have grown up, and now with the new power, if men use their intelligence, the blessings can be maintained and the evils eliminated.

It seems to us to be impossible to overestimate what an intelligent use of electric power can do in the future for bettering the lot of mankind, and after all the eternal desire of man is the betterment of his lot. J. R. H.

4760-Mile Speed Record by the Electrically Propelled U. S. S. *Maryland*

Another record of the superiority of electric propulsion has been established. When bringing back Secretary of State Charles E. Hughes and party from the Centennial Exposition of Brazil, the all-electric U. S. Battleship *Maryland* made the 4760-mile run from Rio de Janeiro to New York in ten days, seventeen hours and fifty minutes thereby breaking the former record of eleven days, one hour and forty-nine minutes which was held by the Munson S. S. *American Legion*.

However, the matter of eight hours' difference in running time by no means expresses the full significance of the new accomplishment of electric marine drive for this is revealed only on consideration of the vastly different weather conditions under which the two runs were made.

The best time of the *American Legion* was made in favorable weather; while the *Maryland* for nearly two days had to proceed against 75-mile-an-hour hurricanes. The violence of the ordeal is described below.

To the many earlier demonstrations of economy and reliability of electric propulsion machinery is now added this new record of its ability to withstand the punishment of rough seas and at the same time plough ahead with practically undiminished speed.

Appreciation is due the officers and crew for their good work in making possible this remarkable performance. The high-speed endurance run of nearly 4800 miles through tropical waters at an average sustained speed of 18.48 knots with a final spurt for 4 hours at 21 knots reflects especial credit on Lieutenant Commander F. T. Van Auken, senior engineer officer, and his associates.

The following quotations from the *New York Times* and *New York Tribune* of September 24 furnish an interesting account of the record breaking trip from Rio de Janeiro to New York:

"The *Maryland* showed that she had been through rough usage. Her aft basket mast was black with the soot of her fires, her wireless had been damaged by a 75-mile wind, her galleries and superstructure were marked by the heavy seas that came aboard, and even some of the cabins showed signs of being inundated. Mr. Hughes was one of those who suffered from too much water when he was doused by a sea which poured in solid 14-inch streams through the ports of his cabin on Friday.

"The ship ran through two storms, one being a forerunner of Friday's adventures. The *Maryland* was still in the Gulf Stream on Friday, ploughing along at eighteen knots, as steadily as a locomotive. She was rolling and pitching, taking solid water over the forecastle and even as far aft as the quarterdeck. The wind was about 75 miles an hour, making a bedlam in the aerials and superstructure of the big ship. Sometimes a wave would sweep through the galleries four and five feet deep, burying men on this high spot to the neck and forcing them to cling desperately. One such sea made hash of the Admiral's car in the port gallery, tore a boat loose and damaged a seaplane. Every hatch was battened fast."

"The chief importance of the voyage, so far as naval designers are concerned, lies in the fact that the *Maryland* is electrically driven and controlled and that the success of the run probably will determine that this form of power shall be utilized to operate many American battleships of the future.

" 'The long voyage provided an excellent test and proved that the *Maryland* can be handled with the greatest efficiency and economy,' was Secretary Hughes' comment on the battleship's performance."

" 'I did not realize until this trip how superior the electric drive is to anything else,' said Admiral Hilary P. Jones. 'It is the most efficient driving force on any warship, in economy, power, ease of handling. I have been amazed by the performance. There is no doubt that the *Maryland* is the last word in fighting ships. There is nothing else like her in the world.' "

"According to Captain David Foote Sellers, the average speed maintained by the *Maryland* was 18.48 knots for the entire trip, with the fastest day's run covering 474 miles, from noon on September 17 to noon on the following day.

" 'We made the last four hours of the voyage to Ambrose Light at 21 knots an hour, and could easily have attained considerably greater speed had the *Maryland* not been limited to 21 knots by the terms of the contract with her builders.

" 'The storm proved the value of the electric drive,' said Captain Sellers. 'That is automatically regulated, so no matter what seas we plough into the speed of the ship is maintained. During the storm we sometimes brought up against seas as if they were brick walls, but the *Maryland* went right through them. We only lost 0.8 of a knot at any time during the worst of the blow.

" 'The engineer officer told me that at one time when we ran up against seas that checked our way there was 8000 more horse power generated to bring the speed up to the normal 18 knots and keep it there. The automatic governor takes care of that, and all that is necessary is to set the motors at the desired number of revolutions, and they keep that speed. There is no racing, either, when the screws lift from the water.

" 'The ship picks up like a subway express. When we left the anchorage at Rio we set the motors full speed ahead and started off like a race horse. We passed a Japanese ship 800 yards from our anchorage, and we were then going eighteen knots. She is the best ship in the world.' "

While the foregoing enthusiastic comments on the performance of the *Maryland* were made with reference to her recent remarkable voyage, it is worthy of note that the satisfaction with her electric propelling machinery dates back to her builder's trials June, 1921, when Captain C. F. Preston, then in command of the ship, said: "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 we were under power, so quietly and smoothly did her machinery operate."

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The U. S. S. *Maryland*

The following data concerning the *Maryland* will be of interest:

Ship built by the Newport News Shipbuilding and Dry Dock Co.
Propulsion machinery built by the General Electric Company.
Launched March 1920.
Third battleship to be electrically propelled.
First battleship to carry 16-in. guns (eight). Range, 20 miles for 2100-lb. shell.
Length, 624 feet; beam, 97½ feet.
Displacement, 33,000 tons.
Speed, 21 knots.
Cruising radius, 10,000 miles.
Shaft horse power, 28,000.
Two Curtis steam turbine-generator units for propulsion.
  Each unit 11,000 kw. at 2080 r.p.m. for 21 knots.
  Each turbine-generator unit alone can propel the ship at 17 knots.
Four 7000-h.p. induction motors, 170 r.p.m.
  Each motor 12 feet in diameter and 56 tons weight.
Six 300-kw. turbine generators for auxiliaries.

The Electrically Propelled Fuel Ship *Kamoi* of the Imperial Japanese Navy

Due to the very successful performance of the electrically propelled vessels of the United States Navy, the Imperial Japanese Navy has been seriously considering electric propulsion for their large vessels, and had the fuel ship *Kamoi* built in the United States and equipped with electric propulsion machinery in order to obtain their initial experience with a low powered ship, as did the United States Navy with the collier *Jupiter*. By a comparison of these two fuel ships we have an excellent opportunity to study the progress made during the last ten years in the development of electric propulsion machinery.

The *Kamoi* was built by the New York Shipbuilding Corporation at Camden, N. J. The electrical machinery was furnished by the International General Electric Company and was built by the General Electric Company. The officers of the Imperial Japanese Navy and the shipbuilders co-operated with the General Electric Company to the fullest extent; and as the result, we have in this ship the best example of electrically propelled vessel that has been produced to date. The steam conditions are excellent and a sufficient number of auxiliaries have been driven electrically to give an exceptional heat balance, that is to say, there is just enough auxiliary exhaust steam to heat the boiler feed water. It can be safely stated that she is the most economical steamship of her size afloat, since tests show that she should make her full speed on 0.87 lb. of oil per shaft-horse-power-hour for all purposes, based on 19,000 B.t.u. per pound of oil and a boiler efficiency of 75 per cent.

It is to be regretted that the ship is leaving this country, but it is a source of satisfaction that she is going to the Far East to be studied alike by the navy and merchant marine of Japan, and where her performance can be followed in a general way by the ship operators of other nations, whose ships make Japanese ports.

The *Kamoi* is a 15-knot 20,000-ton 8000-s.h.p. twin-screw ship with boilers equipped for either coal or oil burning, and the important machinery items are as follows:

Two 4000-h.p. 40-pole 120-r.p.m. 3-phase 2300-volt synchronous motors with amortisseur windings especially designed for operation of these motors as induction motors while the ship is being maneuvered.

One 6250-kw. unity-power-factor 2-pole 2400-r.p.m. 3-phase 40-cycle 2300-volt generator direct connected to a 10-stage Curtis turbine designed for steam conditions of 250 lb. gauge, 150 deg. F. superheat, 1½ inch absolute back pressure.

One propulsion control equipment.

Two 400-kw. 3-wire 110–220-volt direct-current turbine-generator sets for excitation of the main machinery, for driving the electric auxiliaries, and for supplying miscellaneous electrical demands of the ship.

One 625-kw. 2-pole 1100-r.p.m. 3-phase 750-volt alternating-current generator coupled to one of the 400-kw. direct-current generators; this auxiliary generator to be used for emergency propulsion of the ship up to 55 propeller revolutions, or about seven knots.

This is the first ship to be equipped with synchronous-motor drive where the motors have been designed on a basis of all maneuvering being done on induction-motor characteristics without field excitation, and where the motor fields are energized only for steady running ahead or astern. During the official trials conducted on September 7 and 8, and with the ship going full-speed ahead, the propellers were stopped and the propelling motors synchronized at 40 revolutions astern in 18 seconds. If necessary, this can be done in 15 seconds or less, and demonstrates that the combined motor and generator characteristics will give the same speed of maneuvering as can be obtained with the older induction-motor drive.

The practicability of the 625-kw. emergency generator set was also fully demonstrated during the official trials, in that this set had sufficient capacity to reverse the ship promptly while it was going ahead at a speed of seven knots.

The propelling machinery functioned in such a satisfactory manner during these trials that the ship was immediately accepted by the Imperial Japanese Navy. During the week of September 19 the Japanese took the ship to sea for several days for training the crew, and operated the machinery without important assistance from the shipbuilder or the electric company.

The ship sailed from New York for Japan on October 9, and we are told that the Naval Officers and merchant men of Japan are awaiting its arrival with the greatest interest.

The Electric Power Industry

EFFECT OF ELECTRICAL ENGINEERING ON MODERN INDUSTRY

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

Dr. Steinmetz read the subject matter of our present contribution as a paper before the Franklin Institute nine years ago. We print this article as the first of a series of five articles by Dr. Steinmetz to show how his predictions have been fulfilled. Part II will deal with the relation of the electric power industry to the industrial corporation; Part III, with the relation of the electric power industry to the municipal corporation; Part IV, with engineering problems of the electric power industry; and Part V, with economic problems of the electric power industry.—Editor.

I

The use of electricity in modern civilized life is rapidly increasing: in lighting our homes, factories, streets; in industrial power applications; in domestic service, from the fan motor to the electric bell or the heating and cooking device; in transportation: while no great inroads have yet been made into the field of the steam locomotive, an entire system of electric railroads has sprung up all over the country, fully comparable in size and power demand with the steam railway system; large new industries have developed in electrochemistry and electro-metallurgy, supplying us with materials unavailable before—as aluminum—or improving the production of other materials—as copper refining, etc.

All these applications are uses of *energy*. In nearly all, electrical energy is replacing some other form of energy used heretofore: chemical energy of fuel, or mechanical energy of steam or gas engines, etc.

To understand the reasons which enable electrical energy to compete successfully with other forms of energy, which are longer and more familiarly known, we have to look into its characteristics.

Electrical energy can be transported—or, as we usually call it, transmitted—economically over practically any distance. Mechanical energy can be transmitted over a limited distance only, by belt or rope drive, by compressed air, etc.; heat energy may be carried from a central steam heating plant for some hundred feet with moderate efficiency, but there are only two forms of energy which can be transmitted over practically any distance—that is, which in the distance of transmission are limited only by the economical consideration of a source of energy nearer at hand: electrical energy, and the chemical energy of fuel. These two forms of energy thus are the only competitors whenever energy is required at a place distant from any of Nature's stores of energy. Thus, when in the study of a problem of electric power transmission we consider whether it is more economical to transmit power electrically from the water power or the coal mine, or generate the power by a steam plant at the place of demand, both really are transmission problems, and the question is whether it is more economical to carry energy electrically over the transmission line, or to carry it chemically, as coal by the railroad train or boat, from the source of energy supply to the place of energy demand, where the energy is converted into the form required, as into mechanical energy by the electric motor or by steam boiler and engine or turbine.

Electrical energy and chemical energy both share the simplicity and economy of transmission or transportation, but electrical energy is vastly superior in the ease, simplicity, and efficiency of conversion into any other form of energy, while the conversion of the chemical energy of fuel into other forms of energy is difficult, requiring complicated plants and skilled attendants, and is so limited in efficiency as to make the chemical energy of fuel unavailable for all but very restricted uses: heating, and the big, high-power steam plant. Pressing the button turns on the electric light and thereby starts conversion into radiating energy: with chemical energy as source, either special fuels are required—in the candle, kerosene lamp—or a complex gas plant. Closing the switch starts the motor, whether a small fan motor, or a 1000-horsepower motor supplying the water system of a city or driving the railroad train. With fuel as source of energy, boiler plant, steam engine, or turbine, with its numerous auxiliaries, with skilled attendants, etc., are necessary, and the efficiency is low except in very large units. To appreciate the complexity of the conversion of the chemical energy of fuel, compared with the simplicity of electrical energy conversion, imagine the domestic fan motor with coal as source of energy: a small steam engine, with boiler and furnace, attached to the fan: to start the fan, we have to make a coal fire and raise steam to drive the engine. This illustrates how utterly unavailable the chemical energy of fuel is for general energy distribution. General energy distribution, therefore, may justly be said to date from the introduction of electric power.

Equally true is the reverse: the conversion of mechanical or other energy into electrical is simple and economical, while the conversion into chemical energy is not. Hence, one of the two large sources of Nature's energy, the water power, was, before the days of electrical engineering, useless except to a very limited extent, since the location of the water power is rarely such that the energy could be used at its source. The water powers thus have really been made available only by the development of electrical transmission.

Characteristic of electrical energy is that it can be concentrated to an energy density higher than any other form of energy, and results can thus be produced by it which no other form of energy can bring about, or things done directly by the brute force of energy, as we may say, which formerly had to be brought about in a roundabout way.

Thus iron can be reduced from its ores by the chemical energy of coal in the blast furnace, but aluminum and calcium cannot, as their chemical affinity is higher, and require the higher energy concentration available with electric power. Iron reduced in the blast furnace combines with carbon to cast iron. So calcium combines with carbon in the electric furnace to carbide, the starting material of acetylene, and of cyanamid and the modern fertilizer industry. Platinum can just be melted, and quartz softened, in the hottest flames of combustion: the oxy-acetylene flame and the oxy-hydrogen flame. But in the electric arc platinum and quartz and every existing substance, even tungsten and carbon, can be melted and distilled or sublimed. Thus mighty industries have grown up and many new materials made available to man, as aluminum, silicon, calcium, chromium, the carbides, cyanamid, acetylene, etc.; others produced in a cheaper manner, as alkalies, hypochlorites, phosphorus, magnesium, sodium, etc.

Electricity as such is the most useless form of energy: it is not found in Nature in industrially available quantities, and finds no industrial use as electrical energy, but it is always produced from some other form of energy, and converted into some other form of energy: light, mechanical energy, chemical energy, heat, etc. That is, electrical energy is entirely the connecting link, the intermediary, by which energy is brought from the place where it is found to the place where it is used, or changed from the form in which it is found to the form in which it is used. Thus, on first sight, it appears a roundabout way, when, for instance, in modern electrical ship propulsion an electric generator is placed on the steam turbine, a motor on the ship propeller, a few feet away, though it is not different from practically every other use of electric energy: a transmission link, superior to any other transmission by the flexibility given by the simplicity and economy of conversion.

The most serious disadvantage of electrical energy is that it cannot be stored. It is true, there exists the electric storage battery, and it is used to a large extent as stand-by battery in high-grade electric distribution systems to give absolute reliability of service, or as battery floating on a railway circuit to equalize fluctuations of power, or in special applications, as electric automobiles. It does not really store electrical energy, but stores energy by conversion of the electrical into chemical energy, and reconversion, in discharge, of the chemical into electrical energy.

The economic efficiency of the storage battery—using the term in the broad sense including interest on the plant investment and depreciation—is so low that the storage battery does not come into consideration in the industrial storage of energy—that is, in making the rate of electrical energy consumption independent of that of energy production. We can best realize this by comparing electrical energy with the chemical energy of fuel: the latter can be stored with perfect economy. Thus, when using fuel as the source of energy—in a steam plant—no serious difficulty is met by the industry even if the fuel supply is interrupted for months, as in the case of a supply by water, through the closing of the navigation by ice: we would simply bring in a sufficient coal supply to last until the navigation opens again in spring. But with electrical energy from a water power we could never dream of storing energy by storage battery to last over the two or three months during which the river runs dry and the water power fails.

This means that electrical energy must be consumed at the rate at which it is produced, and the cost of electrical energy thereby becomes dependent on the rate of the energy use. This is not the case with most other forms of energy, as, for instance, the chemical energy of fuel. The price of a ton of coal, as determined by the cost of supplying it, is the same whether I dump the coal into a furnace all at once, or whether I use it up at a uniform rate in a small stove, lasting for weeks. If I consume 2400 cubic feet of gas per day, its cost and thereby its price is the same whether I use the gas at a uniform rate throughout the day, of 100 cubic feet per hour, or whether I use the entire 2400 cubic feet in one hour, nothing in the remaining 23 hours: the gas is produced at whatever rate is most economical, stored in the gas holders and supplied from there at whatever rate it is required for consumption. If, however, I use 240 kilowatt-hours of electrical energy per day, it makes a very great difference in the cost of supplying this energy whether I use it at a uniform rate of 10 kilowatt-hours per hour, or whether I use the entire 240 kilowatt-hours in one hour, nothing in the remaining 23 hours. In the former case, 10 kilowatts of generating machinery are necessary in the steam or hydraulic station producing the electric energy, 10 kilowatts capacity in transmission lines, transformers, sub-station and distribution lines, to supply the demand. In the latter case, 240 kilowatts of generating machinery, 240 kilowatts of line and transformer capacity are absorbed, and that part of the cost of supplying the electric energy, which consists of interest in investment in the plant, of depreciation, etc.—in short, the fixed cost—is 24 times as high in the latter as in the former case. If the fixed cost approximates half the total cost in a steam plant, or is by far the largest part of the total cost in a hydraulic plant, it follows that in the case of concentrated energy used during a short time the cost of electric energy—and with it the price—will be very much larger—many times, possibly—as in the case of a uniform energy consumption.

Thus, due to the absence of storage, the cost of electrical energy essentially depends on the uniformity of the rate of its use—that is, on the load factor, as the ratio of the average consumption to the maximum consumption.

If I use 240 kilowatt-hours of electrical energy in one hour, nothing during the remaining 23 hours, that part of the cost which is the fixed cost of plant investment and depreciation is 24 times as great as if I used the same amount of energy at a uniform rate throughout the day. In the former case, if somebody else uses 240 kilowatt-hours, but during another hour of the day, the same plant supplies his energy, and the fixed cost thus is cut practically in two—that is, the cost of energy to both of us is materially reduced. Thus, again, the cost of electrical energy, and with it its price, depends on the overlap or not overlap of the use of the energy by different users, the so-called "diversity factor." The greater the diversity factor—that is, the less the different uses overlap and the more their combination, therefore, increases the uniformity of the total energy demand, the "station load factor,"—the lower is the energy cost. The cost of electrical energy for lighting, where all the demand comes during the same part of the day, is inherently much higher than the cost for uniform 24-hour service in chemical works, and with the increasing variety of load, with the combination of energy supply for all industrial and domestic purposes, the cost of energy decreases.

Thus, unlike other forms of energy, due to the absence of energy storage, electrical energy can have no definite cost of production, but, even supplied from the same generating station, its cost varies over a wide range, depending on the load factor of the individual use and the diversity factor of the different uses.

This feature, of necessity, must dominate the economical use of electrical energy in industrial, domestic, and transportation service.

II

Civilization results in the complete interdependence of all members of society upon each other. Amongst the savages each individual, family, or tribe is independent, produces everything it requires. In the barbarian state some barter develops, followed by trade and commerce with increasing civilization. But up to a fair state of civilization—up to nearly a hundred years ago—all necessities of life were still produced in the immediate neighborhood of the consumer, each group or territory was still independent in its existence, and commerce dealing with such things only which were not absolutely necessary for life. All this has now changed, and in our necessities of life, as well as luxuries, we depend on a supply from distances of hundreds and thousands of miles: the whole world contributes in the supply of our food, clothing, building materials, etc.

That means, our existence is dependent on an efficient and reliable system of transportation and distribution of all needs of civilized life. Such has been developed during the last century in the system of steam railroads, steamship lines, etc., which, in taking care of the transportation and distribution of commodities, have made modern civilization possible. For civilization means separation of production, in time and in location, from consumption, to secure maximum economy.

The necessities of civilized life consist of two groups: materials and energy. Our transportation system takes care of materials, but cannot deal with the supply of energy, and the failure of an efficient energy supply has been and still is the most serious handicap which retards the advance of civilization. The transportation system could deal with the energy supply only in an indirect manner, by the supply of materials as carriers of energy, and when our railroads carry coal it is not the material which we need, but the energy which it carries. But this energy is available only to a very limited extent, as heat, and as mechanical power in big steam units; most of the energy demands of civilized life could not be satisfied by it. In any country village far away from the centers of civilization we have no difficulty to have delivered to us any material produced anywhere in the world; but even in the centers of civilization we could not get the energy to run a sewing machine or drive a fan without *electric power*. Thus, just as our steam railways and express companies take care of the transportation and distribution of materials, so civilization requires a system of transmission and distribution of energy, and our electric circuits are beginning to do this; and just as fifty to seventy-five years ago in the steam railroads, steamship lines, etc., the system of transportation and distribution of materials was developed, so we see all around us in the electric transmission systems the development of the system of the world's energy transmission in progress of development. When we see local electric distribution systems combining, the big electric systems of our capitol cities reaching out over the country, transmission lines interconnecting to networks covering many thousands of square miles, this is not merely the result of the higher economy of co-operation, of mass production, but it is the same process which took place in the steam railroad world some time ago, as a necessary requirement of co-ordination to carry out their function as carriers and distributors of materials in the case of the railroads, of energy in the case of the electric systems.

We must realize this progress, and the forces which lead to it, so as to understand what is going on, and to assist in the proper development, in avoiding, in the creation of the country's electrical network, whatever mistakes have been made in the development of the country's railway network.

Electricity, thus, is taking over the energy supply required by civilization, as the only form of energy which, by its simplicity and economy of conversion, combined with economical transmission, is capable of supplying all the energy demands, from the smallest domestic need to the biggest powers. As we now begin to realize, the economic function of the steam engine is not the energy supply at the place of consumption, from the chemical energy of coal—it is too complicated and inefficient for this—but it is the conversion of chemical energy of coal into electrical energy in bulk, for transmission and distribution to the places of consumption.

If, then, electric power takes the place of steam power in our industries, etc., it is not merely the substitution of the electric motor for the steam engine or turbine. Such would rarely realize the best economy. The method of operation in all our industries, and especially those requiring considerable power, is largely—more than usually realized—determined by the characteristics of the power supply, and what is the most economical method with the steam engine as source of power may be very uneconomical with electric power supply, and electric power supply often permits a far more economical method of operation which was impossible with steam power. Thus the introduction of electricity as the medium of distributing the world's energy demand means a reorganization of our industrial methods, to adapt the same to the new form of power.

For instance, the steam engine requires skilled attendance, and with its boiler plant, auxiliaries, etc., is a complex apparatus, is economical only in large units. Thus, when operating a factory or mill by steam power, one large engine is used, driving by shafts and counter-shafts, by pulleys and belts, and possibly wasting half or more of its energy in the mechanical transmission to the driven machines. But we could not economically place a steam engine at every one of the hundreds of machines in the factory. Substituting electrical power by replacing the engine by one large electric motor would be very uneconomical, as we can place a motor at every driven machine, and these small motors are practically as efficient—within very few per cent—as one big motor would be, and all the belting and shafting, with its waste of energy, inconvenience, and danger, vanishes. With the steam engine as source of power, to run one or two machines only, to complete some work, requires keeping the big engine in operation, and therefore is extremely wasteful. With individual electric motors the economy is practically the same, whether only one or two motors are used, or the entire factory is in operation. On the other hand, with the steam engine, it makes no difference in the cost of power whether it is in operation from 8 a.m. to 6 p.m., or from 6 a.m. to 4 p.m. With electric power, in the former case the power demand would overlap with whatever lighting load the same supply circuit carries, but would not in the latter case, and the latter case thus would give a better load factor of the electric circuit, and thereby a lower cost of power. Again, with electric power, if very large power demands could be restricted to the periods of light load on the electric supply systems, this would reduce the cost of power. Nothing like this exists with the steam engine.

Electrical energy thus makes the power users economically more dependent upon each other, and thereby exerts a strong force toward industrial co-ordination—that is, co-operation.

Another illustration of the industrial reorganization required to derive the full benefit of electric power is afforded by the traction problem. Very often a study of the electrification of a railway shows no economical advantage in the replacement of the steam locomotive by the electric locomotive, even when considering only passenger service. At the same time, an electric railway may parallel the same steam railway, offer better service at lower price, and show financially better returns than the steam railway. But so, also, in the early days of steam, the steam engine in place of the horse in front of the stage coach was no success, and still the stage coach has gone and the steam locomotive has conquered; but it did not by replacing the horse, but by developing a system suited to the characteristics of the steam engine. The same repeats now in the relation of steam traction and electric traction. The steam engine is most economical in the largest units, and the economy of steam railway operation depends on the concentration of the load in as few and as large units as possible: therefore, the largest locomotive which can pass through bridges and around curves. Exactly the reverse is the condition of economy of electric traction: the economy depends on the distribution of the load as uniformly as possible in space and in time—that is, small units at frequent intervals—and therefore, while steam traction has gone to larger and larger units, in electric traction even the trailer car, so frequently used in the early days, has practically vanished. Obviously, then, the electric motor cannot economically compete with the steam engine under the conditions of maximum economy of steam and minimum economy of electric operation, and electric traction under steam traction conditions shows marked economy only in the case of such heavy service that the maximum permissible train units follow each other at the shortest possible intervals—that is, give maximum uniformity of load—and thus the economic requirements of both forms of power coincide. These two instances may illustrate the changes in industrial operation which the introduction of electric power requires and which are taking place today.

To conclude, then: Electric energy is the only form which is economically suited for general energy transmission and distribution. Civilization depends on the supply of materials and of energy as its two necessities. The supply of materials is taken care of by the transportation system of the world. The supply of energy is being developed by the electrical transmission system, which with regard to energy becomes what the railway system is with regard to materials. Introduction of electric power in place of other forms of power rarely can be a mere substitution, but usually requires a change of the methods of power application, a reorganization of the industry, to secure maximum economy.

Electric Heating by Ironless Induction

By E. F. Northrup

The subject dealt with in this article is of the utmost interest and it would take a bold mind even to attempt a prediction as to where electric heating by ironless induction may lead us in the future. The adoption of newly discovered applications for known scientific principles holds boundless possibilities for the future. To those who dare use their imagination some of our present methods look clumsy, inefficient and awkward when compared with some of the methods which are today being suggested by our bold pioneers.—Editor

First. At the request and with the financial backing of Mr. G. H. Clamer, 1st Vice President and General Manager of The Ajax Metal Company of Philadelphia, Pa., the writer began in July, 1916, a series of experimental and theoretical investigations on inductive electric heating which led up to the present applications of this method with currents of higher frequency than are employed for commercial lighting and power.

Second. In what follows it is the writer's object to consider the broad and fundamental principles which apply in heating inductively with currents of frequencies sufficiently high to make the use of iron unnecessary for increasing the magnetic induction. Details of construction and circuit diagrams will be little touched upon, as such are to be found fully described in numerous trade publications and in various published articles.

Third. A charged static condenser is a reservoir of potential energy and when discharged practically all of the potential energy must eventually appear as heat outside the condenser. Under most circumstances the discharge of a condenser is so rapid that a considerable proportion of its contained potential energy is easily transmitted inductively to a conducting mass by means of an inductor of few turns wound around the mass. By charging the condenser and discharging it through the inductor at rapidly recurring intervals the rate of transfer of energy to the conducting mass may be made very great.

Fourth. The early developments of high frequency inductive heating were wholly based upon this conception. To put the conception into practice it was necessary to develop apparatus for rapidly charging a large bank of condensers from a commercial alternating-current circuit and rapidly discharging them with an oscillatory discharge, through an inductor of few turns surrounding a crucible or a mass to be heated. To secure a device which would be scientifically and commercially useful it was necessary to make it capable of delivering many kilowatts.

Fifth. The apparatus operating on this principle eventually took the form of a simple oscillatory circuit. It consisted of a mercury discharge gap without moving parts, a bank of condensers, and an inductor coil of copper tubing. The condensers are charged from a service line of 6600 volts having any commercial frequency. To limit the flow of the supply current and to improve the operation of the discharge gap, a suitable reactance is interposed in the supply line.

Sixth. In heating with oscillatory discharges which transfer energy to a mass inductively, practically the same proportion of the stored electric energy in a single charging of the condensers will appear as heat in the mass being heated whatever be the frequency of the oscillatory discharge. However, with the arrangement employed, no heating of the mass is taking place during the time the condensers are charging. It is advantageous, therefore, to damp out the oscillations as quickly as possible by a rapid absorption of energy in the mass in order that the condensers may be ready for recharging in the shortest time possible. Thus by arranging for rapid discharging of the condensers and for their recharging at rapidly recurring intervals, it has been found possible to draw from the supply and deliver to the mass a very considerable quantity of power.

Seventh. A limit is placed, however, upon the power which can be absorbed in a mass from a succession of oscillatory discharges, for it is impossible without indefinitely increasing the supply voltage to increase without limit the rate of succession and the magnitude of such discharges. With the practicable voltage of 6600 volts which has been used for charging the condensers about 20 kw. to 25 kw. can be absorbed from the supply in single-phase operation. Under favorable conditions perhaps as much as 70 per cent of the power absorbed from the source is finally delivered as heat to the mass. The method of heating with oscillatory discharges lends itself, however, very well to multiphase operation. Excellent results may be secured with a single discharge gap using three electrodes and a three-phase source of supply. With three-phase operation and 6600 volts to charge the condensers, as much as

75 kw. can be drawn from the supply and over 50 kw. can be delivered to the mass.

Eighth. Another and broader view of inductive heating without use of iron to increase the induction is this: The voltages induced in a conducting mass to be heated are proportional to the rate of cutting of the mass with lines of electromagnetic induction. Since the strength of the magnetic field in a solenoid which has the highest possible number of ampere-turns without overheating is feeble, the frequency of the current in the solenoid must be high to obtain a considerable rate of change of field strength. Thus considered it matters not what is the source of current which traverses the inductor coil provided this source yields a current which has high frequency. If the current of high frequency is obtained by an oscillatory discharge of condensers it is necessarily intermittent, flowing only, and with rapidly decreasing amplitude, while the condensers are discharging, and ceasing altogether in the intervals that the condensers are being charged. The instantaneous peak values of such a current and of the impressed voltages at the inductor terminals may be very high while the average or effective values of the current and voltage may be small. A source of current, therefore, which yields high frequency current continuously and of uniform magnitude has the advantage of making the inductive heating of the mass continuous, which permits equal rates of heating to be obtained with much lower peak voltages at the terminals of the inductor. With a source of sine-wave continuous current the coil need only be insulated from turn to turn and from coil to the mass being heated for a voltage which is the square root of two times its effective value; while for the intermittent currents obtained by oscillatory discharge, the peak value of the voltage, for which insulation must be provided, often is ten or more times the effective value.

Other sources of high frequency power than the oscillatory discharge of condensers are now commercially available. Continuous high frequency current in power units of over a hundred kilowatts is obtainable from high frequency static converters.

Such being the case it is well to call attention to the unique features of high frequency heating whether the source of high frequency power is an oscillatory current converter set or a source which yields continuous high frequency current.

Ninth. High frequency inductive heating differs from all previously used methods of inductive heating in that no iron or transformer steel is required to increase the induction through the mass or material being heated. In high frequency heating the necessary rate of change of induction is secured by the rapid motion of a weak field rather than by the much slower change of a dense induction. Thus in high frequency inductive heating the material which is heated by the rapidly moving lines of force is not threaded or interlinked with any iron magnetic circuit. It is true that when iron bars or steel shells are inductively heated with high frequency current, such ferrous material is placed inside the inductor. While it may incidentally increase the induction through the inductor, it is itself the material heated and does not contribute to the heating of other material by increasing the induction through such other material. In ordinary low frequency inductive heating where steel cores are used, these steel cores are laminated, and they are used solely for the purpose of increasing the induction through some other material that is to be heated and any heat which is developed in the steel core itself is wasted heat. As no iron or other material is passed through the mass to be heated, this may take any desired shape or form, as that of a solid cylinder or an ordinary crucible. Thus in heating with high frequency induction, furnaces may take the form of ordinary oil or gas heated crucible furnaces.

Experience has shown also that heating proceeds quite as effectively whether the mass acted upon is one continuous solid, or consists of an assemblage of small and irregularly shaped pieces. Thus pieces of steel placed in a crucible of non-conducting material are readily heated, fused, and greatly superheated. Thus also the constituents of an alloy or scraps of high fusion metals, as platinum, may be fused in refractory that contains no carbon. Hence, melting at extremely high temperatures can be accomplished free from carbon, and in an atmosphere that is either neutral or highly oxidizing, or the melting can be done in vacuum.

When the material which is melted in a non-conducting crucible becomes fluid an automatic vertical stirring of the fluid takes place through an action produced by the electromagnetic forces. The high frequency currents induced in the melt flow chiefly in the surface layer of the molten mass adjacent to the inductor. The current elements by mutually attracting each other tend to contract the surface of the fluid in the vertical direction. By a secondary hydrodynamic action the fluid at and near the axis of the molten mass is squeezed upward, and on reaching the surface flows downward by way of the outer layer. The top surface of a cylinder of molten metal assumes a convex form and a rapid circulation is observed, up near the axis and down by way of the circumferential surface of the cylinder. This circulation is, of course, of distinct advantage for producing alloys of homogeneous mix.

Tenth. These and other particularly favorable characteristics of high frequency inductive heating well adapt this method of electric heating to such wide classes of uses as the following:

Melting Conducting Materials in Non-conducting Containers

In this application carbon free alloys of non-ferrous and ferrous metals, even those containing large percentages of metals of the tungsten group, are readily produced

The melting of gold alloys and metals of the platinum group is easily accomplished in refractory containers that give no carbon or other contaminating substances to the melt.

We term these applications, heating by direct induction, because the currents which cause the heating are developed directly in the mass to be heated.

Melting Very High Conductivity or Non-conducting Materials in a Container which is Electrically Conducting

Pure silver, copper, and even brass possess a conductivity rather too high to permit them to be melted with efficiency by direct induction. Glass, silica, the oxides, porcelain, etc., will not, of course, heat by direct induction. This is true even when these materials are molten as their resistivity is still nearly a million times that of the metals. For melting such materials a crucible of suitable electrical conductivity is provided, and in this is placed the material to be heated or melted. If such crucibles are made of carbon or graphite, temperatures of 2600 to 3000 deg. C. are obtainable; or metals as brass, bronze, silver, copper, etc., may be raised a little above their fusion temperature and be melted with high efficiency. The electric currents are induced almost wholly in the wall of the crucible, which heats rapidly. The material placed in the crucible being in direct contact with its inner surface, readily receives its heat from the crucible. Thus high frequency inductive heating is successfully applied to heat-treating or melting materials of too little or too great conductivity to be heated by direct induction. In this manner most of the refractory oxides have been fused, and the properties of molten high fusion glasses, as Pyrex glass, have been studied. In the writer's view this method could be applied with great economy for the commercial melting of glass.

Heat Treating Steel

A steel or iron mass placed in an inductor coil traversed by an oscillatory or by a continuous high frequency current is heated with peculiar facility up to the temperature where magnetism is lost. Heating can, of course, be carried above this temperature, but up to the temperature where magnetism is lost the heating proceeds from two causes—the eddy currents induced in the material, and the heat developed from hysteresis losses occasioned by the rapid reversals of the magnetism. High frequency inductive heating lends itself very well, therefore, to heating steel masses as drills, milling cutters, dies, etc., for heat treatment and hardening. Masses, however, which have an approximately cylindrical form are those most effectively handled by this method of direct induction.

Inductive Heating to Moderate Temperatures of Large Steel Masses or Shells

Moulds for automobile tires, steel drums, autoclaves, tanks for cracking oil, locomotive wheel rims, and many other masses or shells of steel used in the industries require to be heated to moderate temperatures for one reason or another. It is very feasible to surround such masses or shells with an inductor of strap copper, and heat them by induced currents and hysteresis losses. The possibilities of this application of inductive heating have been very fully and carefully considered and the conclusion is reached that the heating may be accomplished with high thermal efficiency and commercial economy by heating inductively with a frequency as low as 480 cycles per second. Current of this frequency may be obtained from a not-too-costly alternator, direct connected to any form of motor. Such alternators may be obtained from the General Electric Company in 100 kw. units which have an over-all efficiency of approximately 75 per cent. The necessary negative reactance to offset the positive reactance of the heater, and so make it possible to operate the generator at unity power-factor, may be secured by shunting the inductor with static condensers, which are quite moderate in cost.

The striking advantages of high frequency inductive heating appear when it is required to produce an extremely high temperature which must be uniformly distributed over a considerable volume. Thus using 20,000 cycles it is possible to bring a volume of about one-fifth of a cubic foot to a temperature, perfectly uniform throughout this volume, of 2500 deg. C., or perhaps higher, with an input of about 12 kw. at the inductor terminals. Thus, the graphitization of carbon cylinders, crucibles, or blocks is easily accomplished. As will be shown more particularly later, the rate of heating increases with the frequency, and as masses or volumes which are carried to a very high temperature lose heat rapidly, it is necessary in order to reach a high temperature to make the energy input very rapid. To do this inductively requires the use of a high frequency. Hence such moderate frequencies as 480 cycles per second, entirely suitable for heating steel to 300 deg. or 400 deg. C. would not be effective for obtaining such high temperatures as are required in graphitization and for steel melting.

Eleventh. If a frequency other than such standard frequencies as are used on power and lighting circuits is required for inductive heating, it becomes necessary, of course, to provide special apparatus to generate the high frequency power, and this means extra complication, expense, and loss of such power as may be wasted in the special apparatus.

It is well, therefore, to consider briefly the limitations of inductive heating with 25, 50, or 60-cycle current and note if these limitations are such as to necessitate special apparatus to escape them and so justify its use.

Twelfth. The customary and in fact the only commercially possible way of heating to any considerable temperature inductively with ordinary frequencies is to employ the principle of the step-down transformer. Here the material to be heated takes the form of a ring or loop which encircles as a single turn secondary the iron magnetic circuit of the step-down transformer. In any arrangement of this kind there is of necessity considerable magnetic leakage because the single turn secondary cannot be made to fit the iron core closely. This magnetic leakage introduces reactance into the transformer, and in consequence the power-factor is low.

In certain successful induction furnaces of the ring type used for melting or refining steel the coupling is necessarily loose because the high temperatures obtained do not permit of bringing the ring of molten metal close to the iron core. A very low power-factor would result if this type of furnace were operated on 60 or even 25 cycles. It has been found necessary, therefore, to interpose between the commercial supply circuits and the furnace a rotary frequency changer which supplies current to the furnace at 15 cycles or less.

In all types of medium or low frequency induction furnaces in which an iron magnetic circuit interlinks with the primary and secondary electric circuits, the important limitation (which high frequency induction wholly escapes) is imposed, that the melt must be a ring or loop of highly conducting material which is supported in refractory non-conducting material. It is impossible, therefore, to allow the melt to freeze and then start up the furnace from the cold, and not destroy the supporting refractories. Crucibles, solid masses, poorly conducting conglomerates of highly conducting materials, etc., cannot be heated by applying induction in this manner.

If the use of an iron core is abandoned and inductive heating is attempted with 25 cycles, 50 cycles, or 60 cycles severe limitations are at once imposed.

1. With the field intensity which can be obtained in the interior of a solenoid filled with non-magnetic material, the rate of cutting with lines of force of the conducting material to be heated within the solenoid is very slow, altogether too slow to develop currents in the material of a magnitude which will heat it as fast as it will lose heat through the best heat insulation, if the temperature becomes at all elevated.

2. The I^2R losses in the inductor itself constitute a very considerable proportion of the total heat developed. Consequently the efficiency with which heat is supplied to the mass or crucible within the solenoid cannot be high.

3. The inductor and mass within it form a combination which always will have a very considerable self induction. Consequently, the current will lag behind the e.m.f. impressed at the inductor terminals. The power-factor will be objectionably low unless corrected at large expense by means of static condensers or a synchronous machine.

It thus appears that there is no escape from the conclusion that inductive heating without the use of iron and with currents obtained directly from commercial supply circuits is inefficient and wholly impracticable.

On the other hand, if special converter or generator apparatus is provided to supply all the limitations of inductive heating are circumvented and numerous results are made currents from twenty times to four hundred times (depending upon the kind of heating and results to be attained) the frequency of the currents obtained from commercial circuits, possible which can be secured in no other way. Thus the melting can be done in ordinary metal-melting crucibles, it can be made free from carbon or other chemical contamination, it can be made in any kind of atmosphere, or in vacuum, and temperatures approaching those of the arc and uniformly distributed over a large volume can be obtained The relatively high frequency used makes it correspondingly inexpensive to adjust with static condensers the power-factor of the supply to unity.

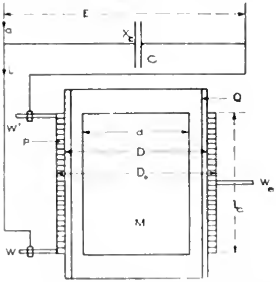

Fig. 1a. Vertical cross section of furnace

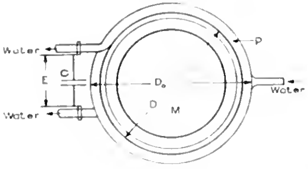

Fig. 1b. Horizontal cross section of furnace

The sole limitation of inductive heating with high frequency is imposed by the cost of the special converter or generator apparatus required for giving a supply of high frequency power. It should be recalled that in most cases of inductive heating with low frequencies special generator apparatus is also required, and possibly quite as expensive as the special apparatus needed for high frequency heating.

Thirteenth. The type and cost of special apparatus for supplying high frequency power will depend upon the quantity of power to be supplied and upon the frequency needed.

For heating large steel masses or shells to a medium temperature the 480 cycles required can best be supplied by motor-generator sets. For all problems where high temperatures are to be obtained and where power units in the neighborhood of 60 kw. or less are required, the oscillatory current high frequency converter is available. Where large power, single, high frequency units are required, the static apparatus as made by the General Electric Company is available. This apparatus supplies high frequency power with continuous sine wave currents. It is constructed to supply power at frequencies in the range of 10,000 to 30,000 cycles. Such static apparatus is obtainable at prices which are not prohibitive in units of 100 kw. or 200 kw.

Fourteenth. We may now with advantage describe a typical form of high frequency inductor, such as would be used for melting ferrous or non-ferrous metals, and then show how certain important factors, also the rate of heating and the efficiency are related to the voltage at coil terminals and to the frequency.

Such typical form of a high frequency inductor arranged to heat a solid cylindrical mass is diagrammatically represented in vertical cross-section in Fig. 1a and in horizontal cross-section in Fig. 1b. Calculations and many tests have shown that an assemblage of this general form is the best possible for high frequency inductive heating without iron.

P is the inductor. It carries the high frequency current and consists of flattened copper tubing wound edgewise. Water is also passed through the tubing to maintain its temperature low. It is generally arranged to enter the water at a centrally located water terminal W_e. The water here divides to flow through the upper and lower halves of the inductor, and makes its exit by way of the outlets W', and W^1, which also serve as the electric terminals.

Q is a thin walled cylinder of electrically insulating material which is also more or less refractory. Quartz cylinders, cylinders of micanite without organic binding material, and asbestos board cylinders have been used.

M is the cylindrical mass to be heated. This cylinder may, of course, be hollow and assume the form of a crucible. For effective heating its conductivity should be between that of mercury and pressed carbon.

E is an e.m.f. impressed at the terminals of the inductor and maintains an effective current *i* of frequency *N* through the inductor.

When the e.m.f. *E* and the current *i* are supplied by a high frequency alternator, the condenser of capacity C may be connected across the terminals and be chosen of a value which will maintain the line current a in phase with the impressed e.m.f. E.

The disposition just described and diagrammed in Figs. 1a and 1b presents a problem on rate of heating and on the efficiency of heating of mass M which is susceptible of fairly precise mathematical analysis. If the mass M were a cylinder having a very thin wall, the formulas deduced* would fit the case accurately. But as M is generally a solid mass or a thick walled crucible, very precise calculations are difficult, if not impossible. We shall deduce a formula, however, which we believe is sufficiently accurate for most engineering requirements. Before doing so we may consider with advantage a few general principles which should be applied in the design of inductive heaters of this type.

It may be assumed that the length l_c of the inductor is fixed and chosen equal to its mean diameter. The radial depth of the inductor $\frac{D_0-D}{2}$ is, of course, subject to selection and may be widely varied. It is usually made about 1.5 cm. to accord with constructions which practice has approved.

It is first to be noted that all possible advantages are secured by making the inductor of *a single layer solenoid*. This is seen to be true from the following observations:

The strength of the magnetic field is proportional to the ampere-turns. Now in the space occupied by an inductor of fixed length and radial depth and traversed by a current to give a certain selected number of ampere-turns, the I^2R heat developed in this inductor (neglecting space occupied by insulation) will be independent both of the number of turns and of the number of layers. Thus if the allotted space were filled with two layers instead of one layer, we would have twice the number of turns, but four times the coil resistance, and we would require (for the same ampere-turns) one half the current Thus $\left(\frac{i}{2}\right)^2 4\,R=i^2R$.

As the voltages at the inductor terminals are high when the frequency is high, the necessary electrical insulation would be difficult to secure with multiple layers. Further, when the frequency is high the distributed capacity of the inductor causes local surges which increase heat losses in the inductor, and this distributed capacity will be increased with added heat losses by using multiple layers.

Secondly, we may assert that for maximum rate of heating (assuming the frequency to be given) the ampere-turns in the inductor should be made as large as possible. Then the feasible maximum of such ampere-turns is determined by the voltage applied at the coil terminals, by safety of the insulation between turns, and more especially by the rate that the inductor may be made to dissipate the heat generated within it and given to it by conduction from the heated mass. Since the inductor is cooled by a flow of water through it, the rate at which its heat may be carried off is very high. But whatever limits are assigned, we may assume that to obtain the most rapid heating possible the ampere-turns should be made as great as possible and then be maintained fixed at this limit. Thus, with a given frequency and a given number of turns in the inductor, we should select the e.m.f. E at the inductor terminals to give the current through the inductor the largest practicable constant value i. As will appear more particularly later, when the product, turns times current, is fixed, the rate of heating will increase nearly in direct proportion to the frequency.

If the e.m.f. at the inductor terminals, and the water pressure-difference at inlet and outlets are simultaneously increased, it is easily conceivable that the field intensity in the interior of the solenoid, and the rate of change of the induction could be made to reach magnitudes so great that metals of the tungsten group would melt rapidly. Such results have already been attained using a small inductor and a small button of the metal. Indeed, the principle is such that given a suitable source of high frequency power supply, molybdenum, tantalum and tungsten could be melted, carbon free in kilogram lots

In deducing the following formulas make reference to Figs. 1a and 1b.

When the coil is carrying a current it is threaded with a magnetic flux. This flux represents electromagnetic energy stored in the medium If there is a mass M in the solenoid a certain proportion of the total flux passes through this mass. Call ϕ this fractional part of the total number of lines of magnetic flux linked with the solenoid which pass through this mass M. If both coil and mass M are very long as compared with their diameters, ϕ will be nearly equal to the ratio of the area of the cross-section of the mass to that of the inductor, both cross-sections being

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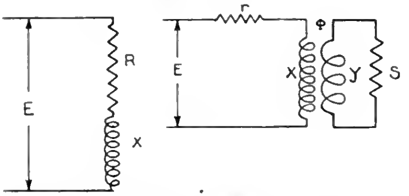
* See "Principles of Inductive Heating with High Frequency Currents," by E. F. Northrup. Trans. of the Amer. Electrochemical Society, Vol. XXXV, 1919 p. 69.

taken vertical to the common axis of solenoid and mass.

When an alternating current i through the coil attains its maximum value I, the total electromagnetic energy given to the electromagnetic field associated with the coil is

$$W = \tfrac{1}{2}LI^2 \qquad (1)$$



Figs. 2a and 2b. Electrical equivalents of furnace circuits

Where L is the coefficient of self induction of the coil.

The energy of that portion of the electromagnetic field, associated with the coil having lines that thread through the mass M is,

$$W_1 = \tfrac{1}{2}\phi LI^2 \qquad (2)$$

It is evident that the energy W_1 is developed every time the current rises from zero to its maximum value I, and if the current is alternating this will occur $2N$ times in the unit of time, where N is the frequency.

If the mass M is a material of suitable electrical conductivity and if the current in the coil rises from zero to a maximum value with extreme rapidity, we may correctly assume that all the energy W_1 is changed into heat energy within the volume of the mass M.

We should think of the electromagnetic energy of the field as flowing into the mass from the outside and as becoming transformed more and more into heat as it penetrates toward the axis of the mass. If the mass is of not too small a cross-section, no electromagnetic energy as such reaches its axis. It is, in fact, practically all converted into heat after having penetrated but a short distance into the surface layer of the mass. This conversion of electromagnetic energy into heat energy is due, of course, to the complicated system of eddy currents set up in the mass, and to hysteresis losses in addition if the mass is magnetic.

Assuming, as in general we may, that the conversion of electromagnetic energy into heat energy is complete before the electromagnetic energy has penetrated to the axis of the mass, we can write for the power supplied to the mass

$$P = 2NW_1 = \phi LNI^2 \qquad (3)$$

If the current is of sine wave form $I^2 = 2i^2$ where I is the maximum and i the effective value of the current. Thus

$$P = 2\phi LNi^2 \qquad (4)$$

or since the reactance $x = 2\pi\ N\ L$ we have

$$P = \frac{\phi x}{\pi} i^2 \qquad (5)$$

If E is the sine wave e.m.f. impressed at the terminals of the inductor

$$i^2 = \frac{E^2}{R^2 + X^2} \qquad (6)$$

and we have, substituting in equation (4)

$$P = \frac{2\phi LN}{R^2 + X^2} E^2 \qquad (7)$$

In expressions (6) and (7) R and X are the equivalent resistance and reactance, as represented in Fig. 2a, of the inductively coupled circuits, as represented in Fig. 2b.

In the circuits shown in Fig. 2b, r is the ohmic resistance (to high frequency current) of the inductor coil. The reactance of the inductor coil is x. The reactance of the mass being heated is y. This may be considered as the reactance of a circumferential outer shell of the mass having a thickness equal to the depth of penetration* into the mass of the induced current. S is the ohmic resistance of the same path through the same shell.

It can be shown† that when the frequency is high and when the current penetration below the surface is not great, the effective resistance and the effective reactance of the conductor are equal. Thus we shall always write $S = y$.

With this understood, analysis (too lengthy to be given here) shows that

$$R = \frac{2r + \phi^2 x}{2} \text{ and } X = \frac{x(2 - \phi^2)}{2}$$

These values for R and X placed in equation (7) give as an expression for the absorbed power

$$P = \frac{4\phi x E^2}{\pi\left[(2r + \phi^2 x)^2 + x^2(2 - \phi^2)^2\right]} \qquad (8)$$

When the frequency is high and an inductor for this frequency is properly constructed from water cooled copper tubing, its resistance r is a small quantity compared with its reactance x. Under these circumstances, r

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* Consult "Transient Electric Phenomena and Oscillations," Chapter VII, by Steinmetz.

† Ibid., p. 376, 1909 edition.

may be neglected with small error and equation (8) becomes:

$$P_1 = \frac{2\phi E^2}{\pi x(\phi^4+2-2\phi^2)} \tag{9}$$

or

$$P_1 = \frac{0.636\phi E^2}{x(\phi^4+2-2\phi^2)} \tag{10}$$

Experience has shown that a favorable and not uncommon value for ϕ is 0.6. Giving ϕ this value, equation (10) becomes;

$$P_{11} = \frac{0.27E^2}{x} \tag{11}$$

or as $x = 2\pi NL$

$$P_{11} = \frac{0.043\,E^2}{NL} \tag{12}$$

Since

$$i = \frac{E}{\sqrt{R^2+X^2}}$$

we have when we place

$$R = \frac{\phi^2 x}{2} \text{ and } X = \frac{x(2-\phi^2)}{2}$$

$$i = \frac{\sqrt{2}\,E}{x\sqrt{\phi^4+2-2\phi^2}} \tag{13}$$

By combining equations (5) and (13)

$$P_1 = \frac{\sqrt{2}\,\phi Ei}{\pi\sqrt{\phi^4+2-2\phi^2}} = \frac{0.45\phi Ei}{\sqrt{\phi^4+2-2\phi^2}} \tag{14}$$

when $\phi = 0.6$ equation (14) becomes

$$P_{11} = 0.37Ei \tag{15}$$

Equations (3), (4), (5), (8), (9), (10), (12), (14) and (15) give various expressions for the power absorbed by the furnace. Equations (10) and (14) are very useful for designing a furnace of the general type represented in Figs. 1a and 1b to absorb a given power when operated with a given voltage and frequency.

We may note the following general principles which are readily deduced from the above equations;

In equation (14), if we place $\phi = 1$, which is the closest coupling possible, $P_1 = 0.45\ Ei$. Thus the power-factor can never exceed 45 per cent or the current will lag behind the e.m.f. 63 deg. 15 min.

In practice the coupling is usually $\phi = 0.6$. In this case the power-factor is 37 per cent or the current will lag 68 deg. 17 min.

By equation (4) we note that when all other quantities are kept constant, the power absorbed is proportional to the frequency. It is on this principle that the chief advantages rest of high frequency inductive heating.

Equations (9) or (10) may be written

$$P \alpha \frac{E^2}{NL} \tag{16}$$

Thus to maintain the absorbed power constant with applied e.m.f. constant, the self induction of the inductor must be changed inversely as the frequency is changed, or the product NL must be kept constant. Since the self induction L of a solenoidal winding of fixed dimensions is proportional to the square of its number of turns N we have

$$P \alpha \frac{E^2}{Nn^2} \tag{17}$$

Hence to maintain the absorbed power constant we must, in designing a furnace, select the number of turns in its inductor proportional to the e.m.f. available.

We can write equation (4)

$$P \alpha NLi^2 \alpha Nn^2 i^2.$$

Hence, the ampere-turns Ni should be maintained constant to obtain constant power P.

In melting metals in an induction furnace, the rate at which energy is absorbed by the melt has a vital bearing upon the melting efficiency of the furnace. This melting efficiency may be defined as the ratio of watthours utilized for changing metal from its solid state at room temperature into molten metal at pouring temperature, to the watthours delivered to the terminals of the inductor.

Of the power supplied at the inductor terminals a certain portion will be wasted in i^2r losses in the inductor itself. If the frequency is low the proportionate quantity of the power thus lost may be very considerable, but with a frequency of 5000 to 30,000 cycles this loss becomes quite insignificant, and it may be made small under certain conditions of heating to moderate temperatures, with a frequency as low as 480 cycles per second.

It can be shown that the efficiency of the rate of supplying heat to the mass (quite a different matter than rate of melting efficiency) is an expression of the form

$$F = \frac{1}{\dfrac{2\,R_{ac}}{\phi^2\,x} + 1} \tag{18}$$

where R_{ac} is the ohmic resistance to high frequency current of the inductor, x its reactance, and ϕ the coefficient of coupling. Thus, if the frequency is high, x is very large compared with R_{ac}, and the heating efficiency may easily reach values above 90 per cent.

Of the power which goes into the melt (which, as stated, may be 90 per cent or more of the power delivered to inductor terminals) a very considerable proportion is lost (hence unavailable for heating the metal and for supplying the latent heat of fusion to melt it) by radiation and conduction. The higher the temperature at which the metal melts, the greater will be this rate of heat loss. It is very evident, therefore, that the faster a given mass of metal is melted, the less will be the time it is kept hot and the less will be its heat loss before it is ready to pour, by radiation and conduction. Hence, for efficient melting fast melting is essential.

When a furnace has been designed so that its inductor has a maximum allowable number of ampere-turns, if these are maintained constant, the rate of heating will increase directly with the frequency (see equation 4). It is in this respect especially that high frequency has a great advantage over medium frequency, because the fast melting possible with the former gives efficient melting.

In applications of inductive heating to large steel masses or steel drums which are brought to a relatively low temperature, as 300 deg. C. or 400 deg. C., comparatively low frequencies can be used efficiently. In some particular cases calculated it was found that very efficient heating could be expected with a frequency of 480 cycles per second, and power with current at this frequency is readily and economically obtainable from a motor-generator set.

Fifteenth. When the power supplied to the heater is derived from any form of generative apparatus which is itself the seat of a high frequency e.m.f., such as a high frequency alternator, it becomes important to bring the current into phase with the e.m.f. near the inductor terminals in order that the generator may supply the power to what is equivalent to a non-inductive load. By thus correcting the otherwise low power-factor the kilowatt rating of the generator will become equal to its kilovolt-ampere rating

On the other hand, when the inductor coil of the furnace forms part, either directly or by inductive coupling, of an oscillatory circuit, whether such oscillatory circuit is the seat of discontinuous or continuous oscillations, no advantage whatever is gained by making a phase adjustment at or near the inductor terminals.

When a phase adjustment is to be made this is easily and not too expensively accomplished by balancing the positive reactance of the furnace with a suitable negative reactance. This negative reactance is best obtained with static condensers. The condensers can be joined in series with the furnace inductor, or be connected across its terminals in parallel to it. The latter method is to be preferred because the voltage at the inductor terminals will never rise then by resonance higher than the voltage at the source.

Thus in Figs. 1a and 1b the capacity C for phase correction is indicated connected to the inductor terminals.

When C is correctly chosen, the supply current a will be in exact phase with the impressed e.m.f. E.

The well known relation for correction of power-factor* with a shunted reactance is

$$X_c = \frac{1}{2\pi NC} = \frac{R^2 + X^2}{X} \qquad (18a)$$

Here R is the equivalent resistance and X the equivalent positive reactance of the furnace circuit. If we neglect, as we may with small error, the ohmic resistance of the inductor coil, we shall have as stated on page 662

$$R = \frac{\phi^2 x}{2},\ X = \frac{x(2-\phi^2)}{2}$$

These values for R and X substituted in equation (18) give

$$X_c = \frac{1}{2\pi NC} = \frac{x(\phi^4 + 2 - 2\phi^2)}{2-\phi^2} \qquad (19)$$

From equation (19)

$$C = \frac{2-\phi^2}{4\pi^2 N^2 L\,(\phi^4+2-2\phi^2)} = \frac{0.0253\,(2-\phi^2)}{N^2 L\,(\phi^4+2-2\phi^2)} \qquad (20)$$

If

$\phi = 0$, $x_c = x$ and if $\phi = 1$, $x_c = x$. If $\phi = 0.6$, a common value,

$$\frac{2-\phi^2}{\phi^4 + 2 - 2\phi^2} = 1.163 \text{ or } x_c = 1.163x$$

It thus appears that the negative reactance or the capacity required for phase correction is little affected by the degree of coupling. This is worth noting, for in melting metals in a non-conducting crucible the coupling will be good or bad according as the crucible is nearly full or empty. Thus if the phase correction is made for an average coupling, it will remain nearly corrected when the coupling varies.

The bulk of a condenser to have a certain capacity C and withstand a certain e.m.f. E at its terminals is proportional to its capacity and to the square of the voltage applied to its

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* See "Alternating Current Phenomena," by Steinmetz, 3rd edition (21), p. 73.

terminals. If it is assumed that its cost is proportional to its bulk, we can write

$$\$\alpha C\,E^2. \tag{21}$$

From equation (9)

$$E^2\alpha\frac{N\,L\,P_1\,(\phi^4+2-2\,\phi^2)}{\phi} \tag{22}$$

and from equation (20)

$$C\,\alpha\frac{2-\phi^2}{N^2\,L\,(\phi^4+2-2\,\phi^2)} \tag{23}$$

Hence by equations (21), (22), (23)

$$\$\alpha\frac{P_1(2-\phi^2)}{\phi N} \tag{24}$$

From equation (24) it is concluded that the cost of the condensers (where cost is rated as proportional to their $C\,E^2$ value) to correct the power-factor is directly as the power absorbed, and inversely as the frequency used. This statement should be qualified, however, by drawing attention to the fact that the rating of condensers is generally based upon their kv-a. capacity. Thus;

$$KV\text{-}A.=\frac{Ei}{1000}=\frac{E.\,2\pi\,N\,C\,E}{1000}=\frac{2\pi\,N\,C\,E^2}{1000} \tag{25}$$

If therefore we assume the cost is proportional to the kv-a. rating, we have

$$\$\alpha\,N\,C\,E^2\,\alpha\,P_1\frac{2-\phi^2}{\phi} \tag{26}$$

in which case the cost of the condensers for phase correction is independent of the frequency. The kv-a., however, of a condenser of given CE^2 rating is determined by its dielectric heat losses and its ability to dissipate the heat generated in it. By properly constructing the condenser to minimize the dielectric loss, and by suitably sub-dividing it into small units to give large heat dissipating surface, the kv-a. rating can be made very large so that the CE^2 rating becomes the determining factor of its cost. With this understood, equation (24) correctly expresses the relation of the cost of the condensers for phase correction, to power and frequency.

Sixteenth. From the foregoing we conclude that the fundamental advantages of high frequency inductive heating are:

(1) The mass heated may assume a continuous cylindrical form through which no iron or other material need pass, as in low frequency induction furnaces which use iron to increase the induction.

(2) High frequency induction gives in continuous masses rapid heating, the rapidity of which increases with the frequency. In melting operations this rapid heating results in highly efficient melting.

(3) The physical construction of a high frequency induction furnace is such that the possible temperatures attainable in any desired atmosphere or in vacuum closely approach the temperature of the carbon arc, and such possible high temperatures may be uniformly distributed over a considerable volume.

(4) When generator apparatus of the alternator type supplies the power, the power-factor can be adjusted to unity with static condensers, and the cost of these decreases with the frequency and becomes low when the frequency is made high.

Seventeenth. High frequency power required for inductive heating without iron may be derived from three classes of apparatus.

(1) For frequencies from 480 cycles to 700 cycles per second an alternator driven by direct connection with an induction motor or synchronous motor may be used.

(2) For frequencies from 5,000 to 50,000 cycles per second, where the power units required do not exceed 70 kw. (input rating) high frequency converters, single or multiphase, may be used. These, as made by the Ajax Electrothermic Corporation, depend for their operation upon the use of a non-vacuum mercury discharge gap. The high frequency current consists of trains of rapidly damped out oscillatory discharges of banks of condensers.

(3) For supplying power in larger units at frequencies from 10,000 to 30,000 cycles per second, the static high frequency converters, as made by the General Electric Company for radio work are very adaptable, and are now available. Such apparatus has been constructed for radio work which, in a single unit, delivers 200 kw., single phase, high frequency power. Several such units may be combined and adapted to supply power to a single heater, and thus the power limitation of high frequency inductive heating is only limited by the first cost of the apparatus. In apparatus of this type use is made of vacuum bulbs to maintain electricity surging in a circuit having inductance, capacity and effective resistance, the load. The current supplied is continuous and of sine-wave form. Because of this latter characteristic coreless transformers may be used with little loss in efficiency to give any voltage and current ratios desired. We look to apparatus of this type to solve the problem of the commercial application of high frequency inductive heating to requirements calling for high temperature and large amounts of power.

Eighteenth. To date (June, 1922) about 1000 kw. of high frequency power are in use for inductive heating of many different kinds. Steel, non-ferrous and precious metals including pure platinum are being melted. Very high melting tungsten alloys are being made. Steel tools are being heated for working and for heat treatment. High melting glass is being melted to study its properties when molten. The metal parts in vacuum bulbs are being inductively heated to drive out occluded gases. It has been demonstrated that carbon blocks imbedded in carbon-black may be graphitized by heating inductively, and the method is commercially promising.

Carefully made calculations predict that autoclaves and large steel shells may be better and more economically heated to a moderate temperature inductively with a frequency as low as 480 cycles per second, than with heat supplied externally with resistance windings.

• Inductive heating puts the heat directly into the material to be heated and when retained with suitable heat insulation, the temperatures obtainable are limited only by the fusion temperatures of the best refractories.

As high frequency power becomes more available at lower costs and in greater quantity nearly every industrial field where high temperature is required will be invaded.

To the scientist engaged in the study of the properties of matter at high temperature and under controllable chemical conditions the method of high frequency inductive heating is absolutely indispensable.

Its future is very bright because it is the most versatile of all known methods of producing temperature and because heat-treating materials through wide ranges of temperature, even in tonnage lots, is economically possible. Time is sure to bring engineers and capital to a further recognition of these facts.

Commercial Radio Telephone and Telegraph Transmitting Equipment

PART II

By W. R. G. Baker and B. R. Cummings
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Part I of this article, which appeared in our last issue, explained why the continuous waves or interrupted continuous waves given out by a vacuum tube transmitter are superior for radio telegraphy to the damped wave trains given out by the spark type of transmitter. Also, a preliminary description was given of a 200-watt and a 1000-watt vacuum tube transmitter for commercial radio telephony and telegraphy. The following installment furnishes a detailed description of the several component parts of these equipments, the completely assembled unit, and the same information for a somewhat similar transmitter of 2000-watt output.—Editor.

The power equipment illustrated in Fig. 3 is a three-unit motor-generator set, consisting of a motor, a double-current self-excited generator, and a high-voltage direct-current generator.

The standard equipment consists of either a 115-volt direct current or a 110/220-volt 50/60-cycle motor. The double-current generator generates direct current at 125 volts for the excitation of the high-voltage direct-current generator, and for the operation of relays and auxiliaries. It also generates single-phase alternating current which is stepped down through suitable transformers for filament illumination. The direct current equipments have a speed regulator. It will be noted that the combination of a speed regulator and a self-excited generator for the high-voltage machine makes the filament and plate voltages practically independent of normal variations in supply voltage.

This combination of units in the power equipment also makes the power supply to the transmitter independent of the line supply; i.e., the motor may operate from any power supply without affecting the output to the transmitter, so long as the speed is maintained.

Suitable protective condensers are mounted on the power equipment to absorb high-potential surges which are sometimes incident to the operation of the set.

The motor starter is mounted within the transmitter structure and is operated by means of momentary contact "start" and "stop" push buttons. Momentary contact control has been provided to insure under-voltage and no-voltage protection. In the case of voltage failure, the power equipment will stop and will not start again until the start button is depressed. The use of the momentary contact system also is utilized by the plate overload relay. This relay is made to break the circuit of the holding coil in the starter, shutting down the power equipment in the event of overload in the plate circuit.

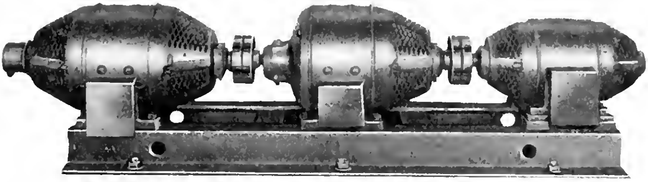

Fig. 3. 2000-volt, Direct-current Motor-generator Set for the Radio Transmitter shown in Fig. 4

The external appearance of the 1000-watt transmitter is shown in Figs. 4, 5, 6, 7, and 8.

Fig. 4. 1-kw. Commercial Transmitter for Telephony, Interrupted-continuous-wave Telegraphy and Continuous-wave Telegraphy

It has been designed with ample consideration to high-voltage clearances and creepage distances, ruggedness, and accessibility to component units. Doors are provided in the panel for easy access to the loading coil, plate coil, and grid condenser adjustments. Additional doors in the bottom of the panel give access to all fuses and the terminal board of the transmitter. All equipment which may require attention from time to time, such as the motor starter and motor-driven interrupter, is accessible from the right-hand side of the transmitter facing the panel. The component parts of the transmitter are mounted on an angle-iron frame. On the metal panel forming the front of the unit are mounted the following instruments and controls:

(a) Wave changing switch
(b) Signal change switch
(c) Power change switch
(d) Antenna ammeter
(e) Plate voltmeter
(f) Plate circuit relay
(g) Plate voltage rheostat

The overall dimensions of the transmitter proper are:

Width 29 in.
Depth 23 inches including projection of controls, etc.
Height 69 inches including projection of antenna insulator
Weight boxed (approximate) 225 lb.

The radiotrons are mounted on a spring suspended rack at the top of the transmitter. They are visible to the operator at all times through the perforated section of the panel.

The wave changing switch is one of the most unique units making up the transmitter. It is designed for four positions, making it possible in one operation to shift to any one of the four wavelengths to which the transmitter is adjusted. It is a gang switch, including four banks which control taps on the following circuits and equipment:

(a) Plate coil
(b) Grid coupling capacity
(c) Grid coupling connection to the antenna
(d) Loading inductance and series condensers

The signal change switch has for its function the changing of the connections necessary when transferring from one method of signalling to another This is accomplished by one operation of the switch, in as much as the eight banks composing the switch transfer all circuits affected by the change in signalling

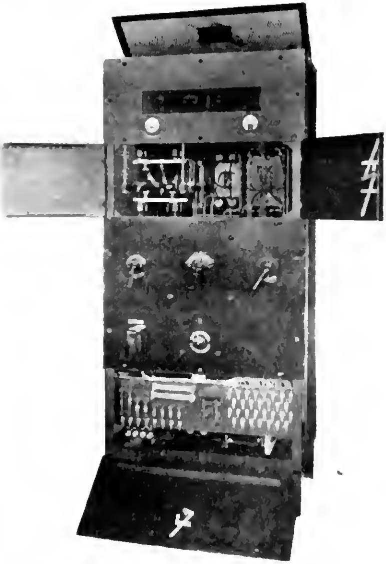

Fig 5. Same as Fig. 4, showing Doors Open for Adjusting Transmitter

The power change switch is a two-bank gang switch, simultaneously changing the plate voltage by variation of resistance in the high-voltage generator field and changing the biasing voltage on the grids of the modulator tubes. The switch has two positions, for "high" and "low" (approximately $\frac{1}{3}$) power respectively Change in power requires no other adjustment than the operation of this switch

The grid coupling condenser is built of mica dielectric in an aluminum case, and has ten taps with respective capacities of 0.0001 to 0.00001 mfd in steps of 0.00001 mfd These taps are provided for best adjustment of grid coupling

The loading coil is made of copper strip, wound edgewise, with rounded edges. The fact that this coil is wound of bare conductor makes it possible to connect to it at any point for exact tuning to required wavelengths. It is accessible through a door in the upper part of the transmitter panel. Four busbars are provided, one for each position of the wave change switch, running the length of the loading inductance. A flexible connector is attached to each bus, and may be shifted along the busbar until opposite the point at which the other end of the connector will be attached to the loading inductance. This arrangement eliminates complication in wiring, and insures positive clearance between the four flexible conductors.

Adjustments for plate and grid coupling are also made through a door in the panel, located in the upper right-hand side of the structure.

The three series antenna condensers have capacities of 0.00028, 0.00078 and 0.004 mfd. These are mounted in the transmitter and are built of mica dielectric in aluminum cases. The 0.00028 unit is used to obtain 300 meters, the 0.00078 unit to obtain 450 meters, and the 0.004 unit to obtain 600 meters. These condensers are switched in and out of circuit by the wave change switch.

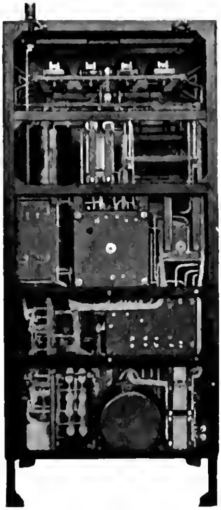

Fig. 6. Rear View of Transmitter shown in Fig. 4

In conjunction with the standard transmitting equipment, provision has been made for remotely operating the send-receive controls from a distant station by a so-called "subscriber." To accomplish this, it is necessary to add one unit at the operator's transmitting station and five units at the subscriber's station. The operator's control unit, shown in Fig. 9, is 12 in. long, 8 in. wide, 6 in. deep and weighs approximately 20 lb. It is designed to be mounted with its top flush with the surface of the operator's table.

The unit contains the following equipment:

(a) Three-position Control Switch. This switch has three positions: "Local," "Remote," and "Interphone." When in the "Local" position, the operator has complete control of the transmitter. When in the "Remote" position, the "send-receive" control is transferred to the send-receive switch in the subscriber's control unit. When in the "Interphone" position, wire telephony is available between the operator and the extension station.

(b) Momentary Contact "Start" and "Stop" Push Buttons. These controls are in the operator's control unit only. It is not possible to start or stop the transmitter from the extension station

(c) Operator's "Send-Receive" Control. This is a tumbler switch, with name plates to designate its respective positions. When the control is thrown to the "Remote" position, the operator has no control over the send-receive switch.

(d) Ringing Push Button. This button is used to ring the bell at the extension station

(e) Jack for Breast Microphone.

(f) Jack for Head Phones.

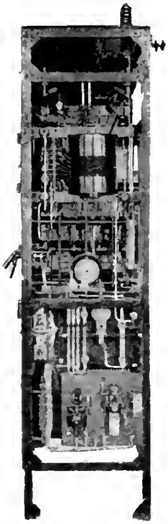

Fig. 7. Side View of Transmitter (Fig. 4) showing Starting Equipment and Sending and Receiving Relay

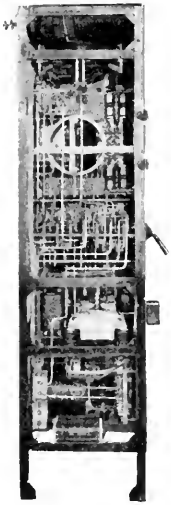

Fig. 8. Side View of Transmitter (Fig. 4) showing Arrangement of Signal Switch

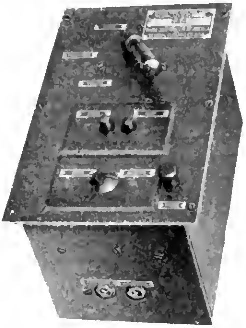

Fig. 9. Operator's Control Unit (Exterior View) for 200 and 1000-watt Radio Telephone Transmitters

The operator's accessory apparatus is shown in Fig. 10.

The five additional units at the subscriber's station are shown in Fig 11. The subscriber's control unit contains a tumbler "send-receive" control switch for actuating the send-receive switch in the transmitter when the operator has thrown the control to the subscriber's station, and a "Ringing" push button to call the operator. The unit is approximately 6 inches long, 3 inches high, and 2 inches deep and is designed for mounting on the desk at the extension station in a convenient position to facilitate the manipulation of the send-receive control.

The desk-stand is identical with standard desk-stand telephone equipment except that no hook is included for the receiver. A desk-stand clamp is supplied for attaching to the edge of the desk at the subscriber's station. This clamp is intended to hold the desk-stand in place when not in use and when there is sufficient roll on shipboard to make its use desirable.

Fig. 10. Operator's Accessory Equipment for 200 and 1000-watt Radio Telephone Transmitters

Two pairs of head phones are included, one for the operator and one for the subscriber's station

In the case of portable or semi-portable sets, such as are provided for ship equipment, space is one of the principal factors governing both the electrical and mechanical design. Ordinarily equipments of this type must be passed through hatchways and doors and are allotted a very definite space in the radio room. In addition, transmitters for shipboard service must provide certain fixed wavelengths on various antennas having a considerable range of electrical constants

The fixed station on the other hand is usually a permanent installation in which case space and weight are ordinarily of secondary consideration. This type of equipment is usually of considerably higher power than the portable sets, hence the requirements for controls and switching are not so severe.

A two-kilowatt fixed station set is shown in Figs. 12, 13 and 14 It will be noted that the design is entirely different from the commercial ship sets previously discussed. The factors to be noted are the ruggedness, simplicity, and freedom from congestion of either the units or the wiring. The resemblance to a power switchboard is quite striking and results from the use of a great number of standard units normally utilized in power practice.

This equipment provides continuous-wave and interrupted-continuous-wave telegraphy on wavelengths from 600 to 3000 meters. The floor space required is 10 sq. ft. and the overall height is 9 ft The equipment may be divided into two sections, the rectifier unit and the radio transmitter.

In the case of the two commercial sets previously considered all power is obtained from a motor-generator set. The motor of this unit can be either of the alternating-current or the direct-current type, hence the equipment is practically independent of the supply voltage or frequency. The two-kilowatt set is designed with the same idea in mind. The equipment is normally supplied for 220-volt 60-cycle power When this supply is not available an auto-transformer may be used. The rectifier unit replaces the motor-generator used with the smaller power transmitters The radiotrons (UV-206) used as oscillators require a direct-current supply of at least 10,000 volts. The most convenient method of obtaining this is by means of kenotron rectifiers.

The function of the rectifier unit is to transform the low-voltage alternating-current supply into a high-voltage direct current. This transformation is accomplished by first stepping up the low-voltage single-phase alternating current to 25,000 volts. This voltage is then impressed on two kenotrons (UV-218) connected for full-wave rectification. The output of the kenotrons has 120 pulsations per second which after passing through a suitable filter or smoothing-out circuit results in practically a direct-current supply. A schematic diagram of this portion of the circuit is shown in Fig 15

Fig 11 Extension Station Equipment for 200 and 1000-watt Radio Telephone Transmitters

Referring to Fig. 12, which shows the panel of the equipment and particularly to the left-hand section which contains the power controls, the upper portion contains a wattmeter, line voltmeter, direct-current ammeter for indicating the high-voltage direct current supplied to the radio transmitter, and a filament voltmeter for use with either the kenotrons or radiotrons. Directly below the meters are mounted three protective relays which have a number of functions, one of which is to prevent overloading the radiotrons sufficiently to destroy the tubes. Below the protective relays is located the filament voltmeter transfer jack. The second section of the panel contains isolating switches for the filament and plate circuits as well as a line switch, rheostats for filament excitation control, and "stop" and "start" buttons. The lower section contains a power switch that, by means of taps on the auto-transformer, provides a variation in the voltage impressed on the primary of the plate transformer thus permitting an adjustment of the output of the rectifier unit. The small handle controls an induction regulator which permits compensation for small changes in line voltage.

The lamps and buzzers mounted on the top of the panels are filament burn-out indicators. The left-hand indicator is in the kenotron filament circuit; the other in the radiotron filament circuit. If a kenotron filament should burn out the buzzer and lamp associated with this circuit would function. These units are designed to insert reactance in the filament circuit to prevent damaging the remaining tube, due to any increase in supply voltage owing to the decreased load caused by the filament burning out

Fig. 12. 2-kw. Radio Telegraph Transmitter for Interrupted-continuous-wave and Continuous-wave Communication. Wavelength 600 to 3000 meters

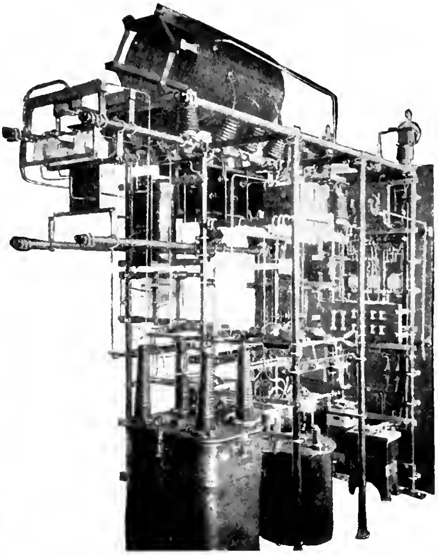

Fig. 13. Rear view of Transmitter shown in Fig. 12

The set may be started or stopped either from the kenotron panel or from the operator's desk Suitable means are provided to discharge all condensers whenever the "stop" button is operated.

The right-hand portion of the panel shown in Fig. 12 contains the controls for the radio transmitter. The handle shown in the upper section provides means for selecting any one of three wavelengths between 600 and 3000 meters. This wave change switch consists of a three-position three-bank switch so that when changing wavelengths it is only necessary to operate one switch, which varies the constants of the antenna and associated circuits. The center section of the panel contains the keying relay, which is remotely controlled by the operator's telegraph key. The two-position switch below the keying relay selects the type of telegraph communication, i.e., continuous-wave or interrupted-continuous-wave.

The rear view of this equipment is shown in Fig. 13. All tubes are mounted on spring suspended cradles. Below the tubes and located on the floor are the plate transformer, kenotron filament transformer and smoothing reactance. The auto-transformer and induction regulator are mounted directly behind the kenotron panel. The oscillation transformer and antenna loading inductance are made in one unit and mounted directly above the wave change switch. The porcelain tube mounted at the rear of the wave change switch supports the grid inductance.

The radio circuits employed in the two-kilowatt transmitter differ materially from those in the two equipments previously described since in these sets regeneration is effected by coupling between the grid and antenna circuits. In the two-kilowatt transmitter, the two radiotrons (UV-206) used as oscillators function as dynatrons, hence the grid and antenna circuits are not coupled. One distinct advantage of this type of circuit is that the wavelength is not determined by the constants of the antenna circuit but is set by the inductance and capacitance of the grid circuit.

Interrupted-continuous-wave telegraphy is provided by inserting a motor-driven commutator in the grid circuit of the oscillators. This motor is controlled, and the grid circuit constants changed, by the communication switch on the radio panel.

Complete control of the equipment is provided from the operator's desk. In addition to the telegraph key which controls the keying relay, two sets of push buttons are provided, "start" and "stop," and "send" and "receive." The "start" and "stop" buttons control the main line contactor which disconnects the power supply on the set-side of the main line switch. The "send" and "receive" buttons control the necessary contactors and interlocking circuits required to connect either the transmitter or the receiver to the antenna and to prevent accidental starting of the transmitter when the "receive" button is depressed

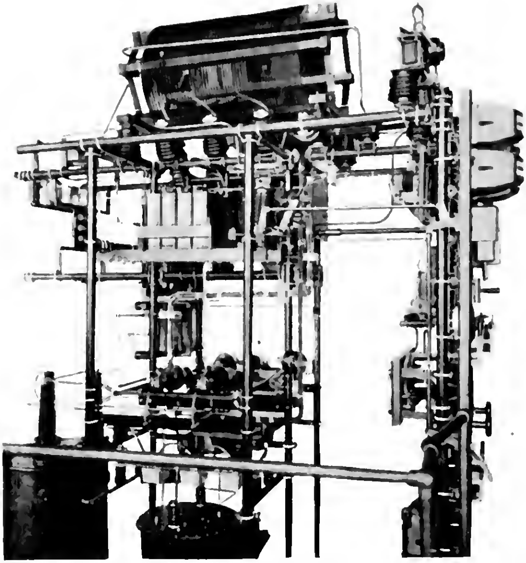

Fig. 14. Side View of Radio Telegraph Transmitter shown in Fig. 12

The range of a radio transmitter is difficult to specify unless very definite conditions are mentioned. For example, a transmitter will have a range at night two or three times as great as in daylight; it will have a greater range on a dark night than on a moonlight night; the nature of the intervening country, the type of receiving equipment used, the amount of interference present, either atmospheric or caused by other radio stations, the ability of the receiving operator to get the most out of his receiving equipment, and numerous other factors enter, which indicate the difficulty of specifying a given range for a particular type of transmitter.

Since some ranges must be specified for these equipments to give the order of their effectiveness, the following ranges have been established as being those of the 200-watt and one-kilowatt transmitters respectively These ranges should be obtained under normal operating conditions:

Rating of Equipment	200 Watts	1000 Watts
Telephone	100 miles	200 miles
Interrupted-continuous-wave telegraph	200 miles	400 miles
Continuous-wave telegraph	400 miles	800 miles

That these figures are conservative is indicated by the performance of one of the one-kilowatt transmitters installed at Washington, D. C., which has communicated satisfactorily in daylight with Omaha, Neb., North Platte, Neb., and Iowa City, Iowa, clearly showing that this set has a daylight transmitting range of over 1200 miles, using continuous-wave telegraphy.

After the installation of the two-kilowatt transmitter was completed at Almirante, comparative tests were made between it and the 25-kw. spark transmitter installed at Swan Island. Distances from New Orleans to Swan Island and Almirante are approximately 950 miles and 1500 miles respectively. Reception in both cases was made at New Orleans. The ratio of the audibilities of the received signals at New Orleans for the two-kilowatt tube set at Almirante and the 25-kw. spark set at Swan Island respectively were 25 to 15 in favor of the tube transmitter.

While the superior transmission effectiveness of vacuum-tube transmitters over spark transmitters is fully realized, it should be remembered that the great majority of ship and low-power shore stations still use spark transmitters, and that considerable time must elapse before continuous-wave transmission becomes universal. During the years 1917 to 1920, the vacuum-tube transmitter was not developed to a stage where it was available for general application; and, as a result, the majority of the tremendous number of ship and low-power shore sets which were built during that time were spark sets.

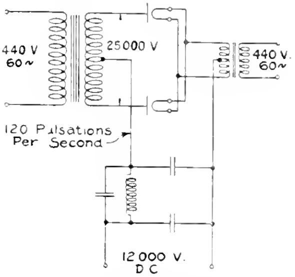

Fig. 15. Diagram of Kenotron Rectifier Connections for 2-kw. Radio Telegraph Transmitter

During the period mentioned, however, vacuum-tube sets were largely utilized for aircraft radio. It was essential that aircraft transmitters be built for telephone transmission, in order that the services of a code operator could be dispensed with. In fact, it was the impetus given to vacuum-tube aircraft transmitter development during this period that contributed most largely to the recent further development of medium-power and high-power ship and shore station transmitters.

Spark sets have given and are still giving extremely satisfactory service, within their inherent limitations. But their field will inevitably become smaller and smaller, due both to the advantages of continuous-wave transmission and to legislation which is gradually taking shape to eliminate unnecessary interference in radio communication.

Present Status of High Voltage Transmission of Power

PART II

By W. W. Lewis

Lighting Department, General Electric Company

This installment of the article concludes the subject of high voltage transmission with a discussion of synchronous condensers, characteristics of long lines, transformers, oil circuit breakers, and bushings. Part I, which appeared in our October issue, treated of the present limit of transmission voltage, line insulation, corona, grounded neutral, protection, and charging the line. It also included tabulated data on 160 transmission systems whose circuit voltages are 66,000 or above.—Editor.

Synchronous Condensers

Synchronous condensers, as synchronous motors are called when used primarily for power-factor and voltage correction, are essential on large power systems for the regulation of voltage at the receiving station. At times of heavy load the condensers are over-excited, drawing leading current from the generating system, and at times of light load they are under-excited and draw lagging current. Synchronous condensers are commonly installed up to about 60 per cent of the kv-a. of the load at 0.8 power-factor for example. They are usually designed to operate lagging for only a nominal kv-a. but may be specially designed to operate lagging up to 75 per cent or more of their rating. The condensers in conjunction with Tirril regulators may be set to hold constant potential at the receiver. The generator voltage is also held constant by means of Tirril regulators either at the same or higher voltage than that of the receiving station. On some systems the generator voltage is varied to suit the load conditions, but this practice is being superseded in favor of the constant voltage operation just mentioned and practically all new systems are being laid out in this manner. Condensers may also be placed at points along the line and constant potential maintained at all points.

Characteristics of Long Lines

About a year ago the writer had occasion to carry out the electrical design of a 750-mile line for the Argentine Republic. In working out the electrical characteristics it was found desirable to consider lines of all lengths up to 3,000 miles. Some of the details of this study may prove of interest.

The performance of such long lines at the usual frequencies is different, or at least appears different, from that of the lines to which we have been accustomed. This arises from the fact that such lines approach in length the quarter or half length of a wave of commercial frequency. The wavelengths for various frequencies are as follows:

	Miles
10 cycles, approximately..............	18,000
25 cycles, approximately..............	7,200
50 cycles, approximately..............	3,600
60 cycles, approximately..............	3,000
100 cycles, approximately..............	1,800
120 cycles, approximately..............	1,500

A 750-mile line, as contemplated by the Argentine Republic, is about one-quarter wavelength for sixty cycles, and one-fifth wavelength for 50 cycles, and it is therefore at a peculiarly critical length for these frequencies. The Argentine development contemplated transmission of a block of power in the neighborhood of 100,000 to 125,000 kw. at about 200,000 volts. Sixty cycles was selected for the main investigation as this best brings out the peculiar character of quarter wavelength transmission.

Two main considerations govern the amount of power which may be transmitted over a line, that is, voltage drop and power loss. For every line there is a particular load* which gives a drop practically equal to the I^2R loss. This load at unity power-factor is determined by the equation

$$Kw. = \frac{Kv^2 \times 10^3}{\sqrt{L/C}}$$

or expressed another way, $I = \frac{e}{\sqrt{L/C}}$ in which $\sqrt{L/C}$ is the natural impedance of the line and all quantities are referred to the receiver end. Thus if $\sqrt{L/C} = 400$ and the voltage at receiver end $= 200$ kv., then 100,000 kw. at unity power-factor is the load for this line that satisfies the preceding criterion. This holds regardless of the frequency. This load may be increased about two-thirds by splitting the conductor into three parts,* each one-third the cross section of the original conductor. Splitting the conductor into two parts gives a smaller increase.

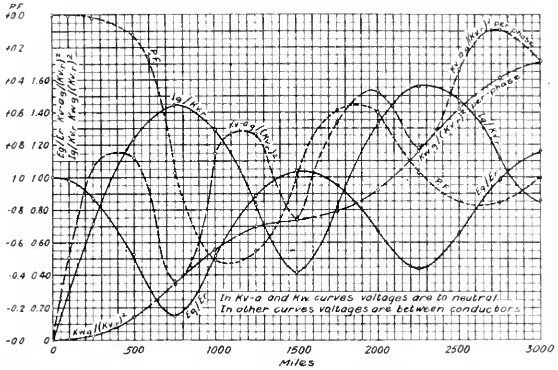

Fig. 24. Curves of Transmission Line with Conductor Consisting of 605,000 Cir. Mils Aluminum with Steel Core. Diameter 0.95 inch, spacing 22 feet. 60 cycles, open circuit at receiver end. In kv-a. and kw. curves voltages are to neutral, in other curves voltages are between conductors

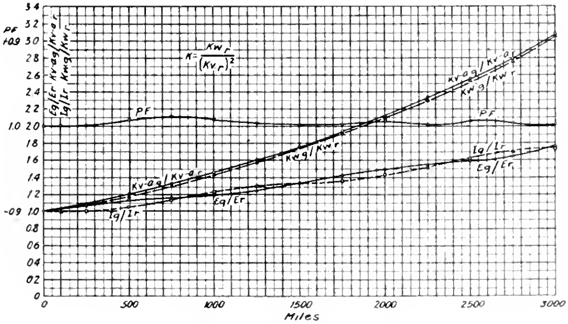

Fig. 25. 60 Cycles. Line loaded. K = 2.5 at Unity Power-factor. K = kw. rec. (kv. rec.)²

Fig. 24 shows the no load or open circuit conditions at 60 cycles for various lengths of line up to 3,000 miles, on a transmission line on which the conductors consist of 605,000 cir. mils of aluminum with a steel core of 78,000 cir. mils, spaced 22 ft. apart in a horizontal plane. It will be noted that there is a very high charging current and very low voltage at the generator end for 750 miles of line and that the power-factor is unity. Between 750 miles and 1,500 miles the power-factor is lagging, also between 2,250 miles and 3,000 miles. At other times the power-factor is leading.

Fig. 25 shows conditions on this line for a particular load $K = 2.5$ at unity p-f., in which K = kilowatts at receiver divided by the square of line kilovolts at receiver. $K = 2.5$ is equivalent to 100,000 kw. at 200-kv. receiver, which is the load that gives IR drop and I^2R loss for this line. Fig. 26 shows the conditions for a heavier load $K = 5$ at unity p-f., or say 200,000 kw. at 200-kv. receiver, and Figs. 27 and 28 for the same load at 0.8 p-f. lagging and 0.8 p-f. leading respectively. Short circuit conditions on this line are illustrated in Fig. 29. Fig. 30 sum-

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*See Thomas, *A.I.E.E. Transactions*, 1909, pages 619 and 620.

marizes the voltage conditions for various loads at unity power-factor from zero to $K=5$. It will be noted that there are tremendous differences in voltage at 750 miles and that at 1,500 miles all the curves draw together. These are respectively the quarter-wave and half-wave length points for this frequency.

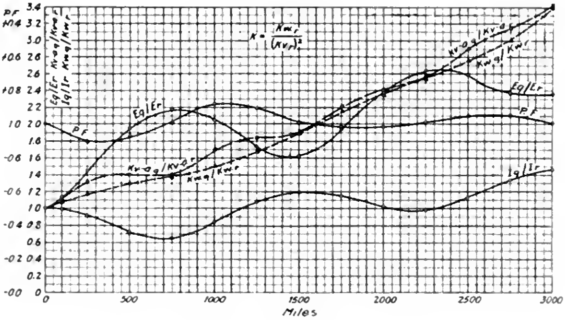


Fig. 26. 60 Cycles. Line Loaded. K = 5, Unity Power-factor

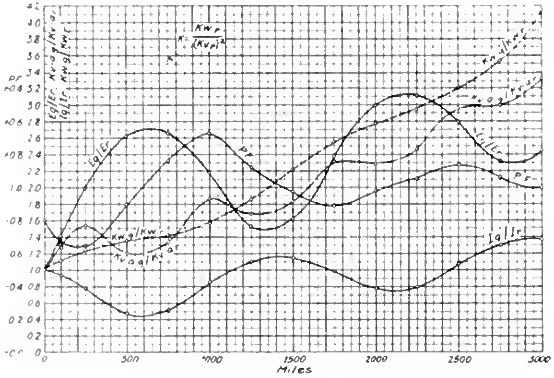


Fig. 27. 60 Cycles. K = 5, 0.8 Power-factor Lagging

Similar curves for other frequencies may be drawn. Fig. 31 summarizes the voltage conditions for 10 cycles, Fig. 32 for 25 cycles and Fig. 33 for 50 cycles.

A transmission line, like a generator, may be unstable and operate at such a point that a sudden access of load will cause it to drop its voltage and increase its current to practically a condition of short circuit. Such conditions are illustrated in Fig. 34.

Assume that the line is operating on the left-hand side of the peak in the upper set of curves. An increase in current causes a decrease in voltage but an increase in kw., as the current increase is greater than the voltage decrease. At the peak of the curve the increase of current and decrease of voltage are equal. On the right-hand side of the peak an increase in current causes a greater corresponding decrease in voltage, hence a decrease in kw. The decreased voltage causes another rise in the current (assuming induction motor load for example), which in turn causes a further decrease in voltage, etc.,

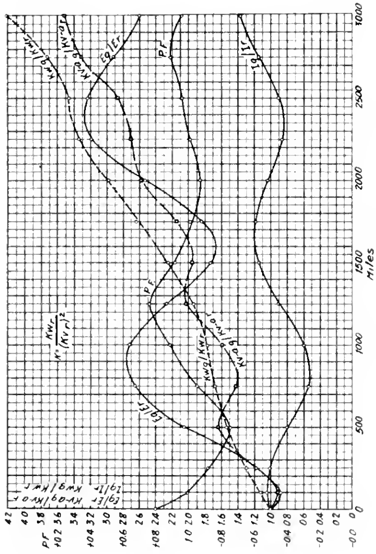


Fig. 28. 60 Cycles. K = 5, 0.8 Power-factor Leading

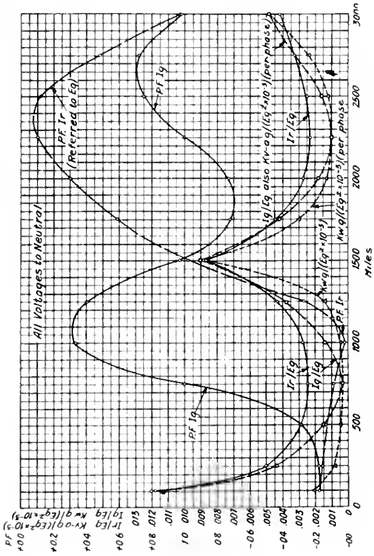


Fig. 29. 60 Cycles. Short Circuit at Receiver End. All voltages to neutral

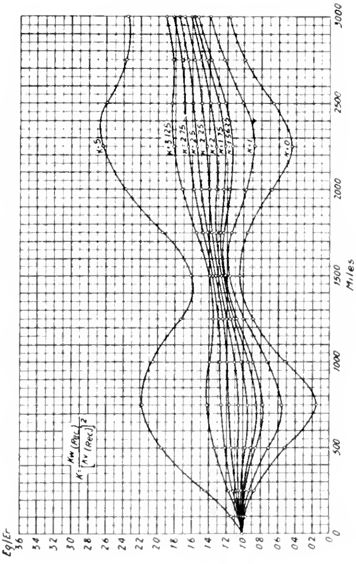


Fig. 30. 60 Cycles. Summary of Ratio Eg Er (Voltage Generator Voltage Receiver) for Loads from Zero to K = 5

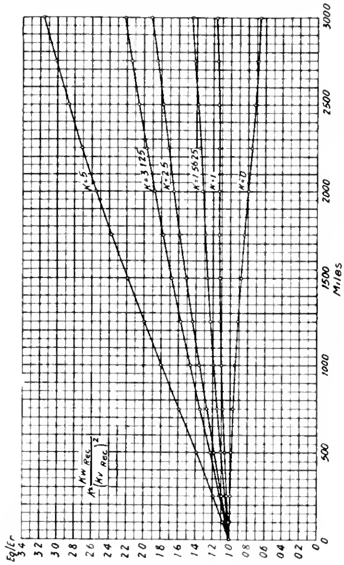


Fig. 31. 10 Cycles. Summary of Ratio Eg Er for Loads from Zero to K = 5

until finally the voltage decreases and the current increases to the point of no voltage and short circuit. Operation on the right-hand side of the peak is therefore unstable.

At the usual operating voltages, say 220 kv. at generator and 200 kv. at receiver, the 750-mile 50-cycle line is unstable, while the 10-cycle and 25-cycle lines are stable, as well as the 375-mile 50-cycle line. A leading power-factor moves the peak of the ampere-kv-a. curve upward and to the right, while a lagging power-factor moves the peak downward and to the left.

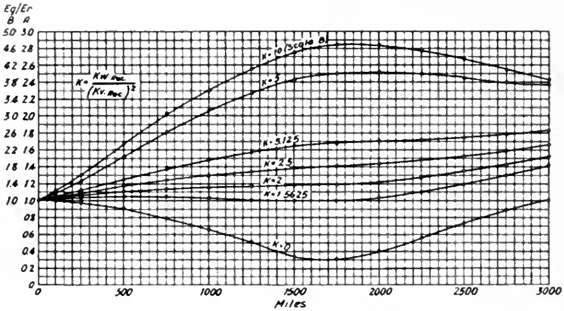


Fig. 32. 25 Cycles. Summary of Ratio Eg Er for Loads from Zero to K = 10

It may be deduced from the curves by plotting them in a different form that for any length of line and power-factor of load, there is a definite limit of power that may be fed over the line. For example, for 300 miles 60 cycles and unity power-factor, we may deduce from Fig. 30 a set of figures as follows:

Frequency	K	Eg Er	Generator Voltage	Receiver Voltage	Kw. Receiver
60	5	1.56	220000	141000	99500
	3.125	1.2	220000	183000	104800
	2.5	1.09	220000	202000	102000
	2.0	1.02	220000	216000	93400
	1.5625	0.96	220000	229000	82000
	1	0.88	220000	250000	62500

Now plotting kw. receiver against voltage receiver we find that the maximum kw. is about 105,000 with about 180 kv. at the receiver. For 0.8 p-f. lagging the maximum kw. is about 60,000 at 150-kv. receiver and for 0.8 p-f. leading the maximum kw. is about 170,000 at about 250-kv. receiver.

For lower frequencies the maximum kw. is increased but occurs at lower voltage. For example, for 50 cycles and unity power-factor the maximum kw. is approximately 110,000 at about 150-kv. receiver.

By plotting similar curves for, say, unity power-factor, and a number of frequencies, it will be found that the curves intersect at about 100,000 kw. and 200 kv. In other words, for this particular length of line and 220 kv. at the generating station, we may carry 100,000 kw. at unity power-factor and any frequency with about 10 per cent drop. For voltages greater than 200 kv. at the receiver we may carry more kw. at 60 cycles than at 50 cycles or below, and for voltages less than 200-kw. receiver we may carry more kw. at 10 cycles than for 25 cycles and above.

A similar family of curves may be found for other power-factors and for various lengths of line. For other generator voltages the kw. will vary as the square of the voltage. Splitting the conductor into three sections as previously discussed will increase the maximum kw. that can be carried about two-thirds, and splitting the conductor into two parts will likewise increase the maximum kw. to a lesser extent.

Of course, in the study of any particular problem the effect of the transformer impedance at both ends of the line must also be taken into account.

For safe operation of long lines of this character there should be two transmission circuits tied together at regular intervals and provided with sectionalizing switches, so relayed that in case of trouble in one section of the line that section would be cut out, permitting operation with double load on the companion section of the other circuit and on the remaining multiple sections as usual.

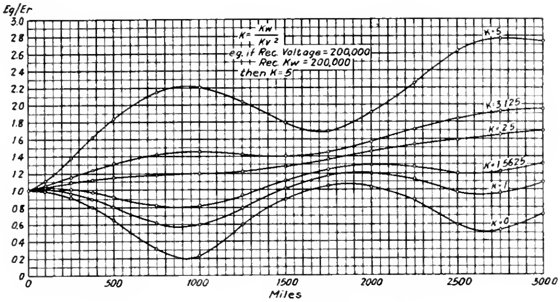


Fig. 33. 50 Cycles. Summary of Ratio Eg Er for Loads from Zero to K = 5

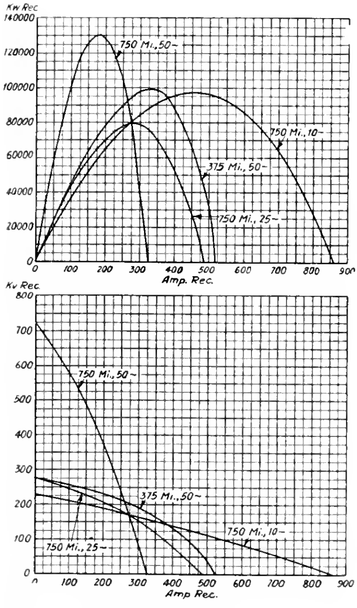
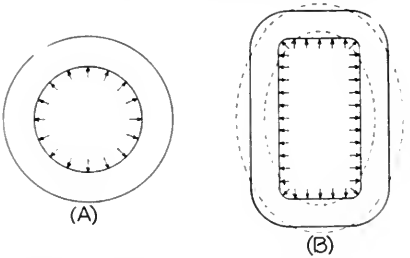


Fig. 34. Line Characteristic. 220 Kv. at Generator. Unity Power-factor at Receiver

Transformers

In designing transformers it is most convenient to base the turn ratio on no-load conditions, and use taps so that they will give approximately the correct voltage for various load conditions. The generating station transformers may have taps in the low tension below the normal voltage, or in the high tension above the normal voltage. In the former case full voltage is placed on an under-voltage tap. This must be taken into consideration by designing the transformers so that the desired core density is not exceeded with voltage applied to the lowest tap. In the latter case, the taps above normal high tension voltage accomplish the same purpose as the low tension taps, the idea of the taps not being to increase the high tension voltage above normal but to maintain normal voltage under load conditions. The step-down transformers usually have high tension taps below normal voltage, so that if the voltage at the end of the line is low, a corresponding tap may be chosen and the low tension voltage kept up to normal.

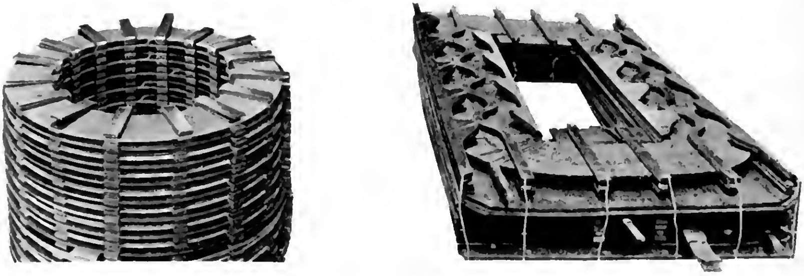
Transformers are usually designed for connection in delta on the low tension and in Y on the high tension. The Y-connection is preferable on the high tension as it allows grounding the neutral and in some cases allows a certain amount of grading of the insulation, thus appreciably lessening the cost for very high voltages. A transformer always should have one winding connected delta and this naturally becomes the low tension winding if the high tension is already connected in Y. Such a delta connection is necessary in order to take care of the triple frequency component of magnetizing current, and also in order that the transformer may allow current to flow in case of a short circuit from line to ground. Sometimes at step-down stations it is desirable to have Y-connection on the low tension in order to ground the neutral of the low tension system. In this case there is no objection to so connecting the low tension winding providing the high tension is connected in delta. When it is desirable to connect both high tension and low tension in Y for grounding purposes or for multipling, a tertiary delta should be provided. If the neutrals are grounded, the tertiary delta must be of sufficient capacity to carry short circuit current. If the neutrals are not grounded, the tertiary delta may be designed for a capacity sufficient only to carry the triple frequency magnetizing current. Frequently the tertiary delta is used to carry station load or to operate synchronous condensers, in which case of course it should be designed for this purpose.



(a) Forces on circular coils are radial and perpendicular to the conductors. No tendency to change form.

(b) Forces on rectangular coils are perpendicular to conductor. Coil tends to become circular.

Fig. 35. Mechanical Forces on Coils. Coils carrying current tend to take form that will enclose the maximum flux



(a) Radial spacers support every turn and do not interfere with oil circulation.

(b) Long spacing strip impedes oil circulation and blankets heat.

Fig. 36. Method of Bracing Against Mechanical Forces Between Coils

Grading the insulation of the high tension windings is permissible from the designer's standpoint only if the neutral is connected directly to the core, because only in this case is he sure that there will be no difference of potential between neutral and core. In addition the tank should be grounded without resistance. Such grading consists only of omitting the coil supports and grounding the ends of the windings. Grading is not carried to the extent of tapering the insulation of the windings themselves.

In this connection attention might be called to the fact that some power companies call for long time insulation tests. Such tests are unnecessary and may be found dangerous in weakening insulation. The purpose of the insulation test is to assure a reasonable factor of safety and to detect any glaring defect in the insulation. These results are accomplished by the double voltage one minute test prescribed in the A.I.E.E. Rules and the reduced but equivalent one minute test usually prescribed for transformers with graded insulation, and no other tests are necessary or desirable.

The circular coil type of transformer is rapidly superseding the old rectangular coil shell type. It is very difficult in the shell type to insulate the coils from each other, and especially the high tension from the low tension. In the circular coil type it is relatively easy to insulate the windings from each other by insulating cylinders and oil.

It is quite difficult in the shell type to brace the coils against mechanical forces. The forces in the individual coils tend to cause the rectangular coils to assume a circular shape (Fig. 35). The forces between coils tend to cause the turns to slip by each other. If the spacers are modified to prevent this, then the oil circulation is impeded and the heat blanketed (Fig. 36).

In the circular coil type on the other hand, the forces in the individual coils which are radial do not tend to change the form of the coil, which is already circular. Bracing against forces between coils is done by radial spacers (Fig. 36), and steel plates or rings braced against the core itself take the vertical thrust of the coil stack. There is no impedance to oil circulation nor blanketing of heat.

On account of the uniform distribution of coils in the circular coil type, and the steel end plates, which are electrically connected to the winding, there is a uniform distribution of potential across the winding at normal and high frequency. The shell type on the other hand, on account of the coils being arranged in groups, has an uneven voltage distribution at high frequencies and excess potentials at certain portions of the windings.

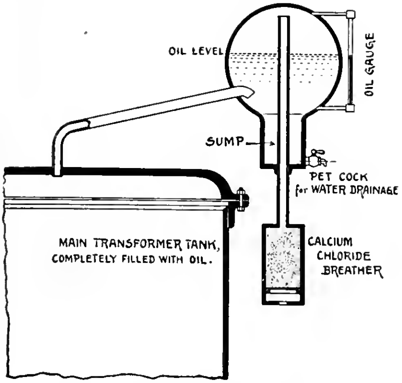


Fig. 37. Diagrammatic Sketch of Oil Conservator Connected to Transformer Tank

It is interesting to note that the high tension transformers sold to the Southern California Edison Company and the Pacific Gas & Electric Company for their 220,000-volt installations were of the circular coil core type, although made by two different manufacturers.

An improvement brought out by the General Electric Company some years ago is called the Oil Conservator (Figs. 37 and 38).

Fig. 38. Large High Voltage Transformer Equipped with Conservator

The principles involved in this device are the elimination of the air space above the oil and the isolation of the hot oil and insulation from the surrounding air. This is accomplished by completely filling the main transformer tank with oil and providing an auxiliary tank for oil expansion, connected by suitable piping to the main tank and mounted integrally with it. The auxiliary tank is open to the surrounding air through a breathing device and is provided with a sump from which any water from condensation may be drawn off without disturbing the main tank.

The connection between the two tanks is such that there can be no rapid interchange of oil, thus keeping the oil in the auxiliary tank, which is in contact with the air, at a relatively low temperature.

The following objects are accomplished by the conservator:

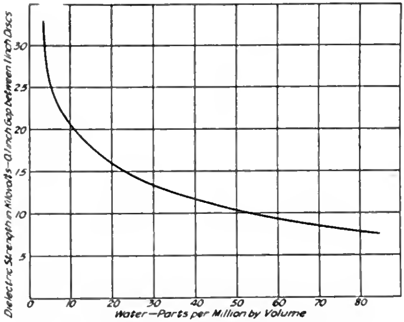


Fig. 39. Diagram Showing Effect of Water on Dielectric Strength of Transformer Oil

1. Eliminates "breathing" and moisture condensation in the main tank, thus preserving the original insulating value of the oil.

All transformers breathe; that is, the surrounding air is alternately drawn in and forced out with changes in temperature. Condensation of moisture inside the tank always results to some extent from such breathing and becomes dangerous when the moisture is so precipitated as to be carried into the cooling ducts between the coils or other vital places. Condensation from breathing is naturally greater in outdoor transformers, but may occur indoors to a dangerous degree under certain conditions.

The oil conservator transformer breathes through its auxiliary tank, and such moisture as passes the breathing device is precipitated before it can enter the main tank. This is illustrated in the diagrammatic sketch of Fig. 37.

The importance of keeping the oil in the main tank free from moisture is made clear by Fig. 39 which shows the effect of small quantities of water on the dielectric strength of oil. Clear, dry transformer oil should stand a test of at least 22 kv. between one-inch disks spaced one-tenth inch apart, and it is not safe for transformers when the dielectric strength is less than about 75 per cent of this value.

2. Avoids explosions due to an ignition of a mixture of air and gas formed from hot oil.

Arcing or static discharging in transformers, or even heavy overloads often result in a partial decomposition of the oil with the formation of a combustible gas. Violent explosions have resulted from the ignition of such gases when mixed with air above the oil level. In the oil conservator transformer, such an explosive mixture could be formed only in the auxiliary tank where there would be no opportunity of ignition.

3. Protects the oil from the "sludging" which takes place to some degree in all transformers after protracted operation even under normal conditions, and is accelerated to a dangerous extent during emergency overloads.

Sludging is simply a decomposition of the oil due principally to exposure to oxygen while hot. If the oil temperature is raised considerably above normal operating temperature, this decomposition becomes very rapid and a precipitate is thrown down which clogs the oil ducts and forms a heat insulating coating on the core and coils. This precipitate further interferes with the cooling of the transformer, resulting in still higher temperature and more complete decomposition of the oil. This condition often results in actual carbonization of the insulation before its severity is realized and the transformer taken out of service.

The oil conservator transformer is immune from oil sludging and needs no attention or cleaning on account of thickening of oil.

4. Preserves the insulation.

A very important advantage of the oil conservator lies in the fact that the organic insulations used in transformers, such as cotton, paper, fiber, etc., deteriorate much more slowly when the hot oil in which they are immersed is not exposed to the air. This has been demonstrated by accelerated life tests on insulations made at the transformer factory of the General Electric Company at Pittsfield, which show that the deterioration of such insulations, when operated at 105 deg. C. with conservators, is not greater than when the insulations are operated at 95 deg. C. or less without conservators.

Dielectric strength tests made semimonthly for a period of two years and a half on the oil in two 30,000 kv-a. banks of 120,000-volt transformers and one spare 10,000-kv-a. transformer at the substation of the American Gas & Electric Company at Canton, Ohio, showed an almost uniform dielectric strength in all the transformers of from 25 to 30 kv. in the standard 0.1 inch testing gap.

The appreciation of operating companies for this device is shown by the demand for transformers equipped with conservators. Up to March 1st of this year the General Electric Company has sold 3,500,000 kv-a. of transformers equipped with conservators.

The ratio adjuster is another improvement brought out by the General Electric Company. By means of this device the taps may be changed without lowering the oil level of the transformer or putting the hand into the oil. The tap leads are carried to the ratio adjuster mechanism located beside the tap coils. In this way complicated leads and connection boards are dispensed with. The ratio adjuster is actuated through an insulating rod connecting the mechanism with the dial and handle, which are located either outside of the tank or directly beneath a manhole in the cover, but above the oil level. To change a tap, excitation is removed from the transformer, the handle is turned over a mark on the dial, and the transformer is ready again to be placed into service.

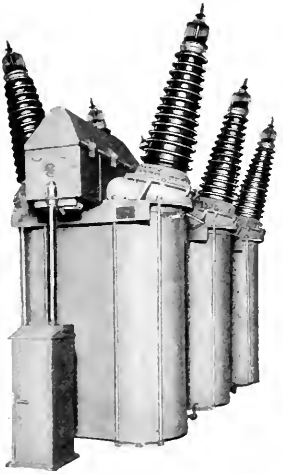


Fig. 40. Large High Voltage Oil Circuit Breaker

Bushings

One of the most important parts of all high voltage apparatus is the bushing through which is carried the high tension lead. Such a bushing should have the following characteristics:

It should stand a dielectric test with, or apart from, the apparatus with which it is associated, equal to the test specified in the Standardization Rules of the A.I.E.E., that is, 2.25 times the normal line voltage plus 2,000 volts for one minute.

Fig. 41. Solid Type Bushings for Voltages Below 73,000

It should have a flashover voltage lower than its puncture voltage. That is, it should be able to withstand flashover without puncture, so that upon application of a voltage exceeding its flashover voltage, a flashover of the bushing will result, which will protect it against puncture. On the other hand, it must have an instantaneous flashover greater than the test voltage.

The bushing should be so designed that it will have a considerable time lag, that is, it will be slow to flashover. The protective spark gap on the other hand should be fast, that is, should have as little time lag as possible.

In order that the bushing shall not deteriorate under the voltage stress of normal service, the insulating surfaces should be entirely free from corona at normal voltage or those voltages which may appear repeatedly along the line. To accomplish this efficiently, a potential distribution is necessary which is uniform along the external insulating surface of the bushing. It is not necessary, however, to suppress corona on the metal terminal parts at points not adjacent to the insulating surfaces, because the presence of corona previous to arc over represents the dissipation of energy and this in return requires a time element which increases the time lag of the bushing. Corona within the tank should be entirely suppressed, so that there will be no danger of such corona or static discharge igniting the gases which may collect in the air space between the oil and the cover.

The bushing should be designed to carry the rated current of the circuit at temperature rises which shall not injure the insulation.

All these requirements for an ideal bushing are met in scientifically designed bushings.

Fig. 42. High Voltage Bushings Equipped with Detachable Terminal Accessories (Left to Right) for (1) Constant Potential Transformer, (2) Lightning Arrester, (3) Oil Circuit Breaker, and (4) Current Metering Transformer

Bushings are divided into two groups: those for operating voltages not exceeding 73,000 volts, which are of the "solid" type (Fig. 41), and those for voltages above 73,000 which are of the "filled" type. These latter range in seven steps from 73,000 to 220,000 volts, and several are shown in Figs. 42 and 44.

The filled bushings, in which we are most interested, consist of an external shell of porcelain and iron, through which there passes from end to end a metal tube surrounded by insulating barriers, spaced concentrically to form ducts filled with insulating oil.

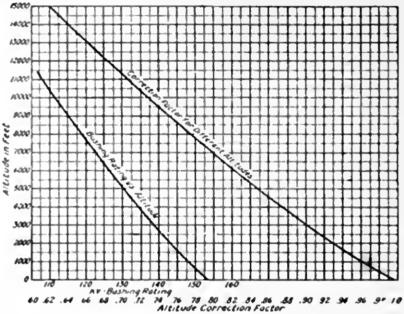


Fig. 43. Curves Showing Correction Factor for Different Altitudes and Variation in Rating of a Typical Bushing with Altitude

The value of oil as an insulating medium is everywhere recognized. This applies to bushings as well as to other types of high voltage apparatus. Its high insulating

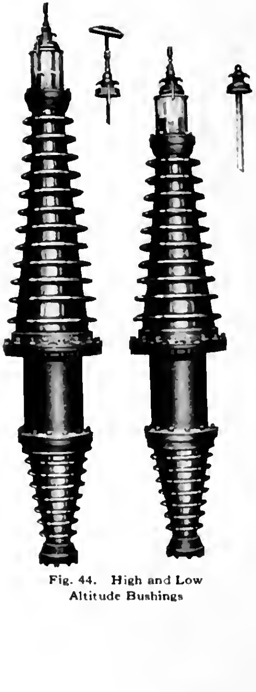


Fig. 44. High and Low Altitude Bushings

strength, reaching extremely high values under impulse voltages, its ability to circulate freely and thus serve as a heat dissipating medium, and its fluid character which eliminates air pockets or voids in the insulation, all combine to make insulating oil the best possible dielectric for bushings for high voltages.

A bushing of this type may be used on a power transformer, a potential metering transformer, a current metering transformer, an oil circuit breaker or a lightning arrester. Detachable terminal accessories are used to adapt the bushing to any one of these classes of apparatus. The bushing may be interchanged among the different classes of apparatus by changing the terminal accessories (Fig. 42).

Altitude has an effect on the flashover of bushings similar to its effect on other types of gaps, such as lightning arrester gaps and line insulators. Fig. 43 shows a curve of the correction factors for the flashover voltage of a typical bushing for various altitudes. Thus a bushing which has a flash over of 375,000 volts at sea-level would flash over at about 330,000 volts at 4,000 feet and about 275,000 volts at 10,000 feet. Since the maximum one minute test voltage of the bushing is definitely related to the flashover voltage, it follows that the normal operating voltage is also definitely related to the flashover voltage, and consequently is affected by the altitude of the installation. For instance, a bushing having a normal operating voltage rating of 154,000 volts at sea-level would be reduced in rating to 135,000 volts at 4,000 feet and to 112,000 volts at 10,000 feet. This is illustrated in Fig. 43.

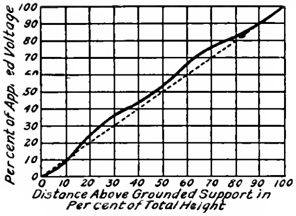


Fig. 45. Curve Showing Surface Distribution of Potential in the Filled Type of Bushing. The dotted line shows uniform distribution.

This effect of altitude upon the rating of the bushing involves only the upper end of the bushing whose insulating surface is exposed to the atmosphere. The puncture strength is not affected by the altitude, nor the strength of the insulating surface of the lower end of the bushing, which is entirely submerged in the oil of the apparatus in which it is assembled. For this reason installations at high altitudes, particularly those exceeding 4,000 feet, are supplied with "high altitude" bushings, whose upper sections have been lengthened to increase the striking distance, corresponding to the decrease in dielectric strength of air at the high altitude. Fig. 44 illustrates the high and low altitude bushings, and it will be noted that they are exactly alike below the supporting flange.

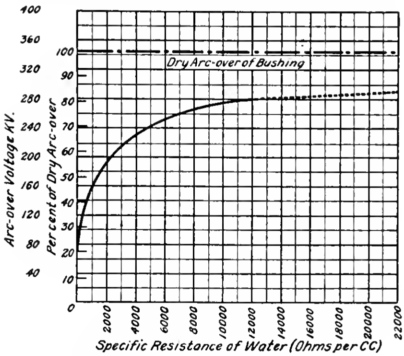


Fig. 46. Curve Showing the Wet Arc-over Voltage of a Typical Bushing for Various Specific Resistances of Water

On account of the various considerations previously mentioned, the "flat" voltage rating has been superseded by the voltage-altitude rating, so that a given bushing may operate on systems of different voltage at different altitudes with the same factor of safety. This also allows the bushing to be assigned to a system according to its operating conditions without violating any established voltage rating.

Fig. 45 illustrates the almost uniform distribution of potential obtained on the surface of this type of bushing. This uniform surface distribution means a uniform surface efficiency, so that the flashover voltage is proportional to the striking distance through the air from the top terminal to the grounded support. The ratings of the bushings are therefore directly proportional to their linear dimensions.

The wet flashover of a bushing under a rainfall of 0.2 inch at an angle of 45 deg. varies from 70 per cent to 90 per cent of the dry value, depending on the size of the bushing; those of lower rating having the higher ratio. The value of the wet flashover voltage is affected greatly by the specific resistance of the water used in making the wet test. This is illustrated in Fig. 46. As a rule rain water is higher in resistance than any tap water available for such tests. Distilled water represents an artificial condition which should not be used in making wet tests on bushings and insulators, distilled water naturally giving a higher wet test than tap water or even rain water, because of its higher specific resistance.

Conclusion

Naturally, only a few of the many interesting and important features of high tension transmission can be discussed in this article, and those not exhaustively, but the writer offers the preceding remarks in the hope that they will be of some assistance and in the belief that an interchange of experience of this sort is always helpful.

On the Oscillations of Certain Electrical or Mechanical Systems Due to a Periodic Impressed Force

By Ivar Herlitz

Union College, Schenectady, N. Y.

The author prepared this article in 1920 while a graduate student at Union College. In it a very interesting and unusual method of solution of a much used differential equation is described. The investigation was undertaken by the author at the suggestion of Mr. A. R. Stevenson, Jr., of the General Electric Company; and in another article in this issue of the Review Mr. Stevenson illustrates the practical use of Mr. Herlitz' method of solution. These joint articles illustrate one advantage of close co-operation between an industry and a college.—Editor.

The fundamental equation for the forced oscillations of an oscillatory system is, as is well known,

$$a\frac{d^2y}{dt^2}+b\frac{dy}{dt}+cy=f(t) \qquad (1)$$

In an electric circuit consisting of inductance, resistance, and capacity in series, y may be the charge on the condenser, in which case $f(t)$ is the impressed electromotive force, a the inductance, b the resistance, and $\frac{1}{c}$ the capacity of the circuit.

In a mechanical problem of great interest to electrical engineers, y is the angular displacement of the rotor of a synchronous machine from its average position, while $f(t)$ is the variable component of the torque acting on the shaft, a then is the moment of inertia of the rotary system, b corresponds to a damping force, and c to the "synchronizing force."

Dividing the equation by a, and substituting

$$\frac{b}{a}=2\beta \quad \frac{c}{a}=\omega_0^2 \quad \omega_0^2-\beta^2=\omega^2$$

we obtain

$$[(p+\beta)^2+\omega^2]y=\frac{1}{a}f(t) \qquad (1a)$$

where p is the differentiating operator $\frac{d}{dt}$.

If $f(t)$ is a periodic function with the period T, say, so that $f(t+T)=f(t)$, the oscillations will finally become periodic with the same period. Superposed on this periodic state is, however, initially a transient term, corresponding to the damped, free oscillations of the system. If $f(t)$ is a pure sine function the periodic state is easily obtained by the well known complex method, that is, by putting $p=j\omega_1$, where ω_1 corresponds to the period of $f(t)$. In other cases, the common method of obtaining the solution is to develop $f(t)$ into a Fourier series and then to apply the complex method on each term separately. If, however, $f(t)$ differs largely from a pure sine function this method becomes long and laborious, and sometimes inaccurate due to the impossibility of taking a sufficient number of harmonics into account. In this article, the solution of equation (1a) will be presented in a form from which the periodic state can be obtained by direct integration (if necessary, graphical) without the harmonic analysis of $f(t)$.

Assuming that $f(t)$ begins to act at the time $t=0$, the complete solution of (1a) is

$$y=\frac{1}{a\omega}\epsilon^{-\beta t}\int_0^t \epsilon^{\beta u}\sin\omega(t-u)\cdot f(u)\cdot du \qquad (2)$$

or

$$z=a\omega y=\epsilon^{-\beta t}\sin\omega t\int_0^t \epsilon^{\beta u}\cos\omega u\cdot f(u)\cdot du-$$
$$\epsilon^{-\beta t}\cos\omega t\int_0^t \epsilon^{\beta u}\sin\omega u\cdot f(u)\cdot du \qquad (2a)$$

It would lead too far to develop the method of obtaining this solution here, but the correctness of it is easily verified by forming the first and second derivatives and substituting in (1a). That the initial conditions, viz., that y and its first derivative have to be zero at $t=0$, are satisfied, is also easily verified.

This solution contains the transient state as well as the final, periodic state. The general form of the transient term is independent of the nature of $f(t)$, and is

$$A\epsilon^{-\beta t}\sin\omega t+B\epsilon^{-\beta t}\cos\omega t$$

If terms of this type are added to the complete solution we must thus be able to determine A and B so that they just cancel out the transient part, that is, so that the rest becomes the periodic state. We therefore write

$$z=\epsilon^{-\beta t}\sin\omega t[A+\int_0^t \epsilon^{\beta u}\cos\omega u\cdot f(u)\cdot du]-$$
$$\epsilon^{-\beta t}\cos\omega t\,[B+\int_0^t \epsilon^{\beta u}\sin\omega u\cdot f(u)\cdot du] \quad (3)$$

where A and B have to be determined to make z periodic with the period T, that is, so that $z(t)=z(t+T)$ for any value of t. It may be mathematically shown by means of the differential equation for z that a sufficient condition for this is that for one single value of t, say $t=t_1$,

$$z(t)=z(t_1+T) \qquad \left(\frac{dz}{dt}\right)t=t_1=\left(\frac{dz}{dt}\right)t=t_1+T$$

This is also almost evident from the fact that the solution of the differential equation is completely determined if the function and its first derivative are given in one point. If now these two are equal at two points, and the right hand side of the equation also has the same value in both points, it is almost evident that the function must repeat itself from this point on.

Differentiating equation (2) or (2a) we get

$$\frac{dz}{dt}=-\beta z+$$
$$\omega\epsilon^{-\beta t}\cos\omega t\,[A+\int_0^t \epsilon^{\beta u}\cos\omega u\cdot f(u)\cdot du]+$$
$$\omega\epsilon^{-\beta t}\sin\omega t\,[B+\int_0^t \epsilon^{\beta u}\sin\omega u\cdot f(u)\cdot du] \quad (4)$$

For t_1 we most conveniently choose the value $t=0$. If we put

$$I_1=\int_0^T \epsilon^{\beta u}\cos\omega u\quad f(u)\cdot du$$
$$I_2=\int_0^T \epsilon^{\beta u}\sin\omega u\cdot f(u)\cdot du$$

we then get, by substituting in (3) and (4), $t=0$ and $t=T$,

$$-B=\epsilon^{-\beta T}[\sin\omega T(I_1+A)-\cos\omega T(I_2+B)]$$
$$A=\epsilon^{-\beta T}[\cos\omega T(I_1+A)+\sin\omega T(I_2+B)]$$

from which equations A and B are easily obtained. The result is

$$A=\frac{I_1(\cos\omega T-\epsilon^{-\beta T})+I_2\sin\omega T}{2(\cosh\beta T-\cos\omega T)}$$
$$B=\frac{I_2(\cos\omega T-\epsilon^{-\beta T})-I_1\sin\omega T}{2(\cosh\beta T-\cos\omega T)} \qquad (5)$$

In the most important cases occurring in practice, $f(t)$ is given as a curve or in a table, so that graphical integration must be used. The procedure will then be as follows:

1. Evaluate the two integrals in (2a) as functions of time for one period of $f(t)$. As the final result I_1 and I_2 are then obtained.
2. Calculate the values of A and B from the expressions (5) and add the results to the integrals, as indicated in equation (3).
3. Multiply by the factors indicated in (3) and subtract the results. The final result is then z, which only has to be multipled by a constant factor to give y.

Numerical example: In a certain case, $f(t)$ was given by curve A, Fig. 1. (To obtain the torque in pounds-feet, multiply the ordinates of the curve by 7500). The constants in equation (1) are in pounds and feet. $a=644$ $b=3400$ $c=635{,}000$ $T=0.333$ sec. and we find

$$\beta=2.64 \qquad \omega=31.3$$

By the graphical integration, the period was divided into 24 parts, each part thus representing a time interval $=T/24=0.0139$ sec. The integrations were performed by adding the ordinates of the curve to be integrated, so that the result has to be multiplied by the time interval mentioned to give the proper result, which is then obtained in mechanical radians. To transform this into electrical degrees we have to multiply by 57.2 times the number of pole pairs, which in this machine was 20. The total factor by which the integrals have to be multiplied thus becomes

$$\frac{1}{a\omega}\cdot 7500\cdot 0.0139\cdot 57.2\cdot 20=5.90$$

The integrals I_1 and I_2 were found to be

$$I_1=-2.743 \qquad I_2=1.202$$

which gives

$$A=0.401 \qquad B=-0.893$$

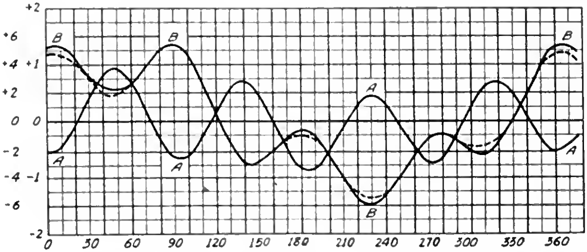


Fig. 1 Graphical Illustration of Calculation. Curve A is the crank effort diagram, f (t). Multiply by 7500 to get torque in lb-ft. Curve B is the angular deviation in electrical degrees calculated by equation (3). The dotted line is also the angular deviation in electrical degrees but calculated by harmonic analysis using four harmonics as described in Appendix D of "Design of Flywheels for Reciprocating Machinery Connected to Synchronous Generators or Motors" by Doherty and Franklin, A.S.M.E., December, 1920.

The result is the full drawn curve B, Fig. 1. The dotted curve was calculated by harmonic analysis of $f(t)$. (In order to compare the results of the two methods, the function $f(t)$ used was not the original curve, but the curve obtained from the first four harmonics of it, which formed the basis for the calculation by the last method.) The two methods thus check very well.

The periodic solution may also be obtained in another form which sometimes may be useful. In order to obtain this solution we most conveniently write equation (2) in exponential complex form,

$$2\,j\omega y=\epsilon^{-\gamma t}\int_{\infty}^{t}\epsilon^{+\gamma u}\cdot f(u)\cdot du-$$

$$\epsilon^{-\delta t}\int_{\infty}^{t}\epsilon^{+\delta u}\cdot f(u)\cdot du \qquad (6)$$

where

$$\gamma=\beta-j\omega \qquad \delta=\beta+j\omega$$

As the following may be of use also for certain non-oscillatory circuits, it should be observed that the solution of the equation of first order,

$$\frac{dy}{dt}+\gamma y=f(t) \qquad (7)$$

has a solution of the same type as each of the terms in (6), namely,

$$y=\epsilon^{-\gamma t}\int_{\infty}^{t}\epsilon^{+\gamma u}\cdot f(u)\cdot du \qquad (8)$$

so that the following results may easily be applied to this case also, as well as to the case where γ and δ in (6) become real. In this case, ω is an imaginary quantity, so that $j\omega$ is real, and (6) is the final form of the solution of (1).

As the state finally must become periodical, we must expect that the solution approaches a certain limit if we increase the time successively by a whole period T and continue this process indefinitely. Taking one of the terms in (6), or the solution (8), we therefore form

$$y(t+T)=\epsilon^{-\gamma(t+T)}\int_{\infty}^{t+T}\epsilon^{\gamma u}\cdot f(u)\cdot du$$

$$=\epsilon^{-\gamma(t+T)}\int_{\infty}^{t}\epsilon^{\gamma u}f(u)\cdot du+$$

$$\epsilon^{-\gamma(t+T)}\int_{\infty}^{t+T}\epsilon^{\gamma u}f(u)\cdot du$$

The first term is simply $\epsilon^{-\gamma t}\cdot y(t)$. In the second term we make a change of variable, putting $u=v+t$. This term then takes the form

$$k=\epsilon^{-\gamma T}\int_{\infty}^{T}\epsilon^{\gamma v}\cdot f(v+t)\cdot dv$$

so that

$$y(t+T)=\epsilon^{-\gamma T}\cdot y(t)+k \qquad (9)$$

Applying the same formula again we obtain

$$\begin{aligned} y\,(t+2T) &= \epsilon^{-\gamma T}\cdot y\,(t+T)+k \\ &= \epsilon^{-2\gamma T}\cdot y(t)+(1+\epsilon^{-\gamma T})k \end{aligned}$$

The process may be carried on indefinitely and we obtain in general

$$\begin{aligned} y\,(t+nT) &= \epsilon^{-\gamma nT}y\cdot(t)+(1+\epsilon^{-\gamma T}+\ldots\ldots \\ &\quad +\epsilon^{-\gamma\,(n-1)\,T})k \\ &= \epsilon^{-\gamma nT}\cdot y\,(t)+\frac{1-\epsilon^{-\gamma nT}}{1-\epsilon^{-\gamma T}}\cdot k \end{aligned}$$

When n increases indefinitely the first term decreases towards zero, and in the limit we get

$$y\,(t)=\frac{\epsilon^{-\gamma T}}{1-\epsilon^{-\gamma T}}\cdot\int_0^T\epsilon^{\gamma v}\cdot f\,(v+t)\cdot dv \qquad (10)$$

where $t+nT$ has been replaced by t, as for the periodic state, the value of the function for $t+nT$ is equal to the value for t. Equation (10) represents the periodic part of the solution and in the case of the equation of first order, or of real values of γ and δ, is the final result. Where the integration can be performed mathematically this expression is probably the most convenient one, also in the case of complex values of γ and δ. Otherwise, the corresponding term with δ is taken together with (10). The imaginary parts will then be found to cancel, and we get after some reduction:

$$y=\frac{1}{2a\omega(\cosh\beta T-\cos\omega T)}\cdot\int_0^T F(v)\cdot f(t+v)\cdot dv$$

where (11)

$$F(v)=\epsilon^{\beta v}\,[\sin\omega(T-v)+\epsilon^{-\beta T}\sin\omega v] \qquad (12)$$

The essential difference between this expression and equation (3) is that (11) represents an integration between fixed limits with the two factors of the integrand in different relative positions for different values of the time, so that one complete integration has to be performed for each point desired. On the other hand, each integration in this case is considerably simpler than the whole process in the previous method, so that when only a few points are needed this last method may be the shortest one. In many cases the relative position of $F\,(t)$ and $f(t)$ which gives the maximum value of the integral is easily estimated, and this maximum value, which often is the only thing that interests, is then obtained by one single integration.

As an example, take an impressed force of the shape as shown by curve A, Fig. 2. The period of this curve is $T=10$ (the units are obviously immaterial for the method and are therefore neglected in this example). Assuming $\beta=0.05$ and $\omega=\frac{\pi}{4}$ we obtain the dotted curve for $F(t)$, or, in numbers

$t=0$	1	2	3	4	5	6	7	8	9	10
$f=0$	3	2	4	3	0	−3	−2	−4	−3	0
$F=1$	1.20	.675	−.325	−1.22	−1.45	−.82	.395	1.49	1.78	1

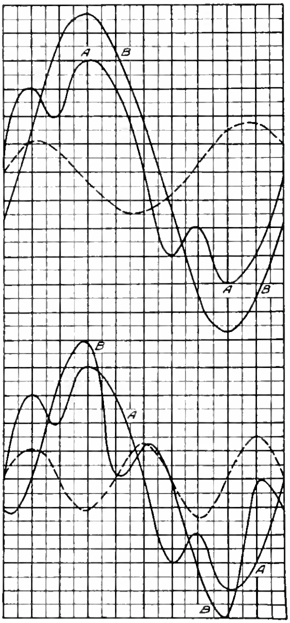


Fig. 2 (upper set of curves) and **Fig. 3** (lower set of curves) **Illustration of an Alternative Method of Calculation by Means of Equations (6) Through (12)**

Neglecting the proportionality factor outside the integral in (11) we get approximately

$$y\,(0)=f_0F_0+f_1F_1+f_2F_2+\ldots\ldots+f_9F_9$$
$$y\,(1)=f_1F_0+f_2F_1+f_3F_2+\ldots\ldots+f_0F_9$$

and so forth, the result being the curve B, Fig. 2. The result thus is very nearly a sine wave.

If, however, with β kept constant, ω is doubled to the value $\frac{\pi}{2}$, we obtain the result as shown in Fig. 3 (the curves are drawn in different scales and thus show only the shapes, and not the sizes, of the functions). In this last case, some of the higher harmonics are very marked.

Error Due to Neglecting Electrical Forces in Calculating Flywheels for Reciprocating Machinery Driven by Synchronous Motors

By A. R. Stevenson, Jr.

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In Part I of the following article Mr. Stevenson points out the errors which exist in the ordinary method of flywheel calculation. Although the existence of these errors has been realized for a long time, the incentive to make use of more correct theoretical assumptions has been lacking because reliable design constants were not obtainable. In December, 1920, Messrs. Doherty and Franklin presented a paper entitled "Design of Flywheels for Reciprocating Machinery Connected to Synchronous Generators or Motors," and this was apparently the first publication to give test results to show that the theory can be accurately checked by experiment. In Part II of this article a correct method of flywheel calculation is illustrated. The method used is based on a form of solution of the differential equation which is given for the first time in the article by Mr. Ivar Herlitz in this same issue of the Review. Part III was written later and demonstrates the correctness of the calculation by comparison with test results.—Editor.

Introduction

Those who drove automobiles before the days of self starters know from personal experience that the effort required to turn the motor is not constant. It takes more strength to pull the engine "over compression" than to pull the crank through "dead center."

By analogy it is therefore evident that the torque required to turn a reciprocating compressor is a variable depending on the positions of the pistons in the cylinders. Given indicator cards, the weights of the reciprocating parts, the dimensions of the cylinders, the length of the connecting rods, the number of cylinders, and the angle between cranks, it is easy to construct a diagram showing the variation of the torque during a revolution. This is called either a "crank effort diagram" or a "torque diagram." The construction of this torque diagram is simply a mechanical problem and will not be described in this article.[*]

In almost all electric motors the current drawn from the lines is roughly proportional to the torque. If there were no flywheel and no flywheel effect caused by the revolving part of the motor, the current drawn by a motor driving a compressor would increase and decrease throughout the revolution in direct proportion to the variations of the torque of the compressor. Variations of an amplitude of more than 60 per cent of the rated current of the motor are usually considered objectionable. Unless the feeder is large, current pulsations greater than this are likely to cause variations in voltage which may result in a flickering of the electric lights on that feeder. Even if the feeder is large, the substation might not have sufficient capacity to prevent flicker.

Flywheels are used to reduce these current pulsations. When a large torque is required to pull the compressor "over compression" the motor slows down. The flywheel has a tendency to keep on spinning at the same speed. It takes a force to slow down the flywheel. The force which causes the flywheel to slow down comes from the compressor. The reaction of this force helps push the machine over compression and thus partially relieves the motor.

A synchronous motor cannot slow down very much. Therefore larger flywheels are needed with this type of motor than with other types. In fact, a synchronous motor can slow down only momentarily. It has to keep up with the synchronous field which is revolving at constant speed. Consider one automobile towing another with a long spring instead of a rope. If the front automobile goes along steadily at 20 miles an hour, the rear automobile cannot run 15 miles an hour very long without stretching the spring to the breaking point. In one second the spring would have to stretch seven feet. Of course, the pull of the spring increases when the spring is stretched; and this increase in pull would tend to speed up the rear automobile. It should be particularly noted that the pull on the front automobile is proportional to the amount which the spring is stretched.

In an exactly similar manner the current drawn by a synchronous motor and the corresponding torque of the motor are both proportional to the distance by which the

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[*] See Appendix A of the paper on "Design of Flywheels for Reciprocating Machinery Connected to Synchronous Generators or Motors," presented before the A.S.M.E., Dec., 1920, by Doherty and Franklin.

motor rotor falls behind its synchronous field. It can be considered that the torque of the motor is due to the stretching of the magnetic lines of force just as the pull between the two automobiles was due to the stretching of the spring connecting them.

Most synchronous motors are designed so that when carrying full load the rotor lags between 20 and 24 electrical degrees behind the no-load position. (180 electrical degrees correspond to the distance between a north and the next south pole. In a two-pole motor, 360 electrical degrees correspond to one revolution. Therefore, electrical degrees and mechanical degrees are the same for a two-pole motor. It is always necessary to multiply the mechanical degrees by half the number of poles in order to obtain the corresponding number of electrical degrees.) If the motor slows down and speeds up so that it gets six electrical degrees ahead or behind this average position, the amplitude of swing will be twelve electrical degrees. But if full-load current corresponds to 20 electrical degrees, then a change in position of twelve electrical degrees will correspond to a change in current of 60 per cent.

The problem, therefore, resolves itself into furnishing sufficient flywheel so that the motor in slowing down and speeding up will never get more than six electrical degrees ahead or behind its average position.

PART I

The ordinary method of calculating flywheels is graphically represented in Fig. 1. Assume that the torque of the compressor is shown by Curve No. 3. It is drawn downward from the zero line and plotted as negative because the torque of the compressor tends to slow down the flywheel. It will be noted that the average torque of the compressor is minus 10,710 lb-ft. In the ordinary method of flywheel calculation the assumption is made that the motor torque, Curve No. 1, is a constant and is equal to the average torque of the compressor. The motor torque is drawn above the zero line at plus 10,710 lb-ft.

In the addition of the motor torque and the compressor torque, the average torque cancels out and there are left "unbalanced torques." These are shown by the Curve No. 2, the area of which is shaded. These unbalanced torques are used up in retarding and accelerating the flywheel. When the compressor torque is less than the motor torque, the excess motor torque accelerates the flywheel. When the compressor torque is larger than the motor torque, this excess load causes the installation to slow down.

In ordinary linear measurements:

$$\text{Force} = \text{Mass} \times \text{Acceleration.}$$

If the mass is given in pounds and the acceleration is given in feet per sec. per sec., the force would be in poundals.

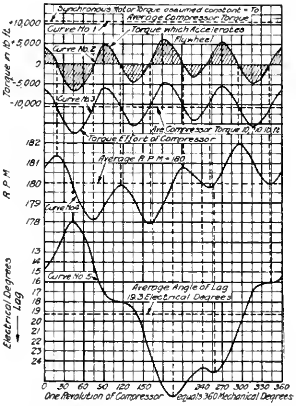

Fig. 1. Graphical Illustration of Wrong Method of Flywheel Calculation. Curve 5 is not consistent with Curve 1

It takes 32.2 poundals to make one pound of force. It is customary, in order to get rid of this odd unit, to write the equation:

$$\text{Force in lb.} = \frac{\text{Mass}}{32.2} \times \text{acceleration.}$$

In the case of a flywheel and angular acceleration, the equation is the same but somewhat disguised. The main difficulty lies in the fact that the outside edge of the flywheel is travelling at a higher linear speed than the points nearer the center. This difficulty is overcome by referring everything to a radius of one foot. The WR^2 of the flywheel is the equivalent weight at one foot radius. The moment of inertia of a flywheel is this equivalent weight at one foot radius divided by 32.2.

Torque is force in pounds at one foot radius.

$$\underset{\text{(in lb. at 1 ft. rad.)}}{\text{Torque}} = \text{Moment of Inertia} \times \underset{\text{(in ft. per sec. per sec. at 1 ft. rad.)}}{\text{acceleration}}$$

At one foot radius there are 2π feet per revolution.

Therefore:

$$\text{Torque} = \frac{WR^2}{32.2} \times 2\pi \times \text{accel. (in rev. per sec. per sec.)}$$

$$\text{Torque} = \frac{WR^2}{32.2} \times 2\pi \times \frac{1}{60} \times \text{r.p.m. per sec.}$$

A torque of one pound at one foot radius will in one second increase the revolutions per minute of a weight of one pound at one foot radius 307 r.p.m.

$$\text{Increase in r.p.m.} = \frac{307 \times \text{torque} \times \text{seconds}}{WR^2} \quad (1)$$

In Fig. 1 it will be noticed that each of the vertical squares represents 2500 lb-ft. torque.

Let us assume that this compressor has direct connected to it a 40-pole synchronous motor.

This machine makes 180 r.p.m. or three revolutions per second. One revolution therefore takes $\frac{1}{3}$ of a second. There are 24 horizontal squares per revolution. Each of these divisions therefore represents $\frac{1}{3} \times \frac{1}{24} = \frac{1}{72}$ of a second.

The area of each square therefore represents $2500 \times \frac{1}{72} = 34.7$ torque-seconds. The flywheel effect of this motor is 20,700 lb-ft.^{2}. There is no other flywheel on the compressor.

Between zero and 19.5 deg. the unbalanced torque is positive tending to accelerate the flywheel. There are 1.36[*] squares in this area each of them representing 34.7 torque-seconds. The total area therefore represents 47.3 torque-seconds. Substituting in equation (1):

$$\text{Increase in r.p.m.} = \frac{307 \times 47.3}{20{,}700} = 0.7$$

It has not yet been shown what the velocity at zero degrees is, but the foregoing shows that the velocity at 19.5 deg. is 0.7 r.p.m. greater than at zero degrees.

Similarly there are 6.36 squares in the area between 19.5 and 75 deg., from which in a similar manner it can be shown that the velocity at 75 deg. is 3.3 r.p.m. less than at 19.5 deg. In this way, without knowing the actual velocity, a curve of changes in velocity can be drawn. This is Curve No. 4. The average of this curve must be the synchronous speed. Draw the average of the curve and label it 180 r.p.m. (The average can be obtained with a planimeter or by adding the ordinates every 15 deg. and dividing by 24.)

The synchronous field is traveling at 180 r.p.m. As long as the motor travels 180 r.p.m. the angular relation between the synchronous field and the rotor will remain the same. But if the motor travels at 179 r.p.m. it will lose one revolution each minute. At the end of one minute it will be one revolution (360 mech. deg.) behind. At the end of one second it will have dropped back six mechanical degrees.

Change in mechanical degree lag =

$$6 \times \left(\begin{array}{l} \text{Difference be-} \\ \text{tween speed} \\ \text{and synchro-} \\ \text{nous speed} \end{array} \right) \times \left(\begin{array}{l} \text{The time} \\ \text{that this ex-} \\ \text{cess or under} \\ \text{speed lasts} \end{array} \right)$$

$$\text{Change in elec. deg. lag} = 6 \times \frac{\text{Poles}}{2} \times \text{r.p.m. sec.}^{\dagger} \quad (2)$$

Again each horizontal division represents $\frac{1}{72}$ of a second. The vertical divisions represent $\frac{1}{2}$ r.p.m. The area of one of these squares represents $\frac{1}{72} \times \frac{1}{2} = \frac{1}{144}$ r.p.m. sec. There are 5.56 squares in the area between zero degrees and 42 deg. This area therefore contains $5.56 \times \frac{1}{144} = 0.0386$ r.p.m. sec.

Substituting in equation (2):

Change in electrical degrees lag =

$$6 \times \frac{40}{2} \times 0.0386 = 4.64.$$

The amount of lag at zero degrees has not yet been shown, but from the foregoing it can be seen that at 42 deg. the lag is 4.64 deg. less than it was at zero. Similarly there are about 20.8 squares in the area between 42 and 195 deg., which corresponds to an increase in the angle of lag of 17.6 electrical degrees. Thus Curve No. 5 of differences in angle of lag can be plotted, and the average of this curve can be drawn.

The actual value of this average lag can be obtained as follows if the P_0 of the motor is known. This particular motor is 360 kv-a., 450 h.p. P_0 for this motor is 870 kw. But by definition P_0 is the kilowatt input at 57.3 electrical degrees lag. It is a constant furnished by the motor builder.

The electrical degrees lag with the rated input, 360 kw., is

$$\frac{360}{P_0} \times 57.3 = \frac{360 \times 57.3}{870} = 23.5.$$

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[*] These curves were originally drawn on co-ordinate paper having five times as many divisions. Therefore 1.36 squares represents 34 squares on the original drawing. This will explain the fractional values of squares given in the text.

[†] R.p.m. sec. is a measure of angular distance because r.p.m. represents an angular velocity and seconds are a measure of time. The product of velocity by time is distance.

This corresponds to full-load torque of the motor which is rated 450 h.p.

$$\text{Torque} = \frac{5250 \times \text{h.p.}}{\text{r.p.m.}} = 13{,}100 \text{ lb-ft.}$$

The average torque required by the compressor is 10,710.

The average electrical degrees lag is therefore:

$$23.5 \times \frac{10{,}710}{13{,}100} = 19.3$$

The purpose of this article is to call attention to the fact that this method of flywheel calculation rests on an assumption which is obviously incorrect.

The unbalanced torques were obtained on the assumption that the synchronous motor torque was a constant throughout the revolution. The result showed that during part of the revolution the synchronous motor lags 10 electrical degrees and at another point 27.6 electrical degrees. Since the synchronous motor torque is proportional to the angle of lag, this change in lag would cause a corresponding change in torque of 2.75 to 1. Therefore the answer is not consistent with the premise which was used as a basis for the calculation.

Sometimes this method gives an answer in electrical degrees deviation greater than is actually the case. In general, however, the answer given by this method is too small.

However, the method of flywheel calculation described in the foregoing can be used with safety if the following precaution is taken.

Consideration of this problem from another standpoint than the foregoing shows that the synchronous motor and the flywheel have a certain natural frequency, F, at which they tend to oscillate. This is given by the formula:

$$F = \frac{35{,}200}{\text{r.p.m.}} \sqrt{\frac{P_0 \times f}{WR^2}} \text{ beats per minute} \qquad (3)$$

where f is the frequency in cycles per second.

The other symbols have all been defined.

If sufficient flywheel is furnished so that the natural frequency in beats per minute is 25 per cent different from the forced frequency, then if the foregoing method shows an angular deviation of $3\frac{1}{2}$ electrical degrees above and below the average, the actual angular deviation will not be more than plus and minus 6 electrical degrees and the current pulsation will not be more than 60 per cent of the motor rated current.[*]

It will be found in many cases that the flywheel required in order to limit the angular deviation as calculated by the foregoing will be much larger than necessary. The correct method is shown in Part II.

PART II

In Part I the ordinary approximate method of calculating flywheels was described. It was especially pointed out that the answer was not consistent with the premise. As a basis for calculation, the synchronous motor torque was assumed to be a constant throughout the revolution; but glancing at the resulting angular deviation curve at the bottom of Fig. 1, it is evident that the synchronous motor torque could not have been a constant.

Any correct method of flywheel calculation must take into account the variations in synchronous motor torque due to the changes in speed and angle of lag.

The torque of a synchronous motor driving a fluctuating load consists of two elements:

(1) The synchronizing torque proper which is proportional to the angle of lag. It was shown in Part I that when delivering full-load torque, 13,100 lb-ft., this synchronous motor lagged 23.5 electrical degrees. Therefore the synchronizing torque per electrical degree lag is 555 lb. ft.

(2) There is also an amortisseur winding on the synchronous motor consisting of copper bars in the pole face. Under a steady load this winding has no effect, but if the rotor runs at a different speed than the synchronous field, an induction motor torque will be created in this winding. This induction motor torque will be proportional to the slip, and can be calculated. In this case a slip of one revolution per minute causes an induction motor torque of 368 lb-ft.

The procedure therefore should be:

(a) Draw the torque curve of the motor.
(b) Subtract this from the torque of the compressor.
(c) This leaves unbalanced torques which cause acceleration and deceleration of the flywheel.
(d) From these unbalanced torques the speed and angular displacement curves can be calculated as described in Part I.

This procedure is illustrated in Fig. 2. It can be noted that the motor torque curve

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[*] This same subject is treated from a slightly different point of view in Mr. R. E. Doherty's article in the August, 1920, GENERAL ELECTRIC REVIEW. A shorter method of performing this calculation is shown in Appendix B of "Designing of Flywheels for Reciprocating Machinery Connected to Synchronous Generators or Motors," a paper presented before the A.S.M.E., Dec. 1920, by Doherty and Franklin.

in Fig. 2 is consistent with the velocity and displacement curves shown in Fig. 2. The motor torque at any point is equal to the induction motor torque, 368 times the slip in r.p.m., plus the synchronizing torque, 555 times the electrical degrees displacement.

The curve of angular deviation obtained at the bottom of Fig. 2 is the correct answer to the problem. The difference between this curve and the curve at the bottom of Fig. 1 is very apparent. The actual swing shown in Fig. 2 is only 11 electrical degrees whereas in Fig. 1 the total swing was 17.6 electrical degrees. Therefore in this particular case the approximate method gave an angular deviation 60 per cent larger than would actually occur. Eleven degrees swing would cause an amplitude of current pulsation equal to only 47 per cent of rated motor current, while 17.6 electrical degrees would have caused a current pulsation equal to 75 per cent of rated motor current.

In most other cases the answer given by the approximate method would not be as great as the actual deviation.

It is necessary to have the curve of motor torque in order to calculate the velocity and displacement curves. But it is also necessary to have the velocity and displacement curves in order to draw the curve of motor torque.

Of course, a curve of motor torque might be guessed and the resulting curves of velocity and displacement calculated, and this process might be repeated over and over again until a consistent result was finally obtained accidentally. However, this would take too long. It is much simpler and easier to use a little mathematics.

An examination of Fig. 2 will show that the unbalanced torques which are available for accelerating and retarding the flywheel at any instant are given by the following equation:

$$\left(\begin{matrix}\text{Unbalanced}\\ \text{torque}\end{matrix}\right) = 555\times\left(\begin{matrix}\text{Elec. deg.}\\ \text{lag}\end{matrix}\right) + 368\times\left(\begin{matrix}\text{Slip in}\\ \text{r.p.m}\end{matrix}\right) - \left(\begin{matrix}\text{Torque}\\ \text{of comp.}\end{matrix}\right) \qquad (4)$$

In equation (1) it was shown that the increase in r.p.m. per second was

$$\frac{307\times\text{Unbalanced torque}}{WR^2}$$

This can be rewritten:

$$\text{Unbalanced torque} = \frac{\text{Change in r.p.m. per sec.}\times WR^2}{307} \qquad (5)$$

But the change in r.p.m. per second = acceleration

Substituting equation (5) in equation (4):

$$\frac{WR^2}{307}\times\text{Accel.} = 555\times\text{Position} + 368\times\text{Velocity of slip} - \text{Torque of compressor} \qquad (6)$$

In order to treat this equation mathematically it is more convenient to express the position in mechanical radians, the velocity of slip in mechanical radians per second, and the acceleration in mechanical radians per sec. per sec.

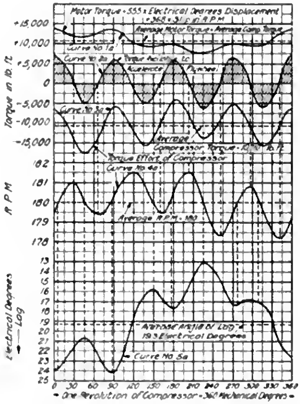

Fig. 2. Graphical Illustration of Correct Method of Flywheel Calculation. Curve 5a is consistent with Curves 1a and 4a

To change electrical degrees to mechanical degrees, it is necessary to divide by half the number of poles $\left(\frac{40}{2}\right)$. To change mechanical degrees to radians, it is necessary to divide by 360 and multiply by 2π.

To change velocity in r.p.m. to velocity in radians per second it is necessary to divide by 60 and multiply by 2π.

To change acceleration in r.p.m. per second to radians per sec. per sec., it is necessary to divide by 60 and multiply by 2π.

The WR^2 of the rotor of this motor is 20,700 lb-ft.^{2} There is no additional flywheel.

After making these changes the equation (6) can be rewritten:

$$\frac{20{,}700}{307}\times\frac{60}{2\pi}\times\left(\begin{matrix}\text{Accel. in radians}\\ \text{per sec. per sec.}\end{matrix}\right)$$

$$=555\times\frac{40}{2}\times\frac{360}{2\pi}\left(\text{Position in radians}\right)$$

$$+368\times\frac{60}{2\pi}\left(\begin{matrix}\text{Slip in radians}\\ \text{per sec.}\end{matrix}\right)-\left(\begin{matrix}\text{Torque of}\\ \text{compressor}\end{matrix}\right)$$

or:

$$644\times\left(\begin{matrix}\text{Accel. in radi-}\\ \text{ans per sec.}\\ \text{per sec.}\end{matrix}\right)=635{,}000\left(\begin{matrix}\text{Position}\\ \text{in}\\ \text{radians}\end{matrix}\right)$$

$$+3400\left(\begin{matrix}\text{Slip in radi-}\\ \text{ans per sec.}\end{matrix}\right)-\left(\begin{matrix}\text{Torque of}\\ \text{compressor}\end{matrix}\right)\quad(7)$$

In equation (7) the angular position is given as an angle of lag measured backward. Also the slip is given as a difference between synchronous speed and the motor speed. Mathematically, it is simpler to think of both these as being measured forward which necessitates changing their signs in the equation. The mathematical expressions for acceleration, velocity, and position are:

$$\frac{d^2y}{dt^2}=\text{acceleration.}$$

$$\frac{dy}{dt}=\text{velocity}$$

$$y=\text{position.}$$

On making use of these mathematical symbols, equation (7) can be expressed:

$$644\frac{d^2y}{dt^2}+3400\frac{dy}{dt}+635{,}000\,y=f(t)\qquad(8)$$

The torque effort plotted negatively is considered as a function of time and is represented by the symbols $f(t)$.

$$\text{Let } I=644$$
$$T_d=3400$$
$$T_s=635{,}000$$

Then this equation (8) would be

$$I\frac{d^2y}{dt^2}+T_d\frac{dy}{dt}+T_s y=f(t)\qquad(9)$$

Considering that y is expressed in radians:

$I=\frac{WR^2}{32.2}=$ The moment of inertia of the flywheel of the motor rotor.

$T_d=$ The damping torque due to the induction motor bars in the pole face in lb-ft. corresponding to a difference in the speeds of the rotor and the synchronous field of one mechanical radian per sec.

$T_s=$ The synchronizing torque due to the direct current field coils and shape of the pole pieces corresponding to an angle of lag between the rotor and the synchronous field of one mechanical radian.

The usual way of solving this equation consists in expressing the torque effort of the compressor as a Fourier's Series and the equation is then solved for each harmonic separately and the answers added at the proper phase angles.

Mr. Ivar Herlitz, of Union College, presents in this issue of the REVIEW a new and interesting method of solving the equation:

$$a\frac{d^2y}{dt^2}+b\frac{dy}{dt}+cy=f(t)^*$$

The example which Mr. Herlitz uses as an illustration is the identical problem which is illustrated in Fig. 2 of this article.

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* According to his method the solution is:

$$y=\frac{1}{a\omega}\left[\epsilon^{-\beta t}\sin\omega t\,[A+\int_0^t\epsilon^{\beta u}\cos\omega t\,f(t)dt]-\epsilon^{-\beta t}\cos\omega t\,[B+\int_0^t\epsilon^{\beta t}\sin\omega t\,f(t)\,dt]\right]$$

where

$$\omega=\sqrt{\left(\frac{c}{a}\right)^2-\frac{b^2}{4a^2}}\text{ and }\beta=\frac{b}{2a}$$

which is derived from his equation (3) by the substitution of the equivalents y for $\frac{z}{a\omega}$ and t for u.

The most important and interesting part of the solution is the evaluation of the integration constants, A and B, so as to eliminate the transient from the equation.

If the length of time for one revolution of the compressor is T seconds, after the transient is eliminated the equation must repeat itself every T seconds.

Mr. Herlitz shows that the equation will repeat itself every T seconds if:

$$A=\frac{I_1\,(\cos\omega T-\epsilon^{-\beta T})+I_2\sin\omega T}{2\,(\cosh\beta T-\cos\omega T)}$$

$$B=\frac{I_2\,(\cos\omega T-\epsilon^{-\beta T})-I_1\sin\omega T)}{2\,(\cosh\beta T-\cos\omega T)}$$

where

$$I_1=\int_0^T\epsilon^{\beta t}\cos\omega t\cdot f(t)\,dt$$

$$I_2=\int_0^T\epsilon^{\beta t}\sin\omega t\;f(t)\,dt$$

It is sometimes difficult for one not thoroughly familiar with mathematical forms to make use of equations stated in this way. However, it is not necessary to be familiar with the equations in order to make use of them. It is merely necessary to make the substitutions indicated in Tables I, II, and III in order to obtain the answer.

At the top of Table I is the rating of the motor. P_0 is a constant furnished by the motor builder. A correct value of P_0 is very important. T_d is also a value furnished by the motor builder but is not so important.

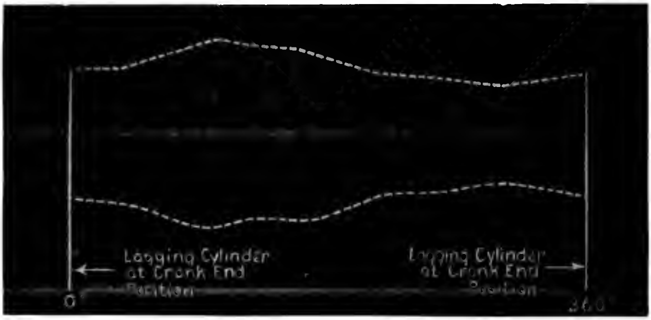

Fig. 3. Oscillograph of the Line Current to Synchronous Motor when the compressor was operating under the conditions illustrated in Fig. 4 without any additional flywheel

In the second column of Table II are given the ordinates of the compressor crank effort diagram in inches.

The way to fill in the tables is very clearly indicated step by step.

Before filling in the bottom part of Table I it is necessary to finish Table II to the bottom of column No. 7 and Table III through the bottom of column No. 5.

Column No. 11 shows the angular position at every part of the revolution but in unknown units.

If K = scale of crank effort diagram
r = radius of crank in feet

Then if column No. 11 is multiplied by $\frac{Kr}{\omega_1} \times \frac{\Delta t}{2}$ the answer will be the angular deviation of the motor throughout the revolution expressed in mechanical radians.

If the deviation in mechanical radians is multiplied by half the number of poles it will give the deviation in electrical radians and if this is multiplied by 57.3 *it will give the deviation* in electrical degrees. This is shown in the last column of Table III. It can be noted that the last column of Table III checks very well with the bottom curve of Fig. 2.

For the ordinary problem the last column of Table III is not necessary.

The difference between the largest value and the smallest value in column No. 11 of Table III shows the amplitude of deviation. The bottom of Table III shows how to obtain the amplitude of current pulsation in per cent of motor rated current from the amplitude of column No. 11.

For this particular problem the amplitude of the current pulsation is 47.9 per cent of

TABLE 1

Motor Rating AT1-40-360 Kw.-450 HP (10 pf)-180-E-440
$P_0 = 870$ $\frac{5250\,HP}{RPM} = T_1 = 13125$ $\frac{T_1 P_0}{Kw.} \times \frac{Poles}{2} = T_S$ 635000
WR^2 of Motor = 20700 $T_d = 3400$
WR^2 of Flywheel = ——
Total WR^2 = 20700 $\frac{WR^2}{32.2} = I = .644$
$\left[\frac{T_S}{I}\right] = 986$ $\frac{T_d}{2I} = \beta = 2.64$
$\beta^2 = 6.98$
$\omega^2 = \left[\frac{T_S}{I}\right]^2 - \beta^2 = 979.02$ $\omega = 31.2$

Time interval corresponding to $\frac{1}{24}$th of a revolution $= \frac{2.5}{RPM} = \Delta t = .0139$
$\beta \Delta t = .0366$ $\log \epsilon^{+\beta \Delta t} = 0.4343\,\beta \Delta t = .01587$
$\Delta \phi = 57.3 \times \omega \Delta t = 24.9$ $\epsilon^{+\beta \Delta t} = 1.0374$

From the bottom line of the 6th. column of Table 2, $I_1 = -19.8500$
From the bottom line of the 6th. column of Table 3, $I_2 = +15.7860$
$24 \Delta \phi = \omega T = 598.3$ deg $\cos \omega T = -.525$ $\sin \omega T = -.851$
$\log \epsilon^{\beta T} = 24 \log \epsilon^{\beta \Delta t} = .381$ $\epsilon^{\beta T} = 2.4128$
$\cos \omega T = -.525$ $\epsilon^{-\beta T} = .415$
$\epsilon^{-\beta T} = .415$ $2 \cosh \beta T = \epsilon^{+\beta T} + \epsilon^{-\beta T} = 2.8278$
$E = (\cos \omega T - \epsilon^{-\beta T}) = -.940$ $2 \cos \omega T = -1.050$
$I_1 E = +18.65$ $2(\cosh \beta T - \cos \omega T) = 3.8778$
$I_2 \sin \omega T = -13.41$
$I_1 E + I_2 \sin \omega T = +5.24$ $A = \frac{I_1 E + I_2 \sin \omega T}{2(\cosh \beta T - \cos \omega t)} = +1.351$
$I_2 E = -14.81$
$I_1 \sin \omega T = +16.89$ $B = \frac{I_2 E - I_1 \sin \omega T}{2(\cosh \beta T - \cos \omega T)} = -.819$
$I_2 E - I_1 \sin \omega T = -31.70$

the motor rated current. This is below the 60 per cent limit.

If the current pulsation had not come out less than 60 per cent it would have been necessary to assume additional WR^2 obtained either by adding an extra flywheel or by making the rotor heavier. Then, this calculation would have to be repeated in order to see whether the current pulsation is reduced by this change to less than 60 per cent. It might be necessary to make several trials in order to determine the correct amount of WR^2.

PART III

The angular deviation shown in Curve No. 5 of Fig. 2 in Part II was originally calculated and sent to the De La Vergne Machine Company on March 4, 1921, with the recommendation that the current pulsation would be about 48 per cent and no extra flywheel would be required.

This article was written about January 1, 1922, in order to illustrate the use of Mr. Herlitz' method; and, by way of example, the curve sent to the De La Vergne Company months earlier was included as Curve No. 5 of Fig. 2 in Part II.

Meanwhile both the motor and the compressor were built, shipped, and installed at The New Colonial Ice Corporation in New York City.

Through the courtesy of the De La Vergne Machine Company an opportunity to test the completed installation was obtained; complete tests were made June 24, 1922, and the following data secured.

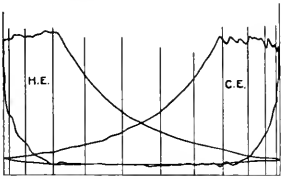

Fig. 4. Indicator Cards of the Compressor taken simultaneously with the oscillograph shown in Fig. 3. Scale 200 pounds per inch

(1) An oscillograph, Fig. 3, was taken of the line current to the synchronous motor.

(2) A contact was arranged on the crosshead of the lagging cylinder to make a circuit each time the piston of the lagging cylinder reached its crank-end position. This moved another vibrator in the oscillograph making an offset line similar to a chronograph record. This offset can be seen in Fig. 3 and serves as a means of registering the phase angles of the oscillograph record of current pulsation corresponding to the calculated curve of current pulsation.

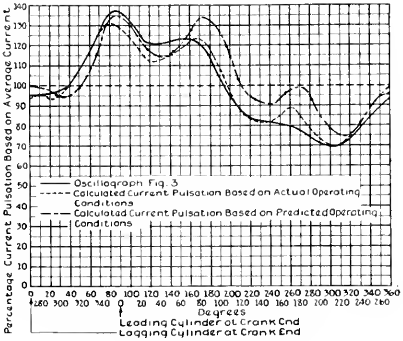

Fig. 5. Curves showing Comparison of Test and Calculated Values

(3) The De La Vergne Machine Company took indicator cards of the compressor simultaneously with the oscillograph records.

The compressor is a two-cylinder double-acting machine with cranks at right angles and cylinders 15 in. in diameter by 18 in. stroke.

A crank-end indicator card and a head-end indicator card are both shown in Fig. 4. The suction and discharge pressures were 15 lb. and 186 lb. gauge.

The ratio of connecting rod length to crank length is 4.17 and the weight of reciprocating parts of each cylinder is 1747 lb.

The crank-effort diagram for the actual operating conditions was constructed from the foregoing data.

The synchronous motor is rated:

40 poles; 360 kv-a.; 450-h.p.; (1.0 p-f.) —180 r.p.m.; 440 volts; 3-phase: 60 cycles.

The voltage at the plant was high, being 480 volts instead of 440 volts, and therefore the P_0 of the motor was actually 925 kw. instead of 870 kw., the value used in Parts I and II of this article.

The WR^2 of the motor is 20,700 and to this was added 1000 WR^2 to cover the revolving parts of the compressor.

The current pulsation was then calculated from the foregoing actual operating conditions.

The full-line curve in Fig. 5 shows the current pulsation measured from the oscillo-

TABLE II

Column No 1 Abscissa of Torque Effort Curve		Column No 2 Ordinates of Torque Effort Curve	Column No 3 $\epsilon^{\beta t}$	Column No 4 Product of Columns 2 and 3	Column No 5 Cos ωt			Column No 6 Product of Columns No 4 and 5	Column No 7 Continuous Sum of Column No 6		Column No 8 A + S From Table No 1 A = ±1.351	Column No 9 Sin ωt See Column No 5 for Angles	Column No 10 $\epsilon^{-\beta t}$ Reciprocal of Column No 4	Column No 11 Product of Columns No 8, 9 and 10
						Angle	Cos			S				
Divide One Revolution of the Crank Effort into 24 Parts	0°	y_0 = 0.8992	ϵ^{0} = 1.0000	0.8992	0 =	0°	1.000	Δ_0 = 0.8992	S_0 =	0	+1.351	0	1.000	0
	15°	y_1 = 1.1714	$\epsilon^{\beta\Delta t}$ = 1.0374	1.214	$\Delta\phi$ =	24.9°	0.907	Δ_1 = 1.1011	$S_1 = \Delta_0 + \Delta_1$ =	2.0003	+3.3513	0.421	0.965	+1.360
	30°	y_2 = 1.8939	$\epsilon^{2\beta\Delta t}$ = 1.0761	2.037	$2\Delta\phi$ =	49.8°	0.644	Δ_2 = 1.3118	$S_2 = S_1 + \Delta_1 + \Delta_2$ =	4.4132	+5.7642	0.764	0.931	+4.100
	45°	y_3 = 2.3689	$\epsilon^{3\beta\Delta t}$ = 1.1164	2.645	$3\Delta\phi$ =	74.8°	0.211	Δ_3 = 0.5581	$S_3 = S_2 + \Delta_2 + \Delta_3$ =	6.2831	+7.6341	0.965	0.898	+6.620
	60°	y_4 = 2.1158	$\epsilon^{4\beta\Delta t}$ = 1.1581	2.450	$4\Delta\phi$ =	99.7°	-0.169	Δ_4 = -0.4141	$S_4 = S_3 + \Delta_3 + \Delta_4$ =	6.4271	+7.7781	0.986	0.865	+6.640
	75°	y_5 = 1.3488	$\epsilon^{5\beta\Delta t}$ = 1.2014	1.621	$5\Delta\phi$ =	124.6°	-0.568	Δ_5 = -0.9207	$S_5 = S_4 + \Delta_4 + \Delta_5$ =	5.0923	+6.4433	0.823	0.832	+4.410
	90°	y_6 = 0.7895	$\epsilon^{6\beta\Delta t}$ = 1.2461	0.985	$6\Delta\phi$ =	149.6°	-0.863	Δ_6 = -0.8501	$S_6 = S_5 + \Delta_5 + \Delta_6$ =	3.3215	+4.6725	0.506	0.804	+1.900
	105°	y_7 = 0.9474	$\epsilon^{7\beta\Delta t}$ = 1.2929	1.230	$7\Delta\phi$ =	174.5°	-0.995	Δ_7 = -1.2239	$S_7 = S_6 + \Delta_6 + \Delta_7$ =	1.2475	+2.5985	0.096	0.774	+0.193
	120°	y_8 = 1.6278	$\epsilon^{8\beta\Delta t}$ = 1.3413	2.188	$8\Delta\phi$ =	199.4°	-0.943	Δ_8 = -2.062	$S_8 = S_7 + \Delta_7 + \Delta_8$ =	-2.0384	-0.6874	-0.332	0.745	+0.170
	135°	y_9 = 2.1267	$\epsilon^{9\beta\Delta t}$ = 1.3914	2.965	$9\Delta\phi$ =	224.3°	-0.714	Δ_9 = -2.117	$S_9 = S_8 + \Delta_8 + \Delta_9$ =	-6.2174	-4.8664	-0.700	0.718	+2.443
	150°	y_{10} = 1.9179	$\epsilon^{10\beta\Delta t}$ = 1.4343	2.751	$10\Delta\phi$ =	249.3°	-0.353	Δ_{10} = -0.971	$S_{10} = S_9 + \Delta_9 + \Delta_{10}$ =	-9.3054	-7.9544	-0.935	0.698	+5.180
	165°	y_{11} = 1.1766	$\epsilon^{11\beta\Delta t}$ = 1.4973	1.761	$11\Delta\phi$ =	274.2°	+0.073	Δ_{11} = +0.1287	$S_{11} = S_{10} + \Delta_{10} + \Delta_{11}$ =	-10.1477	-8.7967	-0.997	0.669	+5.865
	180°	y_{12} = 0.5968	$\epsilon^{12\beta\Delta t}$ = 1.5532	0.929	$12\Delta\phi$ =	299.1°	+0.487	Δ_{12} = 0.452	$S_{12} = S_{11} + \Delta_{11} + \Delta_{12}$ =	-9.5670	-8.2160	-0.873	0.644	+4.620
	195°	y_{13} = 0.7002	$\epsilon^{13\beta\Delta t}$ = 1.6113	1.129	$13\Delta\phi$ =	324.0°	+0.810	Δ_{13} = 0.915	$S_{13} = S_{12} + \Delta_{12} + \Delta_{13}$ =	-8.2000	-6.8490	-0.586	0.620	+2.485
	210°	y_{14} = 1.3377	$\epsilon^{14\beta\Delta t}$ = 1.6716	2.236	$14\Delta\phi$ =	349.0°	+0.982	Δ_{14} = 2.192	$S_{14} = S_{13} + \Delta_{13} + \Delta_{14}$ =	-5.0930	-3.7420	-0.191	0.598	+0.428
	225°	y_{15} = 1.8471	$\epsilon^{15\beta\Delta t}$ = 1.7343	3.208	$15\Delta\phi$ =	13.9°	+0.971	Δ_{15} = 3.115	$S_{15} = S_{14} + \Delta_{14} + \Delta_{15}$ =	+0.2140	+1.5650	+0.240	0.577	+0.217
	240°	y_{16} = 1.7246	$\epsilon^{16\beta\Delta t}$ = 1.7990	3.100	$16\Delta\phi$ =	38.8°	+0.778	Δ_{16} = 2.410	$S_{16} = S_{15} + \Delta_{15} + \Delta_{16}$ =	+5.7390	+7.0900	+0.628	0.556	+2.475
	255°	y_{17} = 1.1316	$\epsilon^{17\beta\Delta t}$ = 1.8662	2.117	$17\Delta\phi$ =	63.8°	+0.441	Δ_{17} = 0.935	$S_{17} = S_{16} + \Delta_{16} + \Delta_{17}$ =	+9.0840	+10.4350	+0.897	0.536	+5.020
	270°	y_{18} = 0.7065	$\epsilon^{18\beta\Delta t}$ = 1.9360	1.368	$18\Delta\phi$ =	88.7°	+0.023	Δ_{18} = 0.0315	$S_{18} = S_{17} + \Delta_{17} + \Delta_{18}$ =	10.0505	+11.4015	+1.000	0.517	+5.910
	285°	y_{19} = 0.9247	$\epsilon^{19\beta\Delta t}$ = 2.0084	1.849	$19\Delta\phi$ =	113.7°	-0.402	Δ_{19} = -0.744	$S_{19} = S_{18} + \Delta_{18} + \Delta_{19}$ =	9.3380	+10.6890	+0.916	0.499	+4.890
	300°	y_{20} = 1.6038	$\epsilon^{20\beta\Delta t}$ = 2.0834	3.350	$20\Delta\phi$ =	138.6°	-0.750	Δ_{20} = -2.508	$S_{20} = S_{19} + \Delta_{19} + \Delta_{20}$ =	6.0860	+7.4370	+0.661	0.480	+2.355
	315°	y_{21} = 2.0893	$\epsilon^{21\beta\Delta t}$ = 2.1613	4.530	$21\Delta\phi$ =	163.5°	-0.959	Δ_{21} = -4.340	$S_{21} = S_{20} + \Delta_{20} + \Delta_{21}$ =	-0.7620	+0.5890	+0.284	0.461	+0.077
	330°	y_{22} = 1.9225	$\epsilon^{22\beta\Delta t}$ = 2.2421	4.320	$22\Delta\phi$ =	188.4°	-0.989	Δ_{22} = -4.270	$S_{22} = S_{21} + \Delta_{21} + \Delta_{22}$ =	-9.3720	-8.0210	-0.147	0.446	+0.526
	345°	y_{23} = 1.3038	$\epsilon^{23\beta\Delta t}$ = 2.3259	3.038	$23\Delta\phi$ =	213.4°	-0.835	Δ_{23} = -2.535	$S_{23} = S_{22} + \Delta_{22} + \Delta_{23}$ =	-16.1770	-14.826	-0.550	0.430	+3.510
	360°	y_{24} = 0.8992	$\epsilon^{24\beta\Delta t}$ = 2.4128	2.167	$24\Delta\phi$ =	238.3°	-0.525	Δ_{24} = -1.138	$I_1 = S_{23} + \Delta_{23} + \Delta_{24}$ =	-19.8500	-18.499	-0.851	0.415	+6.538

TABLE III

Column No 1 Abscissa of Torque Effort Curve	Column No 2 Same as Column No 4 Table 2	Column No 3 Same as Column No 9 Table 2 Sin ωt	Column No 4 Product of Columns Nos 2 and 3		Column No 5 Continuous Sum of Column No 4		Column No 6 B + S' from Table No 1 B = -2.10	Column No 7 Same as Column No 5 Table 2 Cos ωt	Column No 8 Same as Column No 10 Table 2 $\epsilon^{-\beta t}$	Column No 9 Product of Columns Nos 6, 7 and 8	Column No 10 Same as Column No 11 Table 2	Column No 11 Difference Column No 10 Minus Column No 9	Extra Column In Which May Be Listed Mech Deg Elec Deg or Current Pulsation	
						S'								
0°	0.8992	0	Δ'_0 =	0	S'_0 =	0	-8.1900	1	1	-8.190	0	+8.19	Multiply Column No 11 by 2.96 to Obtain Position in Electrical Degrees	24.2
15°	1.214	0.421	Δ'_1 =	0.5115	$S'_1 = S'_0 + \Delta'_0 + \Delta'_1$ =	0.5115	-7.6785	0.907	0.965	-6.730	+1.360	+8.09		23.9
30°	2.037	0.764	Δ'_2 =	1.554	$S'_2 = S'_1 + \Delta'_1 + \Delta'_2$ =	2.5770	-5.6150	0.644	0.931	-5.360	+4.100	+7.46		22.1
45°	2.645	0.965	Δ'_3 =	2.55	$S'_3 = S'_2 + \Delta'_2 + \Delta'_3$ =	6.6810	-1.5050	0.211	0.898	-0.286	+6.620	+6.906		20.4
60°	2.450	0.986	Δ'_4 =	2.415	$S'_4 = S'_3 + \Delta'_3 + \Delta'_4$ =	11.6460	+3.4560	-0.169	0.865	-0.505	+6.640	+7.145		21.5
75°	1.621	0.825	Δ'_5 =	1.334	$S'_5 = S'_4 + \Delta'_4 + \Delta'_5$ =	15.3950	+7.2050	-0.568	0.832	-3.410	+4.410	+7.820		23.2
90°	0.985	0.506	Δ'_6 =	0.499	$S'_6 = S'_5 + \Delta'_5 + \Delta'_6$ =	17.2280	+9.038	-0.863	0.804	-6.260	+1.900	+8.160		24.2
105°	1.230	0.096	Δ'_7 =	0.118	$S'_7 = S'_6 + \Delta'_6 + \Delta'_7$ =	17.8450	+9.6550	-0.995	0.774	-7.640	+0.193	+7.633		22.6
120°	2.188	-0.332	Δ'_8 =	-0.728	$S'_8 = S'_7 + \Delta'_7 + \Delta'_8$ =	17.2350	+9.0450	-0.945	0.745	-6.340	+0.170	+6.510		19.3
135°	2.965	-0.700	Δ'_9 =	-2.075	$S'_9 = S'_8 + \Delta'_8 + \Delta'_9$ =	14.4320	+6.2420	-0.714	0.718	-3.200	+2.443	+5.643		16.7
150°	2.751	-0.935	Δ'_{10} =	-2.570	$S'_{10} = S'_9 + \Delta'_9 + \Delta'_{10}$ =	9.7810	+1.5970	-0.355	0.698	-0.384	+5.180	+5.564		16.5
165°	1.761	-0.997	Δ'_{11} =	-1.758	$S'_{11} = S'_{10} + \Delta'_{10} + \Delta'_{11}$ =	5.4590	-2.7310	+0.073	0.669	-0.133	+5.865	+5.998		17.7
180°	0.929	-0.873	Δ'_{12} =	-0.811	$S'_{12} = S'_{11} + \Delta'_{11} + \Delta'_{12}$ =	2.8900	-5.3000	+0.487	0.644	-1.661	+4.620	+6.281		18.6
195°	1.129	-0.586	Δ'_{13} =	-0.662	$S'_{13} = S'_{12} + \Delta'_{12} + \Delta'_{13}$ =	1.4170	-6.7730	+0.810	0.620	-3.400	+2.485	+5.885		17.4
210°	2.236	-0.191	Δ'_{14} =	-0.427	$S'_{14} = S'_{13} + \Delta'_{13} + \Delta'_{14}$ =	0.3280	-7.8620	+0.982	0.598	-4.620	+0.428	+5.048		14.9
225°	3.208	+0.240	Δ'_{15} =	+0.771	$S'_{15} = S'_{14} + \Delta'_{14} + \Delta'_{15}$ =	0.4720	-7.5180	+0.971	0.577	-4.220	+0.217	+4.437		13.1
240°	3.100	+0.628	Δ'_{16} =	1.944	$S'_{16} = S'_{15} + \Delta'_{15} + \Delta'_{16}$ =	3.3870	-4.8030	+0.778	0.556	-2.08	+2.475	+4.555		13.5
255°	2.117	+0.897	Δ'_{17} =	1.897	$S'_{17} = S'_{16} + \Delta'_{16} + \Delta'_{17}$ =	7.2280	-0.9620	+0.441	0.536	-0.227	+5.020	+5.247		15.5
270°	1.368	+1.000	Δ'_{18} =	1.368	$S'_{18} = S'_{17} + \Delta'_{17} + \Delta'_{18}$ =	10.4930	+2.3030	+0.023	0.517	+0.027	+5.910	+5.883		17.4
285°	1.849	+0.916	Δ'_{19} =	1.692	$S'_{19} = S'_{18} + \Delta'_{18} + \Delta'_{19}$ =	13.5530	+5.3630	-0.402	0.499	-1.075	+4.890	+5.965		17.7
300°	3.350	+0.661	Δ'_{20} =	2.212	$S'_{20} = S'_{19} + \Delta'_{19} + \Delta'_{20}$ =	17.4570	+9.2670	-0.750	0.480	-3.335	+2.355	+5.690		16.8
315°	4.530	+0.284	Δ'_{21} =	1.286	$S'_{21} = S'_{20} + \Delta'_{20} + \Delta'_{21}$ =	20.9550	+12.7650	-0.959	0.461	-5.650	+0.077	+5.727		17.0
330°	4.320	-0.147	Δ'_{22} =	-0.636	$S'_{22} = S'_{21} + \Delta'_{21} + \Delta'_{22}$ =	21.6050	+13.4150	-0.989	0.446	-5.930	+0.526	+6.456		19.1
345°	3.038	-0.550	Δ'_{23} =	-1.67	$S'_{23} = S'_{22} + \Delta'_{22} + \Delta'_{23}$ =	19.2990	+11.1090	-0.835	0.430	-3.990	+3.510	+7.500		22.2
360°	2.167	-0.851	Δ'_{24} =	-1.843	$I_2 = S'_{23} + \Delta'_{23} + \Delta'_{24}$ =	15.7860	+7.596	-0.525	0.415	-1.652	+6.538	✱8.19		24.2

Ψ = Amplitude of Swing in Mechanical Radians = $\frac{Kr}{\omega I} \times \frac{\Delta t}{2} \times Q = 4.9 \times 10^{-3}$ (Kr = 7500)

Amplitude of Current Pulsation in Percent of Motor Rated Current = $\frac{6000\ P_t}{RPM\ Ka} \times \Psi = 4.79$ Percent

Ka = Kilovoltampere Rating of Motor

✱ In Making Sum Omit These Figures

Sum = 153.799 — 19.1

Average Sum = 6.41

Largest Value Col. No 11 = 8.19

Smallest Value Col No 11 = 4.437

Q = Amplitude of Col No 11 = 3.82

gram in Fig. 3 expressed as an average. This has an amplitude of variation of 66.8 per cent of its average value. But since the motor rated current is larger than this average, this current pulsation is only 53.6 per cent of the motor rated current. This compares very well with the original prediction of 48 per cent made a year and a half before the apparatus was tested.

The current to a unity power-factor synchronous motor is approximately proportional to the torque. The Curve No. 1* of Fig. 2 in Part II was reduced to a percentage of its average value and therefore represents the current pulsation predicted before the ice plant was built. This curve is shown by the dash-dot line.

The zero of the oscillogram in Fig. 3 started when the lagging cylinder was at the crank end. The zero of Curve No. 1 of Fig. 2 in Part II started when the leading cylinder was at the crank end. It was therefore necessary to shift this curve 90 deg. in order to make a comparison with the oscillogram.

The discrepancy between these two curves is not wholly due to inaccuracy of calculation because the operating voltage, suction, and discharge pressures at the time the oscillogram was taken were slightly different from those predicted a year and a half previously. (Voltage 480 instead of 440, suction pressure 15 instead of 20, and discharge pressure 186 instead of 200.)

In order to separate the inaccuracy in the method of calculation from the changes in operating conditions, the dotted curve was calculated from the actual operating conditions outlined. It will be seen that the dotted curve checks very closely with the full-line curve and this indicates that the method of calculation is very accurate.

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* The current would be proportional to Curve No. 5 if there were no amortisseur winding or other cause of damping, in which case Curve No. 5 and Curve No. 1 would be of the same shape. It can be seen that even when damping is included, they are very nearly of the same shape and for this reason the current pulsation is often calculated from the angular deviation alone.

Steel Mill Auxiliary Drives

FACTORS AFFECTING THE SELECTION OF ELECTRIC MOTORS

PART II

By L. A. Umansky

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In Part I the author discussed in general the factors affecting the selection of electric motors for auxiliary drives. In this issue, by means of specific examples, he explains the method of calculating the performance of a motor-driven reversing mill table, including friction, acceleration, duty cycle, plugging, and the influence of gear ratios.—Editor.

Study of the Performance of a Motor-driven Reversing Mill Table: General Arrangement

Fig. 11 gives a skeleton layout of a section of a reversing mill table. It is driven by two 90-h.p., 500-r.p.m., 230-volt series-wound motors. The motors are operated in tandem on the same shaft, as shown in the sketch, and are electrically connected in series. There are two such tables, one on each side of the mill.

Let us see what will be the variation of the load on these motors, i.e., what will be their duty cycle.

When the main rolls of the reversing mill are working, the ingot is delivered on the table section after each second pass and it is usually carried some distance away from the main rolls: either to turn it from side to side, or to transfer it crossways to another groove of the main rolls. This distance is different after various passes, but we will assume that the average travel is 5 ft.

Then the table is started and the ingot is brought back to the mill. After the metal has entered the main rolls, the function of the table has ended and it may as well be stopped in order to be reversed later and thus be ready to take the ingot when it will be delivered back after the next pass. Then the performance will be repeated. We will select for our study the following operation: The ingot has just been moved crosswise by the side guards and is at rest on the table; the latter is then started and carries the ingot to the main rolls. The distance (assume 5 ft.) should be covered as quickly as possible, as the output of the whole mill depends on the promptness of the table operation. Not over, say, two seconds should be allowed for the 5-ft. travel and we will see whether this time cannot be bettered.

The table consists of 18-in. rollers and the gear ratio from roller to motor shaft is 4:1 From the weights and dimensions of the rollers, bevel gears, etc., it has been figured that the whole table has a $WR^2 = 28{,}000$ lb-ft.^{2} at the roller shaft.

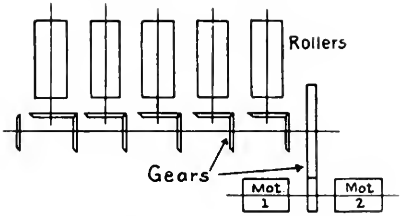

Fig. 11. Layout of the Reversing Mill Table

Then there is the ingot to be considered for calculating of the inertia load. Its weight in this case is 9100 lb. If there is no slip between the ingot and the rollers, the former travels at the same speed, and therefore at the same rate of acceleration as the surface of the roller. The presence of the ingot will have the same effect as if the weight of the ingot were added to the surface of the roller. This will, naturally, add to the WR^2 of the drive a value

$$WR^2_{Ing} = (\text{weight of ingot}) \times (\text{radius of roller})^2 = 9100 \times 0.75^2 = 5120 \text{ lb-ft.}^2 \qquad (27)$$

Thus the total inertia at the roller shaft is:

$$WR_1^2 = 28{,}000 + 5120 = 33{,}120 \text{ lb-ft.}^2 \qquad (28)$$

This corresponds, as per (25) to a $WR^2_{1\text{-}2}$ on the motor shaft:

$$WR^2_{1\text{-}2} = \frac{WR_1^2}{k^2} = \frac{33{,}120}{4^2} = 2070 \text{ lb-ft.}^2 \qquad (29)$$

Each motor armature has a $WR_m^2 = 388$ lb-ft.^{2}. The total inertia on the motor shaft is then

$$WR^2 = 2070 + (2 \times 388) = 2846 \text{ lb-ft.}^2 \qquad (30)$$

Thus, for considering the inertia load this mill table can be substituted by a flywheel mounted on the shaft and driven by the two motors, see Fig. 12. The flywheel has a

$$WR^2 = 2846 \text{ lb-ft.}^2$$

The motor characteristics are given in Fig. 13. The curves refer to the two motors operating in series, as in this case.

Friction

The friction load on the table was known from tests to be approximately 40 h.p. at the roller speed of 100 r.p.m. As the

$$\text{Torque} = 5250 \times \frac{\text{horse power}}{\text{r.p.m.}} \qquad (31)$$

the friction torque at the roller shaft is

$$T_{f,r} = 5250 \times \frac{40}{100} = 2100 \text{ lb-ft.} \qquad (32)$$

This corresponds to a friction torque at the motor shaft:

$$T_{f,m} = \frac{T_{f,r}}{k} = \frac{2100}{4} = 525 \text{ lb-ft.} \qquad (33)$$

For finding these data from a test all that is required is to let the table run free until constant speed is reached, and then take ammeter readings in the motor circuit. The torque corresponding to this current, i.e., the friction torque will be found from the motor characteristic, similar to Fig. 13. In our case the friction torque of 525 lb-ft. corresponds to a motor current of approximately 150 amp.

We will assume that the friction torque does not change with the motor speed. The friction may be represented by a band brake on the flywheel, Fig. 12, set for a definite pressure.

In the case of the mill table, there is no "useful work" to be done and thus only friction and inertia loads must be considered.

Contactor Acceleration

The steel mill auxiliary motors for such service are usually furnished with automatic magnetic control equipment, such as shown in the elementary diagram, Fig. 14.

The operator throws his master switch to, say, the forward running position and then the line contactor *S* and the reversing contactors *1* and *3* close. This throws the motor with full starting and plugging resistance $(R+R_p)$ across the lines.

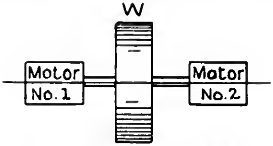

Fig. 12. Equivalent Inertia Load

The inrush of current is limited by the amount of resistance in series with the armature. This definite current corresponds to a certain torque T_m, which will be found from the known characteristics of the motors, Fig. 13. . The motor torque T_m will overcome the friction torque $T_{f,m}$, and the excess torque

$$T_a = T_m - T_{f,m} \tag{34}$$

is the accelerating torque, which starts and speeds up the motors with the wheel W on its shaft, see Fig. 12

While the motors speed up, the counter e.m.f. of their armatures increases and this reduces the current. When the current dies down to a predetermined value, the current-limit or voltage-drop relay, or any other current limiting device causes the contactor *5* to close, and this increases again the armature current. In the same manner the next accelerating contactors *6* and *7* will close, until the armature will be connected directly on the line. The current during the acceleration varies from the peak value, limited by the resistance, to the minimum determined by the setting of the relays or of the series accelerating contactors, as the case might be.

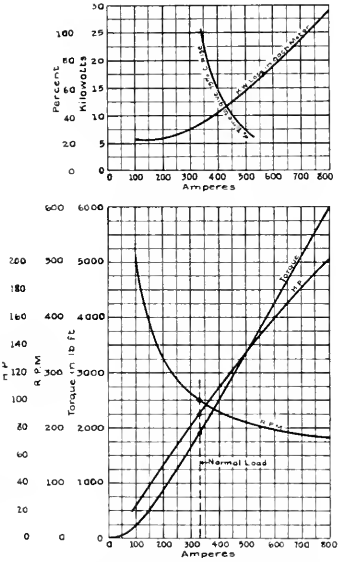

Fig. 13. Pe formance Curves of Two 90-h.p., 500-r.p.m., 230-volt Series-wound Motors Connected in Series and Cperating on One Shaft

Usually the combined starting and plugging resistance $(R+R_p)$ is of such value that the current inrush at motor standstill is below the "drop-out" setting of the contactors; therefore the plugging contactor *5* will close right after the closing of the line and the reversing contactors and the resistor R_p will not take an active part in the acceleration as described. The reason for having the plugging resistance R_p is to limit the current inrush when the armature current is reversed, while the motor is running, to about the same value as have the current peaks while starting from rest; when the motor is "plugged," the contactor *5* of course stays open for some time, until the current dies down to the predetermined value.

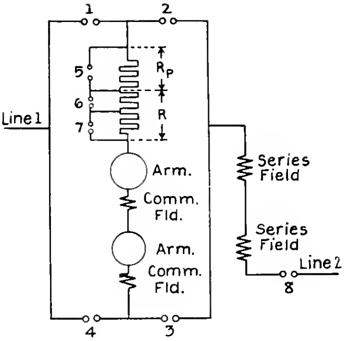

Fig. 14. Elementary Wiring Diagram of the Control Equipment

Assume that the maximum current peaks are 160 per cent of the normal, and that the minimum or "drop-out" value is 100 per cent. This will give an average value of current during acceleration as 130 per cent or 430 amp. (normal current = 330 amp.). From Fig. 13 we will find that in this case the motors will develop an average torque corresponding to 430 amp.:

$$T_m = 2780 \text{ lb-ft.} \tag{35}$$

The available accelerating torque,

$$T_a = T_m - T_{f,m} = 2780 - 525 = 2255 \text{ lb-ft.} \tag{36}$$

The sketch, Fig. 15, illustrates the starting performance. The motor torque during this period, which is called for obvious reasons "contactor acceleration" or "resistance acceleration," is shown as fluctuating between its maximum and minimum values. It is within the accuracy of such calculations as this to substitute this fluctuating torque by its average value, figured as shown.

Once the accelerating torque T_a (36), and the inertia effect or WR^2 (30) are known, it is simple to figure out the rate of acceleration of the motor shaft. Use equation (16):

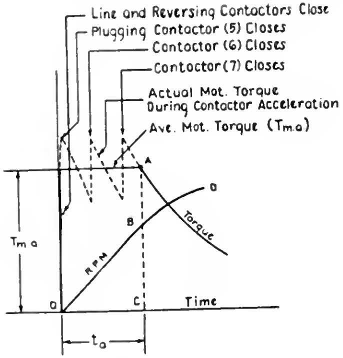

Fig. 15. Curves of Contactor Acceleration Period

$$a_0 = \frac{308 \times T_a}{WR^2} = \frac{308 \times 2255}{2846}$$

$$= 244 \text{ r.p.m. per sec.} \qquad (37)$$

i.e., during contactor acceleration the motor shaft speed will increase by 244 r.p.m. every second. For how many seconds (t_a) will the contactor acceleration last?

After the last contactor 7 closes, the motor is connected directly to the line, and from this instant on, the higher will be its speed the smaller torque it will develop, which fact follows from the known characteristic of the series motors, see Figs. 3 and 13. It will be, as we call it, the "series acceleration" period, when to each value of motor torque corresponds one definite value of motor speed.

Now, by referring to Fig. 15, we see that the point A (motor torque after t_a seconds) lies also on the "series acceleration" torque line. Therefore, the motor speed at this instant can be found from the curve, Fig. 13. The torque of 2780 lb-ft. corresponds to the motor speed of 225 r.p.m. In other words, if the motors were started from rest and were accelerating at the rate of 244 r.p.m. per sec. (37) they will reach the speed of 225 r.p.m. in

$$t_a = \frac{225}{244} = 0.92 \text{ sec.} \qquad (38)$$

Thus the point A can be plotted on the diagram.

As we have assumed that during the contactor acceleration the motor torque and therefore the rate of acceleration have a constant value, the increase of motor speed is uniform and can be represented by a straight line, r.p.m.-line in Fig. 15. It can be plotted by having laid $OC = t_a = 0.92$ sec. and $CB = 225$ r.p.m., and by drawing a line through the points O and B. The line OB gives the motor speed at each instant of contactor acceleration and is therefore called the "speed-time curve" of that period.

For any given motor speed the roller speed is of course known. After $t_a = 0.92$ seconds the roller speed is

$$\frac{225}{4} = 56.25 \text{ r.p.m.} \qquad (39)$$

and the ingot speed (i.e., the roller surface speed):

$$V_i = (\pi \times 1.5) \times (\text{roller r.p.m.})$$

$$= \pi \times 1.5 \times \frac{1}{4} \times (\text{Motor r.p.m.})$$

$$= 1.18 \times (\text{motor r.p.m.}) = 265 \text{ f.p.m.} \qquad (40)$$

If preferred the speed-time curve of the rollers or of the ingot can be plotted instead of the motor speed. It is obvious that they will also be straight lines.

Series Acceleration

After the end of the "contactor acceleration," the motor will still speed up, but as was stated previously, with a diminishing torque and therefore with a diminishing rate of acceleration. Thus the speed-time curve will not be the continuation of the line OB in Fig. 15: it will bend over, as shown by the line BD. We must now calculate how the motor and therefore the whole drive will gain speed with the course of time.

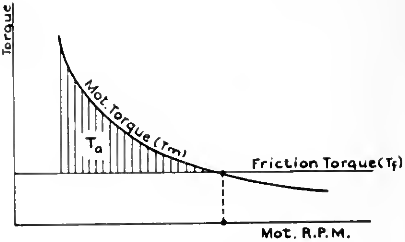

Fig. 16. Curve of Series Acceleration Pe iod

The procedure will be as follows:

We know that at the end of 0.92 seconds the motor speed was 225 r.p.m. and that its torque was still 2780 lb-ft. Then the torque will decrease and we may see by referring to Fig. 13 that when the motor will run at, say, 250 r.p.m. it will develop a torque of 1920 lb-ft. Let us find out how long it takes for the motor to change its speed from 225 r.p.m. to 250 r.p.m. The *average* motor torque during this period of time will be

$$\frac{2780+1920}{2}=2350 \text{ lb-ft.} \qquad (41)$$

This is not strictly correct because the torque does not change uniformly while the speed goes from 225 r.p.m. to 250 r.p.m. But if the speed change or "speed increment" is not great (25 r.p.m., or even 50 r.p.m.) the inaccuracy is entirely negligible.

Part of the motor torque will have to overcome the friction; the latter is as before 525 lb-ft. (33), thus the torque available for acceleration:

$$T_a=2350-525=1825 \text{ lb-ft.} \qquad (42)$$

The rest is simple:

The average rate of acceleration during this period as per (16):

$$a=\frac{308\times T_a}{WR^2}=\frac{308\times1825}{2846}$$
$$=197.5 \text{ r.p.m. per sec.} \qquad (43)$$

Time required =

$$\frac{(\text{change of speed})}{(\text{rate of accel.})}=\frac{250-225}{197.5}=0.126 \text{ sec.} \qquad (44)$$

The length of time required by the motors to speed from 250 r.p.m. to 275 r.p.m. is figured in exactly the same way; and also from 275 r.p.m. to 300 r.p.m., etc. Thus the various points of the speed-time curve *BD* will be successively plotted.

It is very convenient to proceed with these calculations and tabulate them as shown in Table I.

It can be readily observed from this table that the higher the motor speed the longer it takes to change the speed by the same increment (for instance by 25 r.p.m., as in our example). This is quite natural, because the inertia of the drive remains the same, whereas the available accelerating torque decreases. The same point is well illustrated in Fig. 16:

Curve T_m shows how the total motor torque varies with the speed; it has been taken from the motor characteristic, Fig. 13.

T_f represents the friction torque, assumed to be constant; the shaded portion between these lines represents the accelerating torque T_a available at any given speed. The speed (r.p.m.) at which the curve T_m intersects T_f is the "free running speed;" at this speed the motor will just overcome the friction of the drive, and there will be no acceleration. In our case the friction torque is 525 lb-ft. (33). The motor will develop this torque, Fig. 13, at about 400 r.p.m.; thus in this case if the ingot would travel even indefinitely long it may approach very closely, but will never exceed the speed of (40)

$$1.18\times400=472 \text{ f.p.m.} \qquad (45)$$

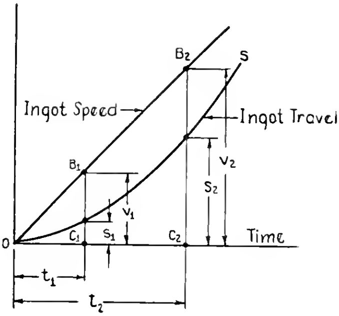

Fig. 17. Distance-time Curve for Contactor Acceleration Period

Distance-time Curve

Once we know the speed of our motor (or of the table) at any given time after it has been started, it is easy to calculate the distance traveled by the ingot from start to any given instant. It is this point that interests the steel mill men mostly.

For the period of "contactor acceleration," the rate of acceleration is constant and the speed-time curve is therefore a straight line *OB*, Fig. 17. We have figured out previously (37) that for this period the rate of motor acceleration

$$a_0=244 \text{ r.p.m. per sec.}$$

As the gear ratio is 4:1, the rate of roller acceleration is

$$a_r=\frac{244}{4}=61 \text{ r.p.m. per sec.} \qquad (46)$$

and the ingot rate of acceleration

$$a_i=\pi\times1.5\times61=287 \text{ f.p.m. per sec.} \qquad (47)$$

Thus the ingot speed after, say, t sec. within this period will be

$$V=a_i\times t=287\times t \text{ f.p.m.} \qquad (48)$$

After, say, t_1 seconds, the speed will be, Fig. 17, V_1 f.p.m. The average speed during the period of t_1 sec. is

$$\frac{V_1}{2}\text{ f.p.m., or }\frac{a_i\,t_1}{60\times 2}\text{ f.p.s.}$$

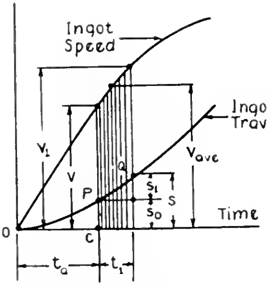

Fig. 18. Distance-time Curve for Series Acceleration Period

As

(Distance traveled) = (average speed) × (time) (49)

we will find that the travel during t_1 seconds

$$S_1=\frac{V_1}{2}\times t_1 \tag{50}$$

or

$$S_1=\frac{a_i\times t_1}{2\times 60}\times t_1=\frac{a_i\times t_1^2}{2\times 60}\text{ ft.} \tag{51}$$

Similarly, the distance traveled in t_2 seconds, Fig. 17,

$$S_2=\frac{V_2}{2}\times t_2\text{ ft.} \tag{50a}$$

or

$$S_2=\frac{a_i\times t_2^2}{2\times 60}\text{ ft.} \tag{51a}$$

In other words, if the ingot has been started from rest and has been accelerated at a uniform rate (as during contactor acceleration) the distance traveled by it is proportional to the second power of the time. We may also note, by observing (50) and (50a) and also Fig. 17, that the distance traveled by the ingot in "t_1" seconds is proportional to the area of the triangle OB_1C_1; in "t_2" seconds to the area OB_2C_2.

In the case of our table we have

$$S=\frac{287}{60}\times\frac{t^2}{2}=2.4\times t^2 \tag{52}$$

where

t — is expressed in seconds
S — in ft.

In this way points of the line OS, Fig. 17, can be calculated and plotted. Two or three points are all that is needed for plotting fairly accurately this part of the distance-time curve. By giving value $t=0.92$ sec. we find that the total travel at the end of the "contactor acceleration" is

$$S_0=2.03\text{ ft.} \tag{53}$$

For the period of "series acceleration," no formula like (51) can be derived, because the rate of acceleration will not be uniform any longer, but will decrease as the motor torque decreases, i.e., with the increase of the speed. The relation between the series motor speed and its torque cannot be expressed by any mathematical formula, as the question of saturation enters. Therefore the following step-by-step method is recommended:

Say, after a period of $t_a=OC$ seconds, Fig. 18, the contactor acceleration ends. We already know the speed-time curve and also, the whole travel S_0 up to that instant. During the additional period of time t_1 sec., the speed changes from V_0 f.p.m. to V_1 f.p.m. The average speed is then

$$V_{ave.}=\frac{V_0+V_1}{2}\text{ f.p.m.}=\frac{V_0+V_1}{2\times 60}\text{ ft. per sec.} \tag{54}$$

and the distance traveled *during this period*

$$S_1=V_{ave.}\times t_1 \tag{55}$$

the *total* travel at the end of this period

$$S=S_0+S_1 \tag{56}$$

Thus the point Q and the following points of the distance-time curve are plotted. It is quite obvious from this and from (55) that the distance S_1 is proportional to the shaded area under the speed-time curve, Fig. 18.

Similar calculations for our mill table were made and tabulated as shown in Table I.

The speed, travel and current are then plotted in Fig. 19 and this curve sheet will give us a fairly good idea of the performance of the mill table during the period under consideration.

The most important curve for the mill operator is, of course, the distance-time curve; from this he will readily see how long the equipment will take to move the ingot over various distances. For instance we have assumed that in our case the average length of ingot travel will be 5 ft. By referring to Fig. 19, we find (see point N) that this will require approximately 1.5 seconds, which is better than the 2-second limit, assumed in the beginning. The curves shown in Fig. 19 are characteristic for our drive whenever it is started from rest.

Motor Duty Cycle

After the ingot has entered the main rolls the table motors may be disconnected from the line. Thus the motor current during the useful part of the operation is represented by the part KLM of the current-time curve. We will assume in this example, for the sake of simplicity, that our motors will be started and run in the same manner 15 times during the rolling of one ingot, i.e., say, every 60 seconds. What will be the heating of the machines if such a cycle is repeated indefinitely?

The heating of an electric motor depends on the amount of losses occurring in the machine which are unavoidable whenever the electric energy is transformed into mechanical energy or vice versa. These losses were calculated and then carefully checked by tests for each of the mill type motors, and are usually given on the performance curve as shown in Fig. 13. The losses are given in kw. for *each* of the two motors for various values of armature current. It is well to note that the losses rise faster than the current, because the copper (or I^2R) losses, constituting a greater part of the whole, are proportional to the second power of the current. During "contactor acceleration" the current was assumed to vary from 160 per cent to 100 per cent of its value, i.e., between 530 amp. and 330 amp. The respective values of losses are 16 and 8.5 kw., Fig. 13, or 12.25 kw. on the *average*. This is somewhat higher than 11.5 kw., which corresponds to the *average current* of 430 amp. during contactor acceleration. This difference would be more considerable if the current peaks were allowed to go higher than 160 per cent of normal. For calculating the heating, the average loss (12.25 kw.) and not the loss corresponding to the average current (11.5 kw.) should be considered.

The losses corresponding to current values for the "series acceleration" were taken directly from Fig. 13 and plotted against time in Fig. 19.

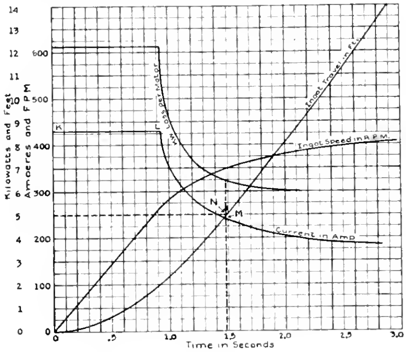

Fig. 19. Performance Curves of the Live Table Drive

The average loss during the 1.5-second acceleration period is determined from this curve as 10.7 kw. Each of the motors in question is designed to carry continuously the rated current (330 amp.) without exceeding 75 deg. C. rise; the corresponding losses are approximately 8.25 kw. In our case the average loss per motor during its operation is higher (10.7 kw.) but on the other hand the motor is not working continuously. The assumed 15 table operations, each requiring 1.5 seconds will take only 15×1.5=22.5 sec. out of the 60 sec. or 37.5 per cent of the

TABLE 1

Period	MOTOR SPEED IN R.P.M.			Ave. Motor Torque T_m	Friction Torque T_f (Const)	Ave. Accel. Torque $T_a = T_m - T_f$	Rate of Motor Accel. $a = 308 \times \frac{T_a}{WR^2}$	Time Required to Change Speed from Min. to Max. (t)	Total Time Elapsed Since Starting	Ave. Ingot Speed $V = 1.18 \times$ (Ave. Mot. r.p.m.)	INGOT TRAVEL		Ave. Amp.
	Min.	Max.	Ave.	Lb-ft.	Lb-ft.	Lb-ft.	R.p.m. per Sec.	Sec.	Sec.	F.p.m	During Period of t sec. $\frac{V \times t}{60}$ Ft.	Total Ft.	
Contactor acceleration	0	225	112.5	2780	525	2255	244	0.92	0.92	133	2.03	2.03	430
Series acceleration													
1	225	250	237.5	2350	525	1825	197.5	0.126	1.046	280	0.588	2.618	370
2	250	275	262.5	1650	525	1125	121.5	0.206	1.252	310	1.065	3.683	300
3	275	300	287.5	1275	525	750	81.0	0.309	1.561	340	1.75	5.433	250
4	300	325	312.5	1000	525	475	51.4	0.487	2.048	369	3.00	8.433	215
5	325	350	337.5	800	525	275	29.7	0.842	2.89	398	5.58	14.013	190
6	350	375	362.5	650	525	125	13.5	1.85	1.74	428	13.2	27.213	165

total time. The motor test curves, Fig. 13, show that, when the losses *while working* are 10.7 kw., the motor may work about 55 per cent of the time, if its heating should not exceed 75 deg. C. rise. Thus it seems as if our motors will operate within their capacity, although the margin is none too large.

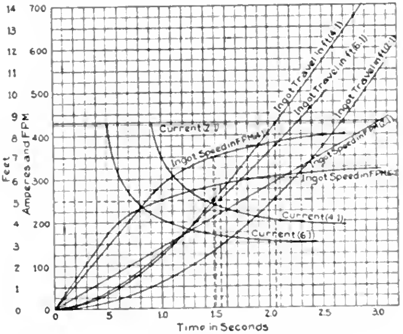

Fig. 20. Comparative Performance of the Live Table with Different Gear Ratios Between the Motors and the Rollers

There are a good many factors contributing to the additional losses in the motors besides those calculated and plotted in Fig. 19. In the first place, the operator controlling the table may not open the motor circuit immediately after the 5-ft. ingot travel; he may keep the motors running even with the ingot already in the main rolls. Although the current and losses are then sufficiently low, they still may add to the motor heating unless the better cooling due to the increased speed overbalances that fact.

Very frequently the motors of both tables (on the delivery and on the entrance side) are controlled from one master switch. Thus when the entrance or front end table is accelerated as described in our example, the delivery, or rear table, is also brought to speed by its motors. This is not required, strictly speaking, by the rolling process, but is being done for the sake of simplicity of the operator's work. Shortly after the ingot enters the main rolls, the motors of both tables are often "plugged," i.e., their armature current is reversed while the motors are running, in order to create a counter-torque for braking; the motors are thus brought to rest and then are accelerated in the opposite direction, so that the ingot is usually delivered against the rotation of the rollers, in order to prevent the ingot (delivered on the table by the main rolls at a fairly high speed) from traveling too far. In other words, each table may be started and plugged every pass, which fact will contribute to the motors heating.

Plugging

The plugging duty is calculated, generally, in the same way as we did for the acceleration from rest. Let us consider a simplified example as follows:

Suppose the table is carrying the ingot and it is desired to stop it. Say, the ingot speed was at that instant 400 f.p.m.; this corresponds (40) to the motor speed of $400 \div 1.18 = 339$ r.p.m.

If the plugging resistance R_p, Fig. 14, is so selected that under these conditions the average plugging current and torque are approximately the same as during acceleration (430 amp. and 2780 ft-lb. respectively) then the total retarding torque $T_a =$ (motor counter-torque) + (friction torque).

$$T_a = 2780 + 525 = 3305 \text{ lb.} \qquad (57)$$

The rate of retardation (negative acceleration):

$$a = \frac{308 \times T_a}{WR^2} = \frac{308 \times 3305}{2846}$$
$$= 358 \text{ r.p.m. per sec.} \qquad (58)$$

i.e., the motor shaft will slow down by 358 r.p.m. every second. As the initial speed was 339 r.p.m., the retardation will last

$$\frac{339}{358} = 0.95 \text{ sec.} \qquad (59)$$

after which the ingot will come to rest. If the ingot speed was, as assumed, 400 f.p.m. at the moment of plugging and the retardation was uniform then

$$(\text{ingot travel}) = (\text{average speed}) \times (\text{time})$$
$$= \frac{400}{2} \times \frac{0.95}{60} = 3.17 \text{ ft.} \qquad (60)$$

Thus the motors should be plugged when the ingot is about 3 ft. away from the desired final point of its travel.

Each phase of the table and motor performance can be figured out in the same way as we have done it in our example. If the complete rolling data are known (duration of each pass, movements of side guards, manipulators, etc.) a complete study of the motor performance can be prepared. Lack of space prevents us from following calculations on these pages, although it is trusted that the general method to be used is made sufficiently clear.

Effect of Motor Characteristics on the Duty Cycle

It is quite clear from this discussion that the motor characteristics, and its armature inertia, influence the calculations from beginning to end. Therefore it is impossible to figure beforehand the performance and the load requirement on the drive, determine the required horse power capacity of the motor and then to select a machine from the motor list, as we have done it for the pump used as an example in the beginning of this article. For steel mill drives, where series motors are used and where the inertia load predominates due to frequent start-stop service we must first select the motor and then check the drive performance. It means, of course, that the calculations may be repeated several times in order to ascertain that proper machines were selected. Fortunately, however, the past experience of motor application to the auxiliary drives helps to eliminate a great deal of extra work and it is usually a question of choice between two or three motors or of their combinations.

It happens not infrequently that a large motor will be loaded up to its capacity not less than a smaller machine. This is due to a higher WR^2 of the armature, so that the extra motor capacity is only taking care of the extra motor inertia.

Influence of Gear Ratio

In our example we were given the value of the gear ratio between the motor and the roller shaft as 4:1. It will be shown now that the value of the gear ratio is of utmost importance. In a good many cases wrongly selected gear ratio resulted in burned-out motors, in excessive wear of control equipments, and in like troubles.

This is a peculiar feature of the frequent start-stop service, not encountered in other motor applications. The reason for this is again the influence of the ever-present inertia forces.

Suppose we are given the same mill table and the same motors and were told to select another gear ratio, with the idea of speeding up the operation of the table; i.e., to reduce the time (1.5 sec.) required, as we have seen, to move the ingot from rest over a distance of .5 ft. Suppose we reason as follows: With a 4:1 gear ratio the rollers run at a speed four times lower than the motor; if we keep the same motor and select a lower gear ratio, say, 2:1, the roller speed will be only half that of the motor, i.e., the rollers will run twice as fast as before, and, therefore, the performance of the table will be speeded up.

The fallacy of such reasoning may be proved very easily, if we begin to analyze the performance with the gear ratio 2:1.

It will be remembered, the WR^2 of table, ingots, gears, etc., brought to roller shaft, was (28) $WR^2 = 33{,}120$ lb-ft.². This inertia, reduced to motor shaft, as per rule (25):

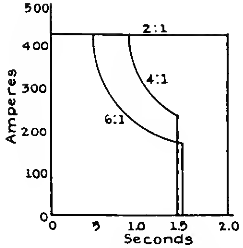

Fig. 21. Motor Current During Acceleration Period as Affected by the Gear Ratio

$$WR^2_{1\text{-}2} = \frac{WR_1^2}{k^2} = \frac{33{,}120}{2^2} = 8260 \text{ lb-ft.}^2 \qquad (60)$$

instead of 2070 lb-ft.² in case of 4:1 gear ratio (30). The inertia of the two motor armatures being the same as before (776 lb-ft.²) the total inertia on the motor shaft will be

$$8260 + 776 = 9056 \text{ lb-ft.}^2 \qquad (61)$$

In other words, by changing the gear ratio we have increased the equivalent flywheel, Fig. 12, on the motor shaft more than three times.

On the other hand, the two given motors will develop the same average torque 2780 ft-lb. during the contactor acceleration, regardless of the selected gear ratio. The friction torque at the roller shaft will be the same as before 2100 ft-lb. (26); but reduced to motor shaft the friction torque is

$$T_{f,m} = \frac{T_{f,r}}{k} = \frac{2100}{2} = 1050 \text{ lb-ft.} \qquad (62)$$

i.e., twice as much as before.

The available accelerating torque

$$T_a = 2780 - 1050 = 1730 \text{ lb-ft.} \qquad (63)$$

Thus, what we did by reducing the gear ratio amounts to putting a heavier flywheel on the motor shaft and to increasing the friction on the same shaft. Naturally, the motor will take considerably more time to accelerate under such conditions and the result may be quite opposite from what we might have expected.

Calculations were made for the same table and motors but with 2:1 ratio and results are plotted in curve sheet, Fig. 20. (Similar curves are also plotted for 6:1 ratio.) It will be seen that the travel of 5 ft. takes 2.1 seconds instead of 1.5 seconds, i.e., we have slowed down the table operation by 40 per cent instead of speeding it up, and all this happened despite the fact that the roller or ingot speed is twice as high as with 4:1 ratio for the *same motor speed*. The point is that the time required by the motor to come to the same speed is simultaneously much more than doubled. For instance, the time for "contactor acceleration," i.e., required for coming from rest to 225 r.p.m., will be 3.72 sec. for 2:1 ratio, instead of 0.92 sec. for 4:1, as can be readily calculated from the above figures. If the motor circuit is opened after 5 ft. ingot travel (i.e., after 2.1 sec.) it will be before the end of contactor acceleration and the line contactors will break the accelerating current which is very much higher than the 250-amp. motor current existing after 5 ft. ingot travel in case of 4:1 gear ratio. This fact accounts for excessive wear of contactor tips. Furthermore, the motor duty cycle is much more severe, as is clearly shown in Fig. 21, and the losses will be such that the motor will operate with barely any margin in its capacity. The result of changing the gear ratio in the other direction will be quite different; assume, for instance, a 6:1 gear ratio. Due to the same facts concerning the inertia values, available torques, etc., the motors in this case will come to their speed in much shorter time. The ingot acceleration will also be higher, as can be seen from the slope of the speed-time curve for this case. The ingot speed will be at first higher with 6:1 ratio than with 4:1, due to the higher value of ingot acceleration during contactor acceleration, and at 0.8 sec. the speeds are equal in either case. After this the ingot speed will be higher with 4:1 gear ratio.

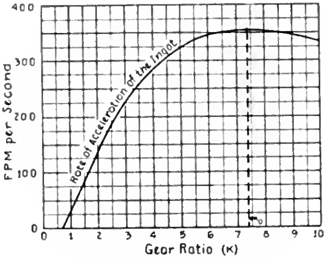

Fig. 22. Effect of the Gear Ratio on the Rate of Contactor Acceleration

The time required to cover 5 ft. travel is practically the same in either case, 1.5 sec. for 4:1, and 1.55 sec. for 6:1. If smaller distances were to be covered, say 2 ft., the 6:1 ratio would have a slight advantage from the standpoint of speed of operation. The heating of the motor will be considerably less for 6:1 ratio, because the "contactor acceleration" period, contributing so largely to the heating will be of shorter duration.

Summing up, the 2:1 gear ratio should not be considered at all for this table. The 4:1 ratio and 6:1 ratio are practically identical, from the standpoint of mill table operation, but the motor heating and contactor wear will be less with gear ratio 6:1. If the motor capacity were exceeded with 4:1 ratio, the same motors might still be used with gear ratio 6:1. On the other hand, if the average ingot travel is considerably more than 5 ft. the use of 6:1 or of higher ratios may slow down the operation.

It is thus clear that the best gear ratio can only be selected when the required travel of the ingot, or, more generally, the travel of the driven auxiliary, is known.

It may be stated in a general way that the longer the travel, the smaller the gear ratio which may be selected. There can be no "best gear ratio," without reference to the corresponding travel of the mill table, or of the screw-down, or of any other similar machine part.

If—speaking again of the mill table—the distance covered by the ingot were quite different after various passes, it is better to find out, by referring to distance-time curves for various gear ratios, which ratio will give the minimum *total* time for handling the ingot on the table after all passes. The corresponding gear ratio will then be the right answer. This will be, of course, a compromise ratio, which will be less efficient for both short and long distances, than the ratios which could be selected separately. This is a very strong argument in favor of splitting the reversing mill table into groups: one, near the main rolls, with its drive designed for short ingot travel and, therefore, with higher gear ratios, and the other outer group for longer ingot travels and with lower gear ratios.

"Best" Gear Ratio

The great influence of the gear ratio on the performance of the auxiliary drives and of the motor led to few attempts to determine directly, without several trials, the "best" or the "most favorable" gear ratio, for a given auxiliary drive, say mill table, and a given motor. Formulas have been suggested, as shown below, but these it must be understood have a limited scope.

What is the "best gear ratio" from the mill operator's standpoint? It is the one with which the operation of moving the material over a certain distance will take the least time. It is the relation between the distance or travel and the time that the operator is solely interested in; what he needs is the distance-time curves for various gear ratios and he will select the ratios on this basis.

Now, we have followed very closely the process of the calculation of the distance-time curve. We know that this curve can be expressed by formula only for the "contactor acceleration" period (the curve is then a parabola). During the "series acceleration" the distance-time curve was determined from the speed-time curve, which, in turn, was calculated by a "step-by-step" method, using the motor characteristics, which are not mathematical, but experimental curves.

Thus, any attempt to work up a formula for the "best gear ratio" must be limited to the "contactor acceleration" period only.

For this period the distance-time relation is expressed (51) as

$$S = \frac{a \times t^2}{2 \times 60}$$

where S = distance in ft. (for instance, ingot travel).

a = rate of acceleration (of ingot) in f.p.m. per second.

t = time in seconds.

The distance covered in a given time (within the contactor acceleration period) is directly proportional to the rate of acceleration a. In other words, our task is to find a gear ratio which will give us the highest rate of acceleration of the driven machine from the start to the end of the contactor acceleration.

We will analyze this problem in the general way and will then apply it to our table. The following data are assumed to be known:

WR_1^2 = Inertia of the driven machine at its shaft in lb-ft.^{2} (as inertia of the table at roller shaft).

WR_2^2 = Inertia of the motor armature at the motor shaft in lb-ft.^{2}.

T_m = Average accelerating torque developed by the motor at its shaft during contactor acceleration, in lb-ft.

T_f = Friction torque at machine shaft (as roller shaft) in lb-ft.

k = Gear ratio between the machine and the motor shafts.

a = Rate of acceleration of the machine (during contactor acceleration) in r.p.m. per second.

$a_m = k \times a$ = rate of motor acceleration, in r.p.m. per second.

We must find out how the machine acceleration a depends upon gear ratio k.

Total inertia, reduced to motor shaft

$$WR^2 = \frac{WR_1^2}{k^2} + WR_2^2$$

Torque available for acceleration at motor shaft

$$T_a = T_m - \frac{T_f}{k}$$

Thus, the rate of motor acceleration, as per (16)

$$a_m = 308 \times \frac{T_a}{WR^2} = 308 \times \frac{\left(T_m - \frac{T_f}{k}\right)}{\left(\frac{WR_1^2}{k^2} + WR_2^2\right)} \qquad (63)$$

$$\text{As } a = \frac{a_m}{k} \qquad \mathbf{(64)}$$

$$a = 308 \times \frac{\left(T_m - \frac{T_f}{k}\right)}{\left(\frac{WR_1^2}{k^2} + WR_2^2\right) \times k} = 308 \times \frac{kT_m - T_f}{WR_1^2 + k^2\ WR_2^2} \qquad (65)$$

If we use the data of our mill table, and insert them in the equation (65), then the roller acceleration a (or ingot acceleration proportional to it) for various values of gear ratio k will be represented by Fig. 22. We see that at first the rate of acceleration increases with the increase of gear ratio but then, after reaching a certain maximum value of over 355 f.p.m. at $k_0 = 7.5$ (approx.) the rate of acceleration drops down.

Why should it be so? Let us carefully examine the equation (65). The expression $(kT_m - T_f)$, as can be seen off-hand, is the accelerating torque at the machine (roller) shaft. The higher the gear ratio, the larger the value this torque acquires. The denominator $(WR_1^2+k^2WR_2^2)$ is the combined inertia of the drive, but reduced to the machine (roller) shaft and not to the motor. This value increases obviously with the increase of gear ratio; we may say that the higher the gear ratio, the higher is the proportion of motor armature inertia in the total inertia; or, to put it differently, for a given rate of roller acceleration the rate of motor acceleration is higher with higher gear ratio, which facts make the inertia effect more appreciable. At first the available accelerating torque increases faster than the inertia; after a while, however, the increase of inertia is greater, so that the rate of acceleration will fall.

Thus we see that there is a definite gear ratio which should not be exceeded, as beyond this value even the rate of "contactor acceleration" will diminish.

It can be easily determined mathematically at what gear ratio k_0 the table acceleration a will have its maximum value. This has been done and found that the required gear ratio

$$k_0=\sqrt{\frac{WR_1^2}{WR_2^2}+\frac{T_f^2}{T_m^2}}+\frac{T_f}{T_m} \qquad (66)$$

The gear ratio determined by use of this formula has been often called the "most favorable" ratio. We know, however, that this should be understood in a very restricted sense. For instance, for our mill table

$$k_0=\sqrt{\frac{33,120}{776}+\frac{2100}{2780}}+\frac{2100}{2780}$$

$$=\sqrt{42.7+0.755}+0.755=\sqrt{43.455}+0.755$$

$$=6.58+0.755=7.335:1 \qquad (67)$$

The corresponding values of rates of acceleration are, per (65):

Roller acceleration $a=75.5$ r.p.m. per sec.

Ingot acceleration $=a\times\pi\times1.5=355$ f.p.m. per sec.

Motor acceleration $a_m=ak=75.5\times7.335$ $=552$ r.p.m. per sec.

Time to come from rest to motor speed of 225 r.p.m. (period of contactor acceleration).

$$T_a=\frac{225}{552}=0.408 \text{ sec.}$$

The above calculations show that there is no reason to exceed the ratio of 7.335:1 for our table, even for very short travels of ingot. For travels of 5 ft. the ratio of 6:1 was already slightly inferior to the 4:1 ratio; for the same travel the 7.335:1 ratio will require even more time and will thus be worse.

In other words, the gear ratio, determined by (66) is the maximum value to be considered. But the best gear ratio must be determined only after several distance-time curves are plotted and a study of them made, as was shown in this article.

Conclusion

It was not intended to give in this article a complete and exhaustive study of such a vast subject as steel mill auxiliary drives. Books, not only articles, can be written regarding the various features of this motor application. But it is expected that this article has shown how elementary are the calculations required to make the application of the electric motors in steel industry a matter of engineering and not of guess work.

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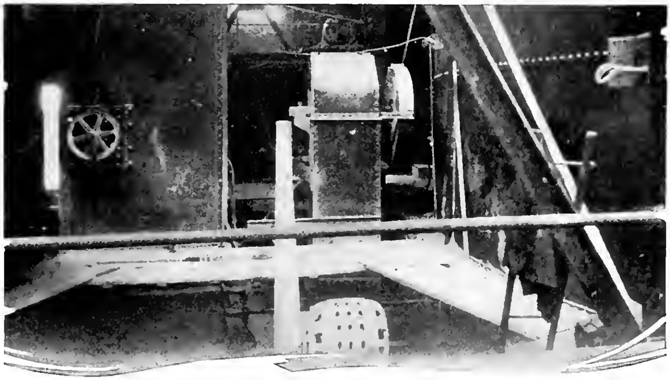

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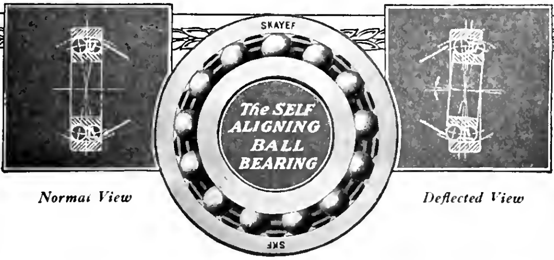

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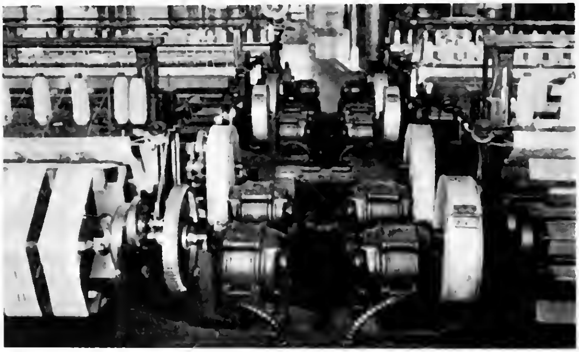

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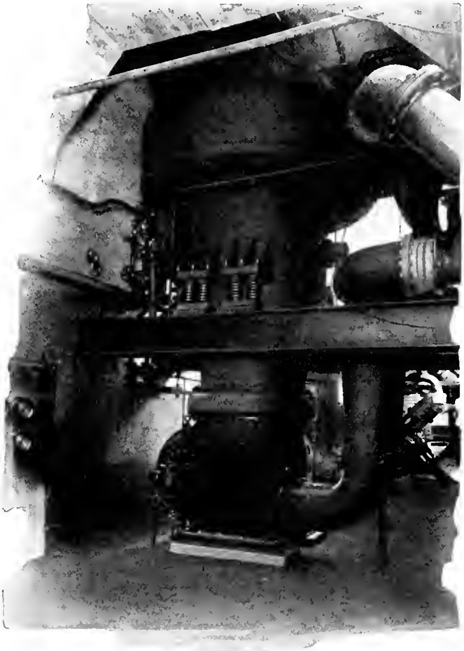

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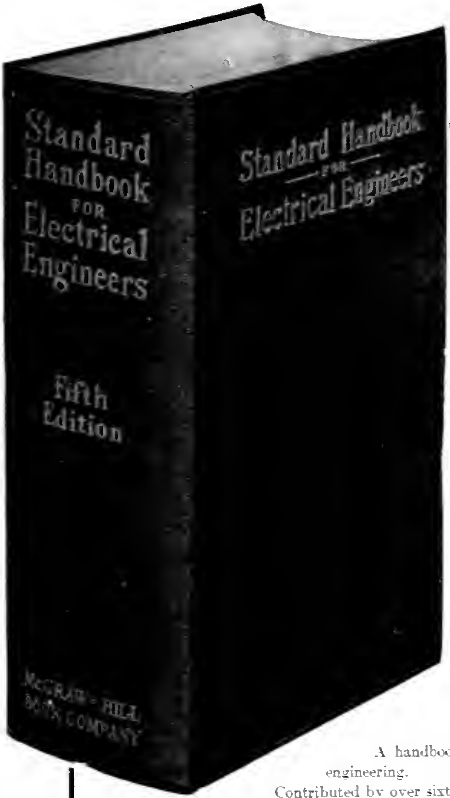

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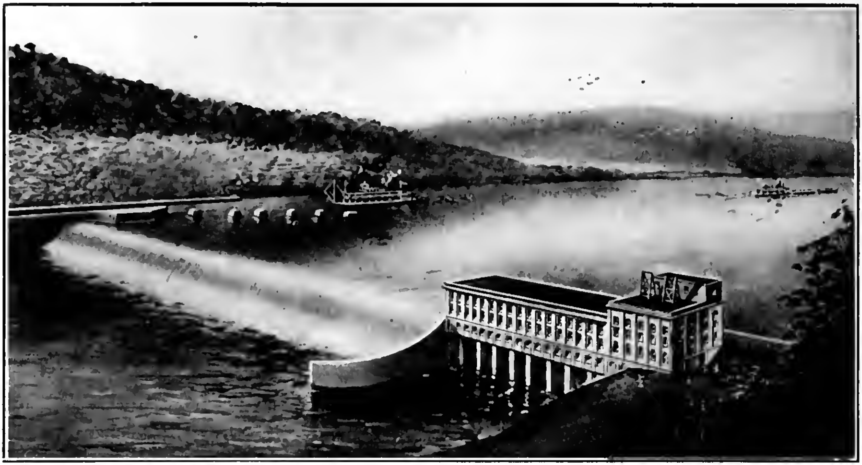

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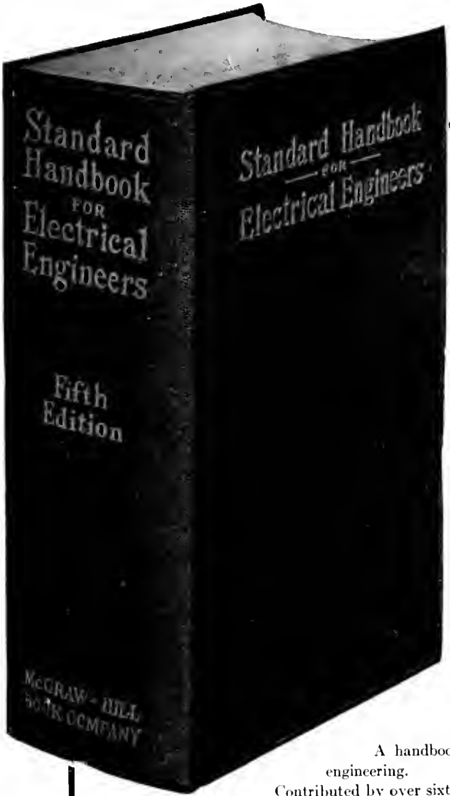
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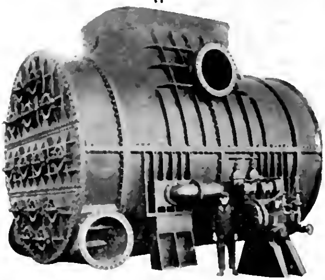

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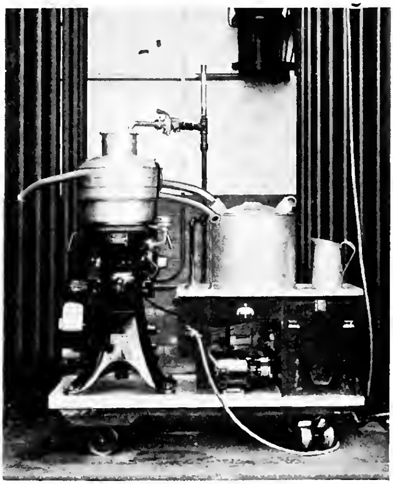

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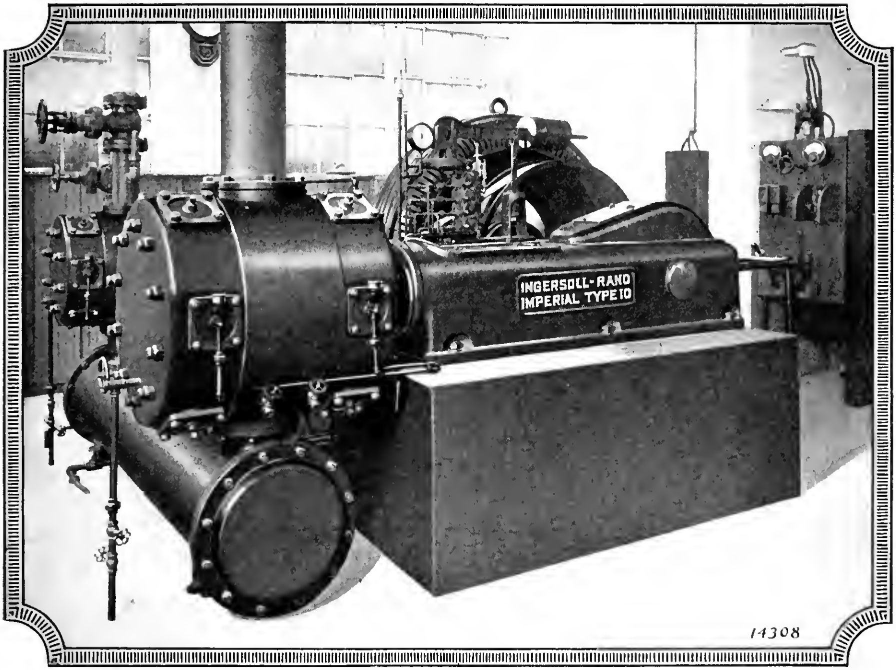
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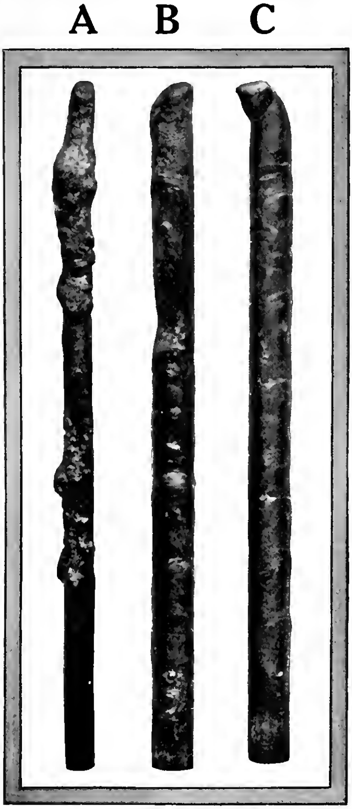

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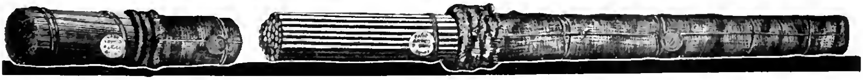

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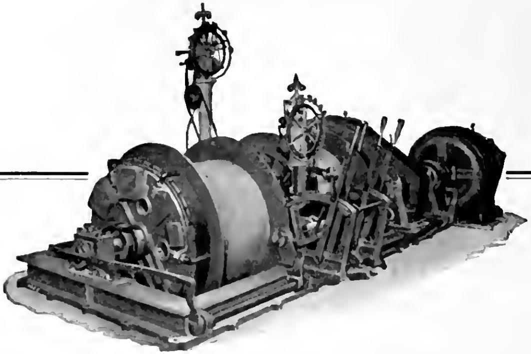

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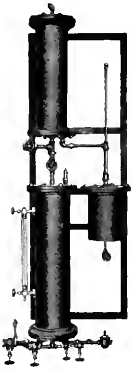

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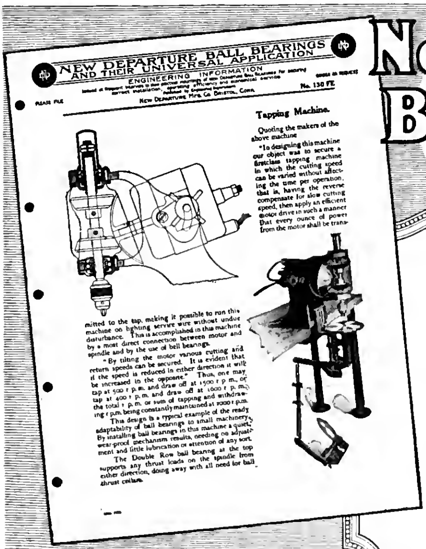

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ENGINEERING INFORMATION

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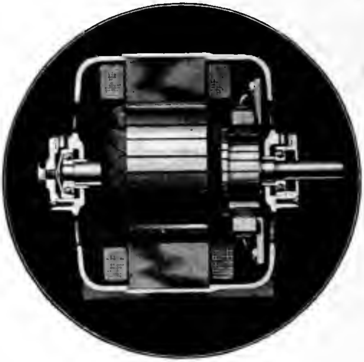

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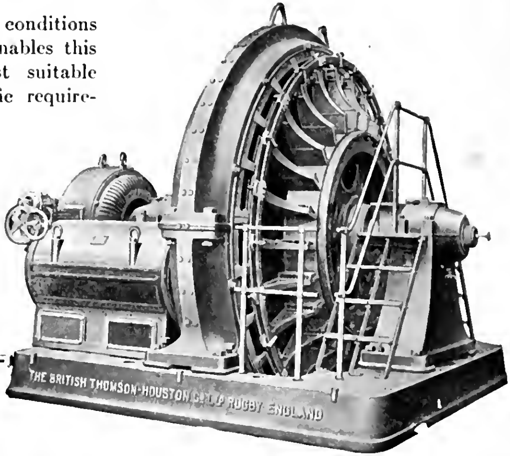

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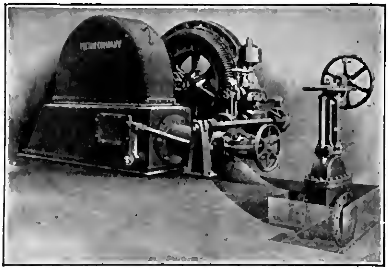

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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

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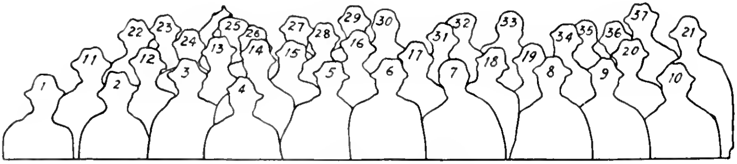
CONTENTS

Thomas A Edison and a group of his early associates on the steps of Building 48 of the Schenectady Works of the General Electric Company. This photograph of Mr. Edison with his old Schenectady friends was taken on October 18, 1922, following a luncheon in his honor. Many interesting details of his visit to the scene of some of his early activities are given in the articles which appear on pages 714 and 718 of this issue of the *Review*



KEY TO THE ABOVE GROUP

(1) H E. Tanis, (2) Charles L. Clarke, (3) Fred Peper, (4) E. S. Beyer, (5) W. S. Andrews, (6) H. Geisenhoner, (7) Thomas A. Edison, (8) Theodore Van Deventer, (9) James T. Dooling, (10) Michael Devine, (11) Arthur Turrian, (12) Julius Tournier, (13) Charles M. Cox, (14) J. D. Wagner, (15) Earle Van Vranken, (16) J. T. H. Dempster, (17) Charles F. Peterson, (18) W. S. Nethaway, (19) Charles H. Kaler, (20) James H. Wilke, (21) A. H. Gardinier, (22) Christian Rach, (23) S. B. Ham, (24) Charles Burger, (25) W. W. Hale, (26) Anthony Shook, (27) Daniel C. Campbell, (28) G. M. Beck, (29) Herman Machols, (30) Herman Lemp, (31) C. E. Smith, (32) A. Dugglin, (33) Peter Kirsch, (34) Herbert W. Leland, (35) John C. Shannon, (36) R. P. Wilke, (37) Fred Righton.

GENERAL ELECTRIC REVIEW

EDISON

We publish in this issue a brief account of Mr. Edison's visit to Schenectady, where he inspected some of the latest developments in the electrical industry and renewed his acquaintance with his old friends.

The name Edison has become so synonymous with work and with invention that on an occasion like this one's thoughts naturally turn to the subject of inventors and inventions.

We believe that Mr. Edison once described the essentials for success as two per cent inspiration and ninety-eight per cent perspiration. We think that this is a very modest statement for a man to make whom the whole world acknowledges as a genius. Surely Mr. Edison has considerably more than two per cent inspiration, but who, even at the risk of being accused of being faulty in his arithmetic, would not be equally willing to acknowledge that Edison has a full one hundred per cent stick-to-it-ive-ness?

Genius without work is of little worth.

We know of many brilliant geniuses who have not achieved a tithe of the success that Mr. Edison has won, but we know of no genius whose whole life, from boyhood to an honorable old age, has been so devotedly consecrated to work.

It is this wholehearted devotion to work, as well as his success as an inventor, that has won for Mr. Edison the enviable place he holds in the hearts of all Americans and that has had a powerful influence in establishing his fame throughout the world.

Mr. Edison's place in the Hall of Fame is assured if the world remembers only his work in the early history of electric lighting and forgets his many other inventions; but his inventions, and the perpetuation of his fame as an inventor, are not the most interesting legacies he will leave to future generations—his example of success achieved through untiring and unending work will be a real asset for generations. We know of no other person who could be better held up as an example to our boys of what sheer hard work, courage and faith can accomplish.

The force of good example is hard to overestimate.

> "Lives of great men all remind us we can make our lives sublime
> And, departing, leave behind us footprints on the sands of time;—
> Footprints, that perhaps another, sailing o'er life's solemn main,
> A forlorn and shipwrecked brother, seeing shall take heart again."

Successful men always make better examples to follow than unrewarded geniuses. This is perfectly natural as the youth starts out in life with "success" as his goal, but the really pleasant feature in pointing to a successful inventor as an example is that even the most successful inventor gives more to the world than he takes from the world.

This is a point that is too often misunderstood by the public. Take the example of an inventor inventing something and getting a patent.

What does he get?

What does he give?

The government grants him a patent, that is, a monopoly on that part of his work which is new, for a period of seventeen years, but the government grants this patent only on condition that the inventor gives so complete a description of his work that any one skilled in the art can make it. When the patent is granted it is published, so that all the world may know the result of the inventor's work. At the end of seventeen years, no matter whether he has made much or little out of his invention, his work becomes public property and any one from that date on may make and use his invention without paying him anything for it.

Who gives the most?

Who gets the most?

One of Edison's great stunts in life is doing things that others have declared impossible. Some of the most prominent men of the day said it was impossible to sub-divide the electric current. Edison did it! And thus made our lighting system a practical reality. We use quotations from Dyer and Martin's book, "Edison, His Life and Inventions," to show how Edison's perseverance and faith did what was then considered an impossibility. Mr. W. H. Preece (afterwards Sir William) after giving a mathematical discussion on the subject said: "Hence the sub-division of the light is an absolute ignis fatuus."

A book by Paget Higgs, published in London in 1879, includes the following sentence:

"Much nonsense has been talked in relation to this subject. Some inventors have claimed the power to 'infinitely divide' the electric current, not knowing or forgetting that such a statement is incompatible with the well-proven law of conservation of energy."

John Tyndall, the eminent scientist, while not quite sharing these views, lecturing at the Royal Institution in 1879 said: "Knowing something of the intricacy of the practical problem, I should certainly prefer seeing it in Edison's hands to having it in mine."

Such an example of overcoming the seeming impossible should be an encouragement to those who are so often told that they cannot do what they are trying to do.

Edison's original idea of using electricity for house lighting, much as illuminating gas was then used, was one of those advances which, after the event, is so obvious that nothing else seems logical, but which, prior thereto, is quite out of reason. The method of human progress will always be more or less what psychologists call trial and error, or fumbling and success. In other words, careful research or experiment of any kind may at any time change the grounds on which prevalent scientific opinions are based. Prevalence of change is Nature's unchangeable process.

J. R. H.

Mr. Edison Visits Schenectady

It was a red letter day in Schenectady's calendar, crowded as it was with memorable events, when Mr. Edison paid us a visit on October 18, 1922. All who know Mr. Edison realize how hard it is to get the great inventor to leave his laboratory in Orange, N. J., even for a few hours. However, on this occasion he accepted the invitation of the officials of the General Electric Company and visited the scene of some of his early triumphs. It is interesting to record here that it was Mr. Edison who, years ago, selected the present site of this huge factory, having moved the Edison Machine Works here in 1886.

Mr. Edison's epoch marking work in the perfection of the carbon incandescent lamp stands out as a milestone in the march of human progress, but Father Time has recorded many hours since October 1, 1879, when this invention was announced to the world. These hours have not been wasted and the most interesting feature of Mr. Edison's visit was his meeting those who have carried on his great work and improved the "child of his brain."

Before coming to Schenectady, Mr. Edison had visited the Edison Lamp Works at Harrison, N. J. In the Schenectady Works he first visited the Research Laboratory where so many of the modern improvements in the incandescent lamp have originated.

There was a very real significance in the men he visited here and in the order in which he visited them.

First: He visited Dr. W. R. Whitney, the Director of Research, and was shown the metalized filament lamp and the furnaces used in their production. The metalized filament lamp was Dr. Whitney's work and was the first substantial improvement on the carbon lamp.

Second: He visited Dr. W. D. Coolidge and was shown the process of swaging tungsten. The production of ductile tungsten, so that that formerly brittle metal could be die drawn into the tiny filament was Dr. Coolidge's contribution to the modern improvements in the incandescent lamp and was the second great step in increasing its efficiency. This single invention gave the public three times as much light for each dollar as they were formerly getting.

Third: He visited Dr. Irving Langmuir and was shown the gas filled lamp, Dr. Langmuir's invention, which marked another big increase in the efficiency of the incandescent lamp. Here he saw a gas filled incandescent lamp of 30,000 watts. Dr. Langmuir also showed the noted inventor some of the latest developments in vacuum tubes which have led to such wonders in radio and other fields and which are destined to lead us, so bold minds predict, into a new era in many lines of work in electrical engineering. This work must have been the source of great satisfaction to Mr. Edison, as so many of Dr. Langmuir's greatest achievements are based on the fact that he made a special and intensified study of the "Edison Effect," announced by Mr. Edison thirty-nine years ago.

We have got a little ahead of our story and must now go back and give some of the events of this memorable day in their chronological order. Mr. Edison's party consisted of Mr. and Mrs. Thomas A. Edison, and Mr. and Mrs. Charles Edison. The great inventor and Mrs. Edison arrived at Schenectady in their car in the afternoon of October 17th, and were entertained by Mr. and Mrs. E. W. Rice, Jr., at their home. Mr. and Mrs. Charles Edison were the guests of Mr. and Mrs. J. R. Lovejoy.

On Monday, October 18th, the visitors arrived in the morning at the entrance of the Research Laboratory at nine o'clock where they were welcomed by the Company's officials. Immediately after this event, those interesting meetings with Dr. Whitney, Dr. Coolidge and Dr. Langmuir, which we have just recorded, took place.

Over and above these meetings recorded in the Research Laboratory, Mr. Edison was shown the life tests of lamps and the model of a special radio wave apparatus. There is a temptation to go more into details regarding the many notable modern developments which held the interest of our distinguished guests throughout the greater part of the morning but this would take too long.

As Mr. Edison was leaving the Research Laboratory, the officials of the Company and the Laboratory employees assembled at the entrance where a bas-relief of Mr. Edison was unveiled. In the illustration on page 717 we reproduce this and feel that we should not pass this event without telling our readers that this piece of work which has such distinctively artistic qualities was executed by one of the foremen in the Porcelain Department, Mr. Julius Pardi. This work reflects the greatest credit on the artist, who spends all his time as foreman in a factory.

After being shown the talking motion picture film in the General Engineering Laboratory, the Edison party went over to Building 28, to see Dr. Steinmetz' experiments on artificial lightning.

Dr W R Whitney and Mr. Edison

Dr. W. D Coolidge and Mr. Edison

Dr Irving Langmuir and Mr. Edison, with Mr. G. F. Morrison on the left

Dr. C. P. Steinmetz and Mr. Edison

In our article we have told of Mr. Edison's visit to the Research Laboratory where he saw the improvements made in the incandescent lamp. The most notable of these were the metalized filament lamp, the drawn wire tungsten lamp and the gas filled lamp.

Some Interesting Views taken during
Mr. Edison's Recent Visit
to Schenectady

1 Employees greeting Edison on his trip down Works Avenue. 2. Edison placing his name in Dr. Whitney's autograph book; 3 Fire Station Hall where Edison dined with his old associates. 4. Edison inspects large turbine wheels in Building 60; 5 Edison and the first large Curtis Steam Turbine Generator. 6. Dr Coolidge and Edison talking things over; 7. Thomas Edison sees again old underground tubes being made. 8. Edison tablet being unveiled over door of Building 5; 9. Dr. C. P. Steinmetz showing Edison results of his home made lightning; 10. The brain power represented in this group cannot be surpassed in the world. 11. Dr. Irving Langmuir showing Edison the latest lamp developments; 12. Edison sees 40,000-Horsepower Turbine Generator on test in Building 60; 13. A character study in Dr. Steinmetz' laboratory

The great inventor showed a keen interest when taken to the underground-cable plant in Building 73, as owing to his foresight and genius the process for insulating underground cable is much the same today as he himself originated when building the old Pearl Street station in New York. Some of our illustrations on the opposite page will show Mr. Edison examining the old turbine in the Works, which is the first 5,000 kw. turbine, erected as a permanent monument in front of Building 60, and also they will show Mr. Edison and his party looking at a huge 40,000 h.p. turbine whose sole purpose is to turn an electric generator. Surely such modern Titans must have taken Mr. Edison back to the days when he was having troubles of his own with the then large steam engines which had been built especially to turn his old "Jumbos."

During Mr. Edison's visit to Schenectady this plaque was unveiled over one of the entrances to the Research Laboratory

After this inspection, the Edison party drove up and down the main avenue of the Works. They were most enthusiastically greeted by the host of employees.

On entering Building 45, where luncheon was to be served, Mr. Edison was introduced to each of his old Schenectady associates, who had worked with him in olden days. We reproduce as a frontispiece a picture of Edison photographed with these old friends.

This luncheon proved itself to be a most enjoyable affair, where everyone was bent on doing homage to the great inventor, whose name was so indelibly stamped on the work that they are carrying on. The tribute which appeared on the menu is worthy of record, so we quote it in full:

"We, your Schenectady associates of thirty-six years ago, witnesses of the promise of those beginnings and participants in its fulfillment, offer our tribute of affection and honor to your great mind and indomitable spirit which, in the years between, created a new epoch of human relationship and achievement.

"We testify to your courage and to your vision that assembled a little group of willing helpers and developed it into an army of over two million people occupied throughout the world in rendering an indispensable service—a service that had its conception in your dream and that grew in the light of your thought.

"We are proud to remember that we were privileged to bear a part in the first days of endeavor. We are happy in this opportunity to greet you across the years and renew, by this word, the fealty that we then sought to express in our work. Our warmest wish is that you may long continue to wear the laurels brought home to you by the children of your brain."

The eulogy that Mr. E. W. Rice, Jr., Honorary Chairman of the Board of the General Electric Company, read on this occasion is printed in full on another page.

After luncheon Mr. Edison and his party visited the Illuminating Engineering Laboratory and saw many colored pictures on the history of lighting. After this the party drove about Schenectady seeing the historical points of interest and then at 5 o'clock drove to the Mohawk Golf Club for tea and an informal reception where two hundred guests greeted him. Mr. Edison had had an arduous day for a man of seventy-five, who has spent all his life on intensive work, but there were many present who remarked that he had been actively interested in everything he had seen, had kept going the whole day at the high pressure of excitement and that at the end of the day when he had tired many younger men he was fresh, cheerful and lively, in fact, what astonished many who had kept more or less in touch with Mr. Edison in recent years was the fact that he looked younger and appeared to be more full of energy than he was ten years ago.

Schenectady will long remember the visit of our noted guest. J. R. Hewett

Address by E. W. Rice, Jr., on the Occasion of Thomas A. Edison's Visit to Schenectady, October 15, 1922

Our distinguished guest objects to speeches. We sympathize with him, but it is simply impossible to let this remarkable occasion pass without a few words in commemoration.

It would indeed take a long speech to even enumerate the contributions Mr. Edison has made to the world—his improvements in multiplex telegraphy, the phonograph, the motion picture, the new storage battery, the carbon transmitter—all wonderful contributions, and in fields outside of our own activities.

I will limit my few remarks to Edison's contribution to our own line of work.

There are four dates which are of great interest to those present here today:

1879—Forty-three years ago, Edison electrified the world by his announcement of his invention of the incandescent electric lamp.

1882—Forty years ago, he started the Pearl Street Station in New York for the generation, distribution, and sale to the public of electricity, according to his system.

1886—Thirty-six years ago, Mr. Edison started the manufacture of electrical machinery here at Schenectady.

1892—Thirty years ago, the General Electric Company was formed, which united and continued the work of Edison, Thomson and other early pioneers.

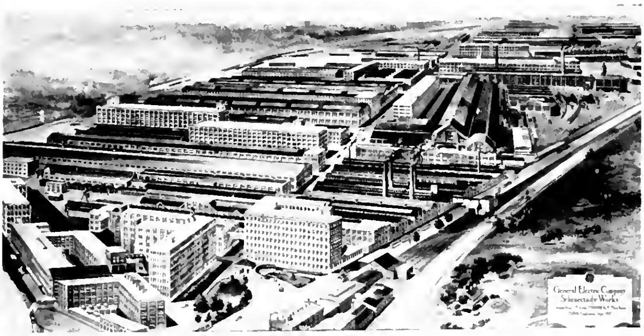
In the three years between 1879 and 1882, Edison invented, developed and worked out the principles and details of a comprehensive system of generation, control, distribution, measurement and utilization of electrical energy for public use on a large scale.

Viewed from the standpoint of today, Edison's achievements of that early period appear almost miraculous. They have stood the test of forty years of the most extensive and intensive technical development of the electrical industry. His system of distribution of electrical energy on the multiple or parallel plan has survived and is the only method by which an unlimited amount of electrical energy can be generated and distributed over an unlimited area in a practical and commercial manner. This simple method seems obvious to the present generation of engineers. It was by no means obvious in 1882. The series system of distribution had many powerful advocates at that time, but Edison's foresight and practical wisdom has been fully vindicated, as the multiple system is universal today. It is employed in the low-tension direct-current network for lighting of our cities, in the operation of our trolley cars, on electrified steam roads, and in the distribution of electricity at the super voltages and super dis-

The Old McQueen Locomotive Works as it Appeared in 1886, When Thomas A. Edison Chose the Site on which now stands the Schenectady Works of the General Electric Company. The two buildings shown are now Building 10 and part of Building 12 tances of our present day hydro-electric power developments.

The incandescent lamp in all its essential features, with its bulb of glass, filament of high resistance, screw base, voltage and candle-power, is substantially as Edison gave it to us forty-four years ago. It has been improved in efficiency and in life by Whitney, Coolidge, Langmuir and others, but otherwise remains the same wonderfully simple practicable device.

The vacuum bulb which Edison first made a practical device in the incandescent lamp is not limited in usefulness to the giving of light. It is the basis of a whole series of useful electrical devices. It is used in the rectifier for changing alternating current into direct current, and also for changing direct current into alternating current. The same vacuum tube through the "Edison effect," discovered by Edison in 1883 and developed by Fleming, De Forest, and Langmuir, has become the basis of wireless telegraphy and telephony.



Bird's Eye View of the Schenectady Works of the General Electric Company. Ground Area 340 Acres. Floor Space 5,800,000 Sq. Ft. 23,000 Employees. Taken in 1917

This same Edison vacuum tube in the hands of Langmuir, Coolidge and others is destined to revolutionize our present methods of transmission and utilization of electricity.

Therefore the vacuum tube of Edison, although forty-four years old, is still the most interesting and promising of all the wonderful products of his genius.

How keen and justifiable must be the pride and satisfaction of those early associates of Edison who have survived the years and are here to greet their old Chief! Many of these older workers are not here, having finished their work. Their presence is sadly missed.

I am sure I properly represent the sentiment of all those present when I suggest that the one who is most missed on this occasion is John Kruesi, an Edison pioneer, the Manager of these Works for many years, respected and loved to an extraordinary degree by all his associates.

We also regret the absence of Mr. Samuel Insull, who was trusted by Mr. Edison with the development of these Works in the early days, and whose energy, foresight and great administrative ability made possible its success; a man who has become the acknowledged leader of the great Central Station electrical industry

We also miss Charles A. Coffin, genius of finance and business, the creator of the General Electric Company, who, by his faith, his energy, and resourcefulness, led the Company through most discouraging difficulties to its present happy position, where it enjoys the esteem and confidence of the entire world.

It has been a great joy and privilege to have lived during this period of the world's electrical development, a period unique in the world's history. Those of us who started under other leaders and associations, but later joined the Edison forces, are none the less devoted and enthusiastic admirers of the great personality whom we have with us today and whom we delight to hail as our Master.

Some Arguments for Railroad Electrification

By W. J. Davis, Jr.

Railway Engineering Department, General Electric Company

There is so much sound logical reasoning in favor of the electrification of steam railroads in Mr. Davis' article that it is hard to emphasize any part as being of special importance. The whole article should be read and studied by those who want real data on this important subject.—Editor.

The apparently higher cost of the electric locomotive as compared with steam, plus the cost of the electric distributing system and substations is responsible for the prevalent belief that railroad electrification is an expensive undertaking which should be deferred until made absolutely necessary by reason of local or other conditions, such as congested terminals, long tunnels, etc. This belief may perhaps be justified in the case of branch lines or lines with light traffic, but for main line work, where the traffic approaches the limit of capacity of a single track with steam locomotives, it is found that additional capacity may be obtained by electrification at less capital cost than by any other method. In such cases, if credit is allowed for increased track capacity, the economies made possible by electrification may be considered as so much net gain in operating cost.

Many of the large trunk line systems, whose average annual increase in traffic is at the rate of five to seven per cent, may find it possible to carry out extensive electrification work with little additional capital over and above normal requirements after the first two or three hundred miles are equipped. Extensions to the electric system may be paid for by diverting to that use the money which would otherwise be spent for new steam locomotives and their accommodation, together with the savings in operating cost effected by the first installation.

The three necessary requirements of a motive power equipment capable of successfully meeting the transportation requirements of the country are briefly:

(1) Availability for Service. By this is meant immediate readiness for duty when required and the ability to continue in service for long periods without necessity of making repairs, grooming, cleaning, etc.

(2) Unrestricted Power Possibilities. The possible ton mileage obtainable per mile of track should not be limited by the inability of the locomotive to deliver as much power in the form of tractive effort and speed as may be required.

(3) Economical Operation. In addition to saving in fuel, this item includes other reductions in operating expenses such as engine and train crew wages, locomotive repairs, round house expenses, locomotive supplies, fuel and water supply.

Availability for Service

One of the results of the strike of the railroad shopmen has been to give prominence to the fact that large forces of skilled workmen are required to maintain steam locomotives in condition to permit satisfactory movement of the traffic. The number of men employed is out of all proportion to the amount of work done when viewed in the light of the performances of machinery in other industries.

Leaving out of consideration the smaller roads, operating records of some of the more important systems show that each road engine is available for service from 25 to 35 per cent of the time under normal and favorable conditions and that the full time of five men on an average is required on each locomotive to make necessary running repairs, keep it clean and properly oiled, and to give it a periodical overhauling in the back shops.

Such an engine in freight service will ordinarily handle about 35,000,000 trailing ton miles per annum and while doing so will deliver about 750,000 h.p.-hr. per annum at the draw bars. Reduced to a unit basis, the cost of steam locomotive repair and cleaning service, including material and labor, is found to be 1.21 cents per h.p.-hr., which is about 10 times the cost of repairs and upkeep of the entire motive power equipment of an electric motor driven industrial plant and 2.5 times that of an electric haulage system of equal capacity, including repairs and maintenance of the distributing system, transmission line and substations.

In contrast to the poor performance of the steam locomotive, operating records show that electric locomotives will on an average spend two weeks each year in the back shop for repairs and general overhauling.

Again, as the electric locomotive has no power plant, no time is lost by requirements of making steam, cleaning fires, taking on coal and water, cleaning boilers and flues, and by the necessity of daily hostler service. It is, therefore, available for service 90 to 95 per cent of the time—a ratio of about 3 to 1 as compared with the steam locomotive.

If allowance is made for possible increases in operating speeds, an electric locomotive of 300 tons will be capable of replacing from 3½ to 5 locomotives of the heavy Mikado type, total weight with tenders, 900 to 1200 tons. Excluding the cost of distributing system and substations, therefore, electric locomotives for a given service will as a rule cost less than the steam locomotives they replace.

Power Possibilities

If a section of road is operating at or near the limit of its capacity, it is evident that provision for handling additional traffic may be made either by increasing the power of the locomotives, and consequently the weight and speed of the trains, or by laying additional tracks. The former method is usually to be preferred as offering reductions in capital cost and in cost of operation.

The power for which a steam locomotive may be designed is limited by the grate area and heating surface of its boiler, in other words, by the size of steam generating plant which it is possible and feasible to carry around and operate on trucks. The electric locomotive is subject to no such restrictions. Performance data now available show that electric locomotives may be built of capacities well beyond the possible requirements of tractive effort and speed which our present knowledge of railroad economics would indicate as being desirable to handle efficiently future growth or developments.

The use of the more powerful locomotives made available by electrification will permit the capacity of a single track road to be increased 75 to 100 per cent, thus postponing the necessity of double tracking for 12 to 15 years. Also the increased speed of the trains and reduction in traffic delays will add to the value of the service and reduce the possibilities of serious traffic congestion during periods of unusual activity in business, such as existed in 1919.

Economies in Operation

Many improvements in design and operating conditions, such as the use of compound engines, high superheats, increased steam pressures, automatic stokers, traction boosters, fuel oil, etc., have been introduced and adopted by the railroads within recent years with the object of reducing the fuel consumption of locomotives. These have to a limited extent been successful where properly applied. Nevertheless, to an electrical engineer familiar with methods of generating power in modern central stations, the net gains from such efforts when compared with the savings promised by electrification appear to be hardly worth while. There are two important operating conditions which make it impossible for a steam locomotive of the present general type to have an efficient power plant, as measured by modern standards.

(1) Excepting one or two experimental equipments, all locomotive engines are built to run non-condensing. The energy thus thrown away in the exhaust steam which would be available to a condensing steam turbine is not less than 85 per cent of the energy in the steam available to the locomotive engine above atmospheric pressure.

(2) The operating load factor is so low and the standby losses so large that it is useless to hope for even moderately high efficiency under service conditions.

The losses due to the first of the above conditions are inherent to non-condensing operation. With regard to the second condition, it may be said that the effect of poor load factor in reducing efficiency is more serious than is generally realized. Operating records show that the yearly load factor of road engines is of the magnitude of about 5 per cent. The operating load factor, or the ratio of actual load to rated load while in service and including idle time will average 15 per cent to 20 per cent. On this basis, the coal consumption of a locomotive in actual service, allowing for standby and light load losses, will be increased by more than 45 per cent; the above results obtain under constant load conditions. As an example, if economy tests on a locomotive should show that it consumes 4 lb. of coal per brake h.p.-hr. at its established rating, the consumption in actual service would be not less than 5.8 lb. per brake h.p.-hr.

In order to determine the saving in coal per 1000 trailing ton miles which may be effected by electrification, we may analyze some operating data applying to a section of a large and well managed trunk line railroad. The section chosen is 300 miles long, single track, with ruling grades of 1.00 per cent and a short pusher section of ten miles with maximum grade of 2.00 per cent. Operating data, freight service only, for 1921 are as follows:

STEAM SERVICE (TAKEN FROM RECORDS)

Ton miles, locomotives only	262,000,000
Ton miles, trailing load	2,102,000,000
Ton miles, total	2,364,000,000
Tons of coal consumed (2000 lb.)	136,200
Coal consumed per 1000 trailing ton miles, lb.	129.6

ELECTRIC SERVICE (ESTIMATED)

Ton miles, locomotives only	199,300,000
Ton miles, trailing load	2,102,000,000
Ton miles, total	2,301,300,000
Ave. watthours per ton mile at power house	26.15
Kw-hr. per annum	60,179,000
Lb. coal consumed per kw-hr	1.92
Tons of coal consumed (2000 lb.)	57,750
Coal consumed per 1000 trailing ton miles, lb.	55
Ratio of coal consumption, steam to electric	2.36

The above comparison favors the steam locomotive in that it does not include the less efficient train movements, such as road and yard switching, work trains, etc. The average coal consumption of steam locomotives over the whole country for all classes of service is more than three times the amount required by an electric system capable of handling the same traffic.

The saving in fuel, while of increasing importance on account of the steadily advancing prices of coal, is as a rule not alone of sufficient magnitude to demand the adoption of an electric traction system. In addition to the increased track capacity obtainable, the use of larger train units and higher speeds permits changes in methods of handling freight and passenger traffic which results in substantial reductions in nearly all of the principal items making up operating costs. In the aggregate these savings will prove sufficiently large to yield an attractive return on the capital cost of electrification.

There are many indirect reductions in operating costs which will follow the adoption of the electric system. These will include such items as reduced maintenance of track and structures due to decreased axle weights, the use of shorter wheel bases and improved riding qualities of the locomotives; postponement of necessity for double tracking; savings in maintenance and cost of water supply, shop equipment, round houses and turntables; reduction in overtime caused by delays; practical elimination of ruling grade problems; reduced operating costs due to reduction in company coal movements; and improved service to shippers due to increased speed and greater reliability in operation.

These savings all have a real monetary value, the magnitude of which may be determined in specific cases with a fair degree of accuracy. Nevertheless, we may neglect them entirely and still show that electrification will pay where justified by the density in traffic, by considering only the seven main operating items usually included in statements of operating costs. The tabulated summary given opposite shows a comparison between steam and electric operation as applying to sections of the main lines of two large railroad systems. As a matter of convenience, we will refer to them as Road "A" and Road "B." Both are single track with the usual percentage of sidings. The length of the sections considered are 330 miles for Road "A" and 260 miles for Road "B." The costs are given in the form of percentages, the basis being the total cost of the steam service for the freight traffic. It is assumed that electric power will be purchased in each case. The figures for steam service were obtained from operating records. The costs for the electric system are estimated.

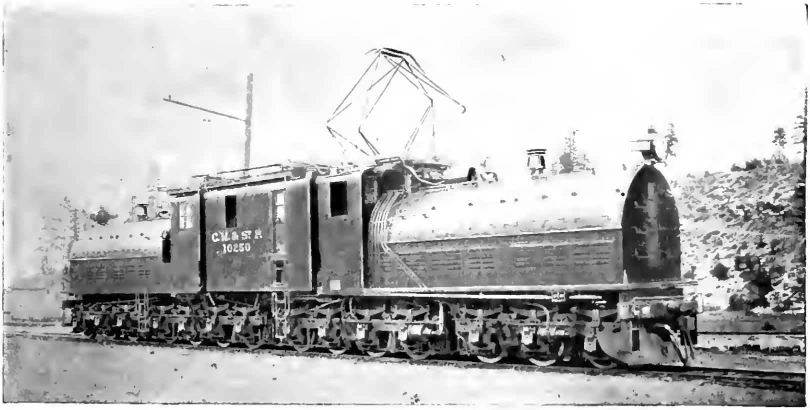
It will be seen that the total net savings in operation are 40.38 per cent for Road "A" and 36.57 per cent for Road "B." Expressed in terms of capital cost, these savings become 16.3 per cent and 17.1 per cent of the net cost of electrification after deducting the replacement value of the steam locomotives.

If allowance is made for normal increase in traffic over the amortization period, the capital cost of the electric equipment may be fully paid off in five to seven years. These two cases may be considered as fairly representing the economies to be expected from electrification of first class single track roads operating under heavy traffic conditions.

When viewed in its true light of a superior system for transportation work, electrification will be found to cost less than the steam service it will replace. The net cost including locomotives for the equipment of a single track after allowance for credits will vary from $18,000 to $30,000 per route mile, depending on local conditions and the amount of traffic to be handled. This calls for considerably less capital than required to lay additional tracks, especially through a rolling country. While the steam locomotive will doubtless continue for many years to hold a prominent and useful position in transportation work there are abundant signs that its replacement by the more powerful and more efficient electric locomotive on our more congested routes is nearer at hand than is generally realized.

Item	ROAD "A"			ROAD "B"		
	Steam	Electric	Reduction	Steam	Electric	Reduction
1. Fuel or power.......	33.80	27.50	6.30	38.34	32.70	5.64
2. Locomotive repairs..	30.40	10.70	19.70	23.65	8.35	15.30
3. Lubricants & supplies	2.35	1.41	.94	2.39	1.44	0.95
4. Enginehouse expense.	4.62	0.77	3.85	9.00	2.50	6.50
5. Enginemen.........	13.76	6.82	6.94	13.60	8.22	5.38
6. Trainmen..........	15.07	8.10	6.97	13.02	7.82	5.19
7. Maintenance trolley.	....	4.32	*4.32	....	2.39	*2.39
Total............	100.00	59.62	40.38	100.00	63.43	36.57

* Increase.



Three thousand volt, direct-current, 265-ton, gearless passenger locomotive

Cooling of Turbine Generators

By A. R. Smith

Construction Engineering Department, General Electric Company

The difficulty of thoroughly cleaning the air used for cooling turbine generators has led to the introduction of the recirculating system. The various methods for cooling the air when recirculated are discussed in this article, which compares all systems of turbine generator cooling from various standpoints. In subsequent issues there will be published by the same author "Heat Transfer in Surface Air Coolers," "Physical Considerations of Surface Air Coolers" and the "Economics of Using Surface Air Coolers and Heaters in Steam Power Plants."—Editor.

The recent introduction of what has been termed the "recirculation system" and the advent of the "surface coolers" has apparently confused users of turbine generators to the extent that many are uncertain as to what systems for cooling turbine generators are available and which is the best suited to their particular conditions.

This article is intended to show what the fundamental requirements are and to describe the important features of the various systems now available.

Requirements

Directed, or forced, circulation of air as employed for the cooling of turbine generators permits a relatively high air temperature rise and consequently the circulation of a smaller amount of air as compared with electric units where the circulation of air is largely the result of convection currents. The cubic feet of air per minute required varies with the capacity and the efficiency of the generator. For units ranging from 7,500 to 30,000 kw., the cubic feet of air per minute per kilowatt capacity will range from 3.0 to 2.25 cu. ft.; while for units ranging from 1,000 to 6,000 kw. the cubic feet of air per minute will range from 5 to 3.5 cu. ft. These figures are based on sea level conditions; therefore, for high altitudes they may have to be increased.

Inasmuch as the amount of air circulated per minute is dependent on the generator losses and the permissible temperature rise of the air, the cubic feet of air per minute to be circulated can better be expressed in terms of the kilowatt loss in the generator. The usual requirements will range between 85 and 100 cu. ft. per min. per kw. of loss in the generator.

The temperature of the air entering the machine should not be higher than the A.I.E.E. standard ambient temperature of 40 deg. C. (104 deg. F.). The temperature of the exit air will obviously depend upon the losses in the machine, the exact flow of air, and the entering temperature. If we assume an average of 90 cu. ft. per kw. of loss the temperature rise will be 36 deg. F., and the exit temperature will be 140 deg. F., provided the entering temperature is 104 deg. F. The above volumes and temperatures are given to show the customary limits and to give some idea of the temperature of the water which may be required for cooling the air.

Impurities in Air

Foreign matter which commonly exists in the air at a power plant, aside from leaves, papers, etc. which can readily be kept out by screens, consists of the following: Oil, dirt, coal, coke, soot, lint, acid, salt and moisture. Oil, coal, coke, and soot are inflammable and not readily removed by washing the air. Oil or moisture together with lint make an excellent binder for holding the inflammable materials. Acids may easily destroy the insulation and salt may form a deposit without the assistance of other impurities. Moisture is detrimental to a machine if allowed to condense on the windings.

It is not safe to judge the cleanliness of the air entering a generator by simply observing the conditions at the air intake. The proper method is to study the deposits in the machine and then determine the possible source of such deposits with a view to eliminating them. The most improbable conditions sometime exist; for example, in one station acid fumes from a storage battery were carried out of the battery room, along the building, and back into the generator room where they eventually destroyed the machine windings. Machines requiring large volumes of air will reduce the barometric pressure at the intake, and the supply will be replenished from many directions, drawing with it impurities from various sources.

Effect of Deposits

Any deposit in a machine will reduce the effective area of the small ventilating ducts and may entirely close some of the apertures with the result that the friction loss is increased and the flow of air reduced, which in turn must increase the machine temperature. And, again, any coating is relatively a poor conductor of heat, which reduces the rate of heat transmission per degree temperature difference between the air and the machine, which in turn means that the machine must operate at a higher temperature.

An increase in the machine temperature will result in a reduction of capacity and efficiency which must be minimized by more frequent cleaning. This may necessitate taking a machine out of service at a most inopportune time and will add to the operating cost of the plant.

Combustible deposits in the machine are sometimes ignited by static sparks. This may result in simply burning off the deposit or it may injure the insulation or be the cause of a serious fire. On the other hand, a fire started by a short circuit may be distributed and spread by the burning of the combustible deposit.

It is generally conceded that any deposit, and especially a combustible deposit, is probably the cause of many turbine generator fires, although it is often difficult to determine after a fire has occurred just what was the cause and the contributory effect of the deposit. There have been several cases of surface fires where the machine was shut down immediately upon detection of fire and any damage to the winding averted. It is reasonable to infer that cases such as these might have proved more disastrous if the fire had not been discovered in time.

Two Methods of Cooling Generators

The heat generated by the generator must be carried off either by air or by water. The first method and the one now generally employed is to carry the heat off by means of filtered (or washed) air. This is termed "Direct Cooling."

The second method now coming into vogue is to carry the heat off by means of water and simply using the air as a transfer medium between the generator and the water. This is termed "Indirect Cooling."

Inasmuch as the air washer may be used without modifications as an air cooler some confusion will exist in the term "washer." Therefore, in this article the devices will be classified according to utilization. When used to clean the air regardless of the process it will be termed a "filter." When used to remove the heat from the air it will be called a "cooler."

Filters

There are three general classes of filters. The one most extensively used in this country is the air washer, which consists of water sprays for washing the impurities from the air and depositing them in the sediment basin at the bottom. To prevent the air from carrying water through in suspension and to assist in the washing of the air, eliminator plates are provided at the exit end of the filter.

The cloth filter extensively used in Europe consists of frames covered with cheese cloth and arranged so as to present a large surface area in a compact space and designed to facilitate the removal of the cloth for washing and replacement.

The third type of filter used to some extent in Europe and now being introduced into this country consists of many small frames filled with short sections of copper plated steel tubes, which are coated with an especially prepared oily substance to which the dirt adheres. The sections are cleaned by dipping them into a soda solution and then recoating them by dipping in a bath of the adhesive fluid.

Coolers

There are three classes of coolers available. The first may best be termed the "spray cooler" and is simply an air washer used as a cooler.

The second can best be termed the "film cooler" and consists of a series of eliminator plates continually flooded with water, against which the air impinges. Both these types of coolers provide direct contact between the air and the water and are analogous to jet condensers.

The third class, now being introduced, is the "surface cooler" and resembles to some extent the surface condenser and the automobile radiator. The mechanical construction is somewhat like the surface condenser but the tubes are provided with metal fins so as to present a large surface for contact with the air similar to many automobile radiators.

Perfection in Cleaning the Air

All the filters depend on the principle of forcing the air to come in contact with a surface or with water, with the result that the small particles of foreign matter are deposited; but there is always some air which passes through without making a direct contact. As a consequence no filter, although extremely effective, is 100 per cent perfect.

When considering the enormous amount of air circulated through a machine a very small percentage of dirt may rapidly assume large proportions.

A 20,000 kw. turbine will circulate approximately 1,000,000 tons of air if operated continuously for a year. If the air contained one tenth of one per cent dirt, the total accumulation of dirt in the filter would be 1000 tons. If the filter were 99 per cent efficient there would be 10 tons passing into the generator. All of this will not adhere to the surface; but if it is assumed that 1 per cent will remain in the machine, a year's accumulation will be 200 lb. These figures are used simply by way of example—they may be more or less, depending on conditions.

Fig. 1. A Dry Air Filter

The indirect system is not free from criticism in this respect unless the closed circuit for the air is perfectly tight or unless the infiltrated air is filtered. For example, if it is assumed that 1 per cent of the air circulated is lost and replaced through various small openings at low pressure points in the system then there is still 10 tons of dirt passing into the machine. But the direct system has the same possibilities of admitting unfiltered air in addition to dirt passing the filter.

The secret of success with the direct system is to use as perfect a filter as can be obtained and to make the system tight; while with the indirect system success depends on making the air circuit as tight as possible. The most essential consideration is to eliminate oil vapors and the like which greatly assist in the retention of the dirt which finally reaches the machine.

Temperature Limitations

The temperature of the air is not affected in passing through a dry filter; therefore, if the air is 40 deg. C. or 104 deg. F., or less and the drop in pressure through the filter not excessive, the generator should be capable of carrying full rated load. On the other hand, such a filter will not assist in improving conditions by lowering the temperature below the atmospheric temperature.

The wet filter (air washer) although using recirculated water can lower the air temperature to practically the wet bulb temperature by evaporation and in some localities this may be an important consideration. The cooling of a generator must not be confused with the cooling of a human body which takes advantage of evaporation and is governed largely by the wet bulb temperature; whereas, the generator gives off no secretion which would cause evaporation and therefore is subject to the actual temperature of the air

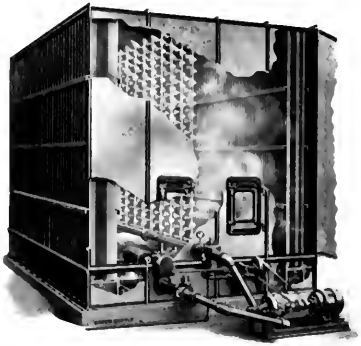


Fig 2. A Wet Air Filter or Air Washer May be Employed as a Spray Cooler. (The illustration is that of a washer manufactured by the Carrier Engineering Corporation)

entering the generator as would be measured by a dry bulb thermometer.

The spray cooler or the film cooler does not cool by evaporation but simply by conduction, because the air being re-circulated becomes saturated. The exit air temperature can be reduced to within 10 deg. F. of the entering water temperature.

The surface cooler can be designed to cool the air to within 5, 10 or 15 deg. F. of the available water temperature depending on the amount of surface employed. The cost of the cooler, however, increases greatly if a terminal temperature difference of below 15 deg. F. is required. If the turbine condensate is used as a cooling medium to reclaim the generator losses the vacuum maintained and the light load operation must be taken into account. The temperature of the condensate is seldom less than 5 deg. F. below the temperature corresponding to the vacuum. On the other hand, during light load periods the amount of condensate flowing, unless recirculated, will reduce the effectiveness of the cooler. However, suitable arrangements can be generally made to reclaim all or part of the generator losses by the employment of surface coolers.

Water Supply

The supply of water and its character has an important bearing on the choice of a filter or a cooler.

A wet filter should use fresh water. If this is recirculated, as is usually the case, the quantity consumed depends on the relative humidity, and is relatively small so that either local or city water may be utilized.

A spray or film cooler should not use salt water or condensate. The objection to the former is the possibility of salt deposit and the objection to the latter is the aeration of the condensate. The quantity of water required makes it imperative to use the local water supply if it is suitable, as city water is generally too expensive.

A surface cooler may use salt water, local water, city water or condensate, providing such water is not injurious to brass tubes similar to those used in surface condensers.

With either spray, film, or surface coolers the water supply must be absolutely reliable or provision must be made to supply the cooler from another source on short notice. This fact may at first be considered a handicap for any kind of cooler; but there are many methods of insuring against interruption of service in event of failure of water supply. There are other places in a power plant that require an uninterrupted supply of water such as boiler feed supply and turbine bearings and these are readily taken care of.

Fire Hazard

Fire hazards may be internal or external. The wet filter or any kind of cooler eliminates the external fire hazard. The cloth filter not only does not eliminate external fire hazard, but is a fire hazard in itself.

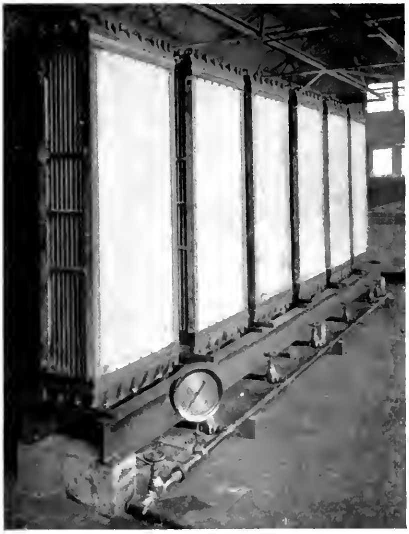


Fig. 3. Group of Surface Coolers on a Hydraulic Test Stand

Internal fire hazards are present whether the generator is clean or dirty so that the real problem is to reduce to a minimum the seriousness of a fire. The difficulty of immediately extinguishing a fire once it has started in a turbine generator is better appreciated by those who have attempted it, and the resulting damage from a fire allowed to continue for any length of time may be considerable, not only to the winding, but to the laminations and the castings.

The direct system of cooling must have the supply of air shut off immediately even though water, steam or a dead gas is employed as an extinguisher and the dampers used for this purpose are seldom sufficiently tight to completely shut off the flow of air. Also such emergency dampers are so seldom used that they may not function when required. Or, the supposed fire may be a false alarm and the machine taken out of service unnecessarily.

The indirect system prevents a serious conflagration, whether attended to or not because the limited supply of air available will permit the consumption of only a few pounds of carbon or hydro-carbon contained in the insulation, and this system readily permits the replacement of the air by a dead gas on the slightest suspicion of fire, possibly without interruption in service and with no detrimental after effects.

Moisture

Moisture introduced into the air by wet filters or spray and film coolers in the form of suspended vapor is not injurious to the generator because the machine is warmer than the air when in operation and no condensation will occur. But saturated air should not be allowed to circulate through a machine having a lower temperature than the wet bulb temperature of the incoming air.

With the direct system of cooling, fogs are sometimes formed in the turbine room in cold weather. The cooling system should be such that any fog drawn in should first pass through the washer, which means that the station inlet for air should be on the far side of the washer and not between the generator and the washer.

Provision can be readily made to prevent any water from entering a generator in the event of tube leakage in a surface cooler.

Noise

The direct system of cooling, if taking air from the outside and delivering it outside the building, is reasonably quiet, but when receiving air from, or discharging air into the turbine room, the noise is usually objectionable. The indirect system is inherently quiet inasmuch as there is no exit for the sound waves except through the generator casing.

Turbine Room Ventilation

Attempts to regulate the turbine room temperature in winter and to control ventilation in large power plants by means of the generators have not been very satisfactory. There have been many cases of excessive roof or ceiling condensation during cold periods which may be partly attributed to the discharge of air from the generators and there have been cases of frost deposits on insulators due to cold air entering around windows and doors when the generators are pulling air from the turbine room, thereby causing a slight vacuum to exist.

Neglecting for the moment the possible economies of utilizing the heated air from the generators, it is obvious that the heating and ventilation of turbine rooms can best be provided for and the regulation taken care of without complications in the same manner as in any other building, if the indirect system of cooling is adopted.

Investment

The proper way to compare the costs of the various kinds of filters and coolers is to include with the cost of the cooler or filter all necessary ducts, dampers, and piping, also to charge each with the cost of floor space occupied by it.

While the cost of the equipment for the direct system is relatively small the cost of proper air ducts leading out of doors and substantial dampers is usually a larger factor than the cost of the filter and in many cases these ducts occupy some of the most valuable space in the building. With the indirect system the coolers can be built in the generator foundation without dampers and the basement floor underneath made available for other apparatus.

Economy

The two possible economies, neglecting ordinary operation and maintenance, are:

First: The reclamation of heat from the generator losses, and,

Second: The reduction in the cost of water or the cost of pumping it.

With the direct system it is possible to discharge the air into the boiler room and burn it. This is an old idea, but has been employed in only a few cases because of the complication of ducts and because there is available only about half the air required by the boilers. With the indirect system using surface coolers it is possible to absorb all or part of this heat by circulating the condensate through the surface coolers, depending on the temperature of the condensate and the load on the generator. The return on the investment for surface coolers will vary widely for different conditions.

The pumping head is less and the quantity of water circulated may be less for the surface coolers than for any other system except the dry filter; while the character of water which may be used in surface coolers, and be unsuitable for the wet filters or spray and film coolers, may in many cases obviate the necessity of purchasing city water.

The Electric Power Industry

PART II

THE RELATION OF THE ELECTRIC POWER INDUSTRY TO THE INDUSTRIAL CORPORATION

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

Last month we published the first article of this series by Dr. Steinmetz. The present contribution was read at the convention of the Association of Iron and Steel Electrical Engineers held at Cleveland, Ohio, in September, 1922, under the title of "Improvement in Efficiency of Electric Power Supply." Three subsequent articles by Dr. Steinmetz will appear in the Review to complete this series. Their titles will be as set forth in our editorial note last month.—Editor.

I

The following discussion of the economic relations between the electric power industry and the industrial corporation using electric power and producing by-product energy can be very general and suggestive only, as the relations depend on local conditions, and involve many features outside of engineering proper. I have been greatly interested in the subject for many years, and given it considerable study since my paper read before the Franklin Institute in 1913, on the same subject, and I thought the following suggestions might therefore be of interest.

Energy or the rate of energy flow, that is, power, is a necessity of every industrial operation, in other words, is or may be called an essential raw material of the industry. Therefore some source of power, as a steam engine, has been an adjunct to every industrial plant.

Power production is an industrial operation, just like the making of steel rails, or of furniture, or the running of a railroad or a hotel.

The high efficiency of modern industrialism is essentially due to the subdivision of industrial operation so that every industrial operation is carried on in a separate plant by a separate organization such as to secure the maximum possible economy for each particular operation, whether the making of steel rails or the running of a hotel.* However, the plant and organization most efficient for one industrial operation, such as the making of structural steel or the running of a railroad, cannot be most efficient for another and entirely different operation, such as the production of the power which is needed as raw material in the principal industrial operation. Thus best economy requires the separation of power production from the industry served by it. This was not possible, as long as there were no means of transporting or transmitting and distributing the power. It became possible by the development of electrical engineering, and thereby a new industry has been developed, the industry of electric power production, transmission and distribution, co-ordinate with the older industries, such as that of making steel rails, or running a railroad.

This made it possible to segregate the power production from the industry using the power as raw material, and thereby to secure maximum economy in both.

Increasingly since then, industrial electric power supply from a general electrical power system has taken the place of the local industrial steam or electric power generating plant, and that not merely where a small or moderate amount of power is involved, but even with such large powers as the operation of a metropolitan rapid transit system or trunk line railway electrification.

With this, the efficiency of the electric power industry has become of importance to all industries, and to the public at large.

An important factor in industrial economy is the cheapness of the raw material. The principal raw material of the electric power industry is energy; hydraulic energy of the water powers, and fuel energy of coal, gas, oil, etc.

Thus the development of the country's water power is of interest not only to the corporations exploiting the water power, but to all industries and the public at large.

The raw material of an industry is cheapest when it can be secured as by-product of another industry, though generally it is not safe for an industry to depend entirely on a by-product as source of raw material, due to its limitations.

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* This does not necessarily mean a separate corporation, but often and increasingly so, a number of industrial operations are controlled by the same corporation, but then best economy usually leads to separate technical and administrative organizations for each industrial operation.

Energy, the raw material of the electric power industry, is by-product of many other industries, for instance, the steel industries in the blast furnace gases, etc.*

Thus we get the general conclusions:

Power production has become a separate industry.

It is more economical for an industry to secure energy from the electric power industry than to produce its own power.

Economy requires that by-product power of an industry is not wasted even partly, but is used to its fullest extent as raw material for power.

II

Comparing the possible economy of power production in a general electrical power system with that of a local isolated power station:

The different classes of general station service: Domestic light and power, street lighting, industrial power, railway power and special applications, such as electro-chemical and furnace work, etc., have a diversity factor. That is, the peak loads of the different services occur at different times, so that the station peak load is less than the sum of the individual peak loads. This gives a higher station load factor, that is, a higher ratio of average load to station capacity, and thereby a more economical operation.

The large scale of power production—often several hundred thousand kilowatts—leads to the use of large and more economical units in generating, transmitting and converting apparatus. That is, the huge steam turbine is more efficient and cheaper per kw. than smaller units; the cost of transmission or distribution over the same distance decreases per kw., with the increasing amount of power delivered; the cost per kw. of converting apparatus, as transformers and synchronous converters, decreases and the efficiency increases, with increasing size, etc.

In getting raw materials such as fuel, oil and condensing water; in handling it and the waste products as ashes, in short in all operations of the plant, a large electric system, whose main and single aim is power production, may secure economies not available to the isolated electric station adjunct to another industry.

The big system may develop a highly efficient trained operating force, and secure technical specialists and administrative assistance for all parts of the operation, where the isolated station is limited by its smaller size and subordination to the main purpose of the industry served by it.

In some cases the lower rate at which a large and established electric power system can secure money may result in a lowering of that part of the cost due to the interest on the investment. However, this does not come into consideration when the industry served by the central station also is a big industry, but then may even reverse.

An isolated electric power station, operated by and as an adjunct to another industry, as a rule also has a diversity factor by supplying lighting, power, etc., and thereby has a better load factor than given by its separate classes of service. However, the nature and distribution of the load on the local station is fixed by the requirements of the industry served by it, while in the general power system the distribution of load between the different classes of service may be varied to a considerable extent by devoting special attention to the development of the one or other class, and the diversity factor and load factor improved thereby. One of the earliest illustrations hereof was the development of a summer lighting load in pleasure resorts as Coney Island, etc.

The operation of the isolated plant necessarily is secondary in importance to that of the industry served by it, and is handicapped in its technical staff, as the foremost attention of the prominent electrical engineers attached to the industry must be given to the *application* of the electric power to the industrial operations rather than to the generation of electric power, and, specializing in the former, they cannot be as competent in the latter, as the central station engineers whose specialty is power production.

On the other hand, in any industry which produces a considerable amount of energy as by-product, as the steel industry in the blast furnace gases, etc., it would be uneconomical to pay for power from a central station and waste the power available from the by-product energy, even if under special conditions this may temporarily appear cheaper; unless some other use could be found in the industry for the by-product energy. However, then it would not be by-product energy any more.

An advantage of the isolated station obviously is that it saves the profit made by the central station on the sale of the power; this may be more or less counterbalanced by the

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* In some respects, mechanical energy may be said to be by-product of every heating plant, as from 5 to 15 per cent of the fuel energy can be collected as mechanical energy between boiler and radiator, though this usually is not done.

administrative and technical complication of operating an electric power station in addition to the main industry.

III

The characteristic of electric energy is that it cannot be economically stored (in the quantities and under the conditions considered here). Therefore it must be used at the rate at which it is produced. Thus, if the load is not constant, the station cannot be fully loaded all the time; and the more the load varies, the less is the station output compared with the output which the station could give at uniform load, and the higher therefore the cost of power.

This makes the cost of electric power dependent on the load curve, that is, the variation of the load throughout the day and throughout the year, and on the load factór, that is, the ratio of the total (daily or annual) load on the station to its capacity.

With a daily load curve as given by Fig. 1 (winter lighting load) of load factor 0.33, the station gives only 33 per cent of the output, which it could give if continuously carrying its maximum load. With an annual load distribution as given by Fig. 2, the load exceeds 150,000 kw. for eight hours only. The additional apparatus required to take care of these additional 30,000 kw. of annual peak load makes the power during the eight hours of the peak cost more than a dollar per kw-hr., while the average cost throughout the year may be a fraction of a cent per kw-hr. With the station load curve, Fig. 2, an additional amount of kw-hr. larger than the total kw-hr. now sold by the station could be supplied without any additional investment, if limited to the off peak period, and the only additional costs due to this amount of off peak energy would be that of fuel, and some attendance, etc., and as the fixed costs usually are the major—and with water power almost the entire—cost of the power, the cost of off peak power therefore should be lower still than that of continuous power, while that of peak power is much higher. Off peak power is somewhat of the nature of a by-product in many respects; its cost is low, but if developed beyond the limit, it ceases to be off peak power and becomes peak power.

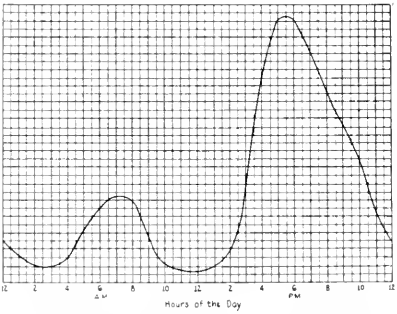

Fig. 1. General Shape of Winter Lighting Load Curve

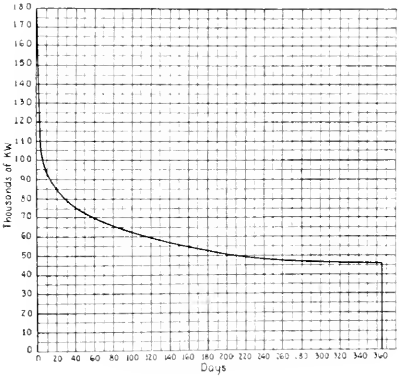

Fig. 2. Annual Load Curve

The size of the generating, transmitting, converting and distributing plant, and practically every other element entering into the cost of electric power, except fuel and size of prime mover, are determined by the kv-a. delivered by the station, while the power is measured by the kw., and the cost of power per kw. thus essentially depends on the ratio of kw. to kv-a., that is, the power-factor of the load.

Thus the lower the power-factor, the higher the cost and the higher therefore should be the price of the power. For instance, if the cost of power, exclusive of fuel and the fixed charges due to the mechanical part of the generating plant, constituted the fraction q of the total cost of power, at power-factor p, Q kw. would represent $\frac{Q}{p}$ kv-a. apparent power, thus $\left(\frac{Q}{p} - Q\right)$ kw. additional generator and line capacity, costing as much as $q\left(\frac{Q}{p} - Q\right)$ additional kw. of power would be required, and the cost of power at power-factor p thus would be $Q+q\left(\frac{Q}{p}-Q\right)=\left(1-q+\frac{q}{p}\right)Q$, that is, would be increased by the factor $1+\frac{q}{p}(1-p)$.

Thus, considering as standard the cost of power at unity power-factor and continuous load, the cost increases with decreasing power-factor, and it increases with increasing fluctuation of load, that is, with increasing ratio of maximum to average load, or, as explained, with maximum demand factor, as seen above. This really is not strictly true, but it depends whether the maximum demand overlaps with the station peak or not.

IV

There are three ways of supplying power to an industry.

The isolated local plant without connection with any electric power system. The advantages and disadvantages of this arrangement have been discussed in the preceding. Where considerable energy is available as by-product of the industry, the cost of power from a local isolated plant may figure lower than power can possibly be bought from the central station. This, however, may have little meaning, as it depends on the value assumed for the by-product energy used as fuel by the local plant. If the by-product energy is not sufficient for the total power demands of the industry, additional fuel has to be used; where there is more by-product energy than required to produce the power, the surplus may be wasted, or an attempt made to find some other use for it. Or it may also be converted into electric power and some of the electric power sold. Or some industrial uses for the surplus electric power may be developed, such as electric smelting or refining. The latter probably is the most economical arrangement.

Or the electric power required by the industry may all be bought from an electric power system, and no local plant operated. This is most convenient, but depends on the rates which can be secured from the electric power company. In general, the power would be bought in bulk under a rate based on maximum demand and on power-factor. It would therefore be economically desirable to arrange the industrial operation so as to have as nearly a uniform power consumption as possible, without large peaks of power consumption, so as to have the maximum demand exceed the average demand as little as possible and thereby get the best rates. For power, synchronous motors would be used as far as possible, and operated over-excited so as to compensate for the lagging currents of induction motors. Power-factor corrective devices, such as synchronous condensers, may be installed in the substation. The substation with its transforming, regulating, power-factor controlling devices, etc., may be owned and operated by the power company, or by the industrial corporation, or it may be owned by the one and operated by the other. The power may be metered on the primary side of the substation, or on the secondary side. The general economic principle, I believe, should be that everything pertaining to power generation, transmission, transformation, control, etc., should be operated and preferably also owned by the power supply company, as being a legitimate part of the electric power industry; while everything pertaining to the application of the power to the specific industry served by the substation should be operated by the industrial corporation. The specific arrangement which can be made will, however, to some extent depend on the financial strength, on the progressiveness of the management and the farsightedness of the engineering staff of the two companies.

If there is considerable by-product energy, some arrangement should be made to fully utilize this available energy. If the by-product energy is wasted entirely by not being used, or wasted intrinsically by being put to an inferior use, for heating only, instead of first taking out the available mechanical power, then the arrangement is uneconomical, even if financially the central station power supply should figure out an advantage.

Where considerable by-product energy is available, and where central station power supply is possible from an electric power system, central station service may be combined with the operation of a local station.

A part of the plant may be operated from the local station, another part by the central station power, leaving both electrically separated, but with arrangements whereby feeders may be connected over from the one service to the other. Or part of the time the plant may be operated from the local station alone, and central station power used only when the load exceeds the capacity of the local station. Or the connection to the central station may be entirely or essentially that of standby or emergency service, and normally the local plant supply all the power.

Or the local station and the central station both may feed into the same set of local busbars, from which the power supply of the plant is taken. Various possibilities then exist in the arrangement of the load distribution between local and central stations.

Power may be bought from the central station at unity power-factor constant load, that is, unity load factor, and the fluctuation of load and the wattless current supplied by the local station. This would give the lowest cost (except off peak power) of the central station power, and therefore should give the best rates for power, those of continuous non-inductive load. It necessarily makes the local station operate less efficiently, and where operated by by-product power requires sufficient storage facilities for such by-product power to supply it at the rate demanded by the load fluctuations. Also, the generator armatures and the generator fields may not be able to carry the excess current required in both to supply all the lagging currents of the system. This would have to be looked into.

Or, instead of carrying all the load fluctuations and all the wattless currents by the local station, investigation may show it more economical to throw some load fluctuation and some wattless currents on the central station supply, when the gain in efficiency of operation of the local station, given thereby, is greater than the increase of cost of central station power. For instance, the central station rate may be the same for power-factors from 90 per cent to unity, and then it would be of disadvantage to carry more wattless currents by the local station than necessary to keep the power-factor of the central station supply above 90 per cent.

Where a daily or annual peak are a factor in the cost of central station power generation, and off peak power therefore of lower cost than continuous power, lower rates may be secured if the plant operation can be organized so as to disconnect the central station supply for a few hours during the day, and to operate on local power only. Or a two-rate metering may be arranged, that is, a lower meter rate during the off peak period. This would allow the use of central station power during peak load, if so required by the industry, but put a premium on avoiding it and securing the lower rate of the off peak power.

Another way of operation would be to carry constant load on the local station, and take the fluctuations by the central station service. In this case a less favorable price of central station power would result, but the local station would work at best economy. With by-product energy, the local station may then be operated at such output as to consume the by-product energy at the rate at which it is produced, and eliminate the need of storage.

The most economical arrangement between local station and central station power supply to a large extent depends on local conditions of power demand and supply, on the possibility of modifying the power demand to get more favorable conditions, and is deeply involved in the matter of rate making. While the economic principle of rate making is to arrange the price in proportion to the cost of power, as depending on quantity and quality (such as load factor and power-factor, peak and off peak) the actual rates may not quite represent this, and the lowest rate may not always be the most economical.

V

With considerable amounts of by-product energy, and a local station built to utilize all the by-product energy, the power output of the local station may sometimes or frequently exceed the power demand of the industry, so that power could be fed back into the central station system. That is, sometimes the central station would supply power to the local plant, at other times the local station would return power to the central station, and with such a power exchange, in which the central station supplies the deficiency and takes the surplus of local power, an arrangement of charge for the power received and credit for the power returned would have to be made.

Consider first continuous power at unity power-factor. In the central station—or more correctly perhaps at the center of the distribution of the electric power system—such power generated has the same value as returned from the local station. At the local station, however, such power costs more than at the central station, by the cost of bringing it from the central station to the local station. That is, by the part of the cost of power, due to interest on investment, depreciation, maintenance and repair, of transmission, transformation, distribution, control and regulation, loss of power, etc. Inversely, the value to the central station, of continuous unity power-factor power returned from the local station, is less in the local station by the cost of bringing this power to the central station. The difference in the value of the power supplied by and returned to the central station thus is at the local station twice the cost of transmission. Similar is the relation for power of any other quality, for instance, power received respectively returned during the peak load of the central station, or off peak power. Fluctuating power supplied by the central station costs more than continuous power, and the more so, the greater the fluctuation, that is, the lower the load factor or the more the maximum demand exceeds the average demand. This is due to the increased fixed cost of the power, that is, the part of the cost due to the capacity in generators, lines, transformers, etc., tied up by it, which to a considerable extent depends on the maximum power demand rather than the actual or average power supply, and therefore becomes the greater, per unit of power delivered, the more the maximum exceeds the average. Inversely, the greater the fluctuation of the power returned to the central station, the less is its value to the central station, so that the difference in value, between power received from and power returned to the central station, increases with increasing fluctuation. This difference is due to the fluctuation of power being determined by the local station and not by the central station, and the local station thus may consume power from the central station during the peak load, where the power cost is greatest, and return power during the off peak, where the central station has a surplus of power, and the returned power is of little value to it. The reverse would be the case if the fluctuation were determined by the central station, that is, if the central station could supply power to the local station during the off peak period of the central station when the power is cheap, and receive power back during the peak load of the central station, when the power is valuable to it. However, the latter would be difficult to arrange unless the local station and the central station are under the same management.

Power of less than unity power-factor, supplied by the central station, costs more to it, as the central station has to supply not only the true power, but also the so-called "reactive power," and the latter does not register as power, but costs practically as much as true power in all items except fuel and mechanical generating plant. Inversely, the power returned at less than unity power-factor would be of less value, as the central station, while receiving power, would have to supply reactive power, and the value of the returned power thus would be the difference between the value of the true power and the cost to the central station of the reactive power. However, this applies only if the reactive power is of lagging currents as consumed by induction motors. A power-factor of less than unity, of the returned power, due to leading currents (referred to the central station) such as due to the operation of the over-excited synchronous machines in the local station, might make this power more valuable to the central station than at unity power-factor, by compensating for lagging currents in other parts of the system, and thereby worth a higher price than unity power-factor power. That is, a credit may be given to the local station for leading currents, just as a charge is made for lagging currents.

As stated, a charge for lagging currents is usually made by basing the power charge on the power-factor. While this may be rather the simplest arrangement, it is not entirely fair and is open to a number of objections, and a better way of dealing with the matter of lagging and leading currents probably would be to separate their rates from those of power. That is, to have one rate for power supplied to or received from the local station, based on cost of power to the central station, as depending on maximum demand or load factor, but without considering the power-factor, and a second rate for reactive power, that is lagging currents, based on the cost to the central station of producing the lagging currents, and giving a credit for leading currents. Such charge for reactive power would be entirely independent of that for true power, but might consider in the rate the maximum demand factor of reactive power.

VI

Theoretically, the most economical arrangement between a local station using the by-product energy of an industrial plant, and a central station of the electric power industry, would be an interchange of power whereby any power deficiency of the local station is supplied by the central station, and any surplus power of the local station supplied to and credited by the central station. With independent ownership and operation of the two stations, the fluctuations of power interchange necessarily are determined by the power requirements of the industry, without regard to the economy of the central station, so that the value to the central station of the returned power is very low, and the credit received for the power returned to the local station therefore may be small compared with the price of the power bought from the central station. Better economy would result by operating both stations—within the limits permissible by the requirements of the industry—so that the power returned to the central station occurs during times when power is of considerable value to the central station, and the power supplied to the local station at such times when power is of lesser value to the central station. This would require a co-ordination of the operation of both stations which would practically mean the operation of the local station by the central station system. This may generally be difficult to arrange, unless the same financial interests control both corporations, the industrial plant and the electric power supply system. Assuming, however, that it can be arranged, the local station then would be one of the stations of the electric power system, located at a source of cheap energy (the by-product energy) and at a distribution center (the industrial plant). The industrial company would have nothing to do with the operation of the local station, but would buy its power from the power company, and the power company would buy the by-product energy from the industrial company; even the storage of the by-product energy in accordance with the needs of the local plant would be within the scope of the power company. The application of the power to the specific requirements of the industry, such as the design of motor application for the particular duty cycle of the reversing rolling mill, etc., would belong to the electrical staff of the industrial corporation, which so could devote all its energy and skill to the most economical application of electric power to the specific industrial processes. Everything, however, which pertains in general to electric power generation, control, etc., and is not specific to the particular industry served, would come under the staff of the power company, such as questions of power-factor compensation, etc.

Principles of operation of the local station then would be worked out in accordance with maximum economy of the power system.

The fundamental principles of operation of an electric power system is to get as much output as possible out of the most economical stations and call upon the less economical stations only after the more economical ones are fully loaded.

That is, in a system comprising several steam stations, during times of light load only the most economical stations would be kept running, and with increasing load less economical stations started, so that the least efficient stations (usually the small, old stations) or machines in the stations (for what applies to the different stations, equally applies to the different machines in the same station) may be operated only a few times during the year or in emergencies due to accidents to some of the more efficient machinery.

Where hydraulic stations and steam stations operate in the same system, the hydraulic stations would be operated at continuous full load, and the variations of the load taken by the steam stations, since the efficiency of power production of the hydraulic station decreases with decreasing load much faster than that of a steam station, as in the hydraulic station practically the total cost is fixed cost, in the steam station a part of it proportionate cost. Obviously, if there is water storage, and a season when the total water supply is less than needed to operate the hydraulic station continuously at full load, it would be most economical to shut it down during periods of light load on the system and carry full load during the peak load of the system.

A local station utilizing by-product energy would have to some extent the same characteristic as a hydraulic station: low proportionate cost of power, due to cheap energy. Compared with the huge main stations of the electric power system it probably will be less economical, and thereby also have somewhat the characteristics of secondary stations. The former would favor continuous full load operation, the latter shut down during light load on the system, and the most economical method of operation therefore would have to be worked out on the basis of the cost of power production under different circumstances.

However, these economic considerations usually have to be more or less modified by conditions of control or transmission, etc. For instance, it may be economical to keep a station in operation, though this station is not quite as economical as others, if this station is near a heavy demand for power, and its operation therefore materially reduces the transmission losses and costs. Or a secondary station at the end of a long feeder may be kept in operation for voltage control, even when at light load the main station could supply the power over the feeder (though in this case, the alternators in the secondary station may run as synchronous condensers, and the steam plant shut down).

VII

The difficult problem in the relation between the electric power company and the industrial corporation as user of electric power and producer of by-product energy is the financial one of the rate for power and energy. This, however, is beyond the scope of the present article. It appears obvious that such rates must be fair; that is, a rate based on "All What the Traffic Will Bear," or, as more politely expressed, "Based on the value of the service to the user," could not lead to permanently satisfactory relations, but the rates should be based on cost plus a fair profit. While theoretically simple, such is often very difficult to work out, due to the uncertainty of the cost. For instance, in determining the cost of off peak power, the question arises, whether any cost of investment should be charged against off peak power or not, and if so, how large a part. As the plant investment is used in the production of off peak power, it appears unfair not to make any charge for its use. Inversely, however, if an investment charge is made against off peak power, we may figure out a "cost" of off peak power such that a large block of off peak power, sold below cost, would give a profit to the company, which again does not appear reasonable. Another such question is that of the cost of by-product energy. Intrinsically, it has no cost. But to make no charge for it would not be right, since it has a value. To charge it at the reproduction value, or its fuel value, would not be fair, and would make its use economically unattractive. It might be charged at the value which could be recovered from it by other uses, but this again is rather indefinite. Thus many features require further discussion and settlement, and probably the best way would be to work out the engineering economy of the relation without any regard to the rate question, and have a committee consisting of representatives of both corporations, including members of the engineering staff, make a continued study of the cost relations with a view of finally arriving at a fair agreement. I believe that a great step in advance of the industrial development of our country would be taken if these economic relations could be worked out in a specific instance, between a progressive industrial corporation using considerable power and producing considerable by-product energy, and an equally progressive electric power corporation.

Million-volt Testing Set

PART I

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How much is a million volts? As given in the following article, the answer is the electrostatic pressure required to spark over a 9-ft. air gap. However, to the huge majority of us the rating of very high voltage in spark-foot units does not afford a real conception of the pressure. It will be of interest therefore to consider one million volts in more familiar units. At 1,000,000 volts a current of less than one ampere would suffice to operate nine thousand 110-volt 100-watt incandescent lamps in series or one lamp every 100 feet for 170 miles; that is, from Schenectady to New York City. A testing set which will give 1,000,000 volts, 60 cycles, three-phase, and up to 1,500,000 volts, single-phase, has been recently completed for the High Voltage Laboratory at the Pittsfield Works of the General Electric Company. The following article, reprinted from the Journal of the A. I. E. E., Oct., 1922, explains the general layout of the set, describes the construction of the component units, and discusses the formation of some of the single-phase arc discharges obtained. In Part II of this article, illustrations of three-phase arc discharges will be included, and discussion given of the set with respect to tests on line insulators and the effects of grounded neutral, resistance and reactance in the circuits, and wave form.—Editor.

Introduction

The highest voltage now used in power transmission is 220,000 volts between lines three-phase, or 127,000 volts to neutral which is grounded without resistance.

This transmission potential seems a long way below a million volts and the usefulness of the latter is not at once apparent. However, the circuit breakers of a 220,000-volt system are required to be tested at 500,000 volts, and the bushings are designed for a dry arcover of not less than three times the line voltage, or 660,000 volts. Tests on line insulators and lightning arresters may be at equally high potentials.

The requirements for ordinary commercial tests thus approach 700,000 volts to ground with the tendency constantly upward and, furthermore, in the potential employed, experimental and research work are also always far beyond commercial practice.

In X-ray work, especially for therapeutical purposes as in the treatment of cancer, the penetration of the rays is inversely as the wave length or proportional to the maximum frequency, which in turn varies directly as the voltage.

X-ray tubes are seldom operated at potentials (d-c.) of over 100,000 volts which corresponds to an X-ray frequency of 24,000,000,000,000,000,000 or 24×10^{18}. This frequency looks formidable but it is far below the frequency of the gamma rays of radium which are therefore preferred for cancer treatment in spite of the great cost of radium. A potential of something like 2,000,000 volts would be required for an X-ray frequency equal to that of the gamma rays (about 48×10^{19}).

There is evidence to show that atoms may be disintegrated by high-voltage discharges of great intensity, which therefore makes the high voltage useful in physical research. Thus the engineer, the physician, and the physicist are alike in aiming at infinity in their demands for ever higher potentials.

The million-volt testing set here described is a step forward in this direction. It was designed and built for the high-voltage engineering laboratory of the Pittsfield Works of the General Electric Company.

General Description

The set was primarily designed for several connections, for example: (a) a million volts, three-phase, with neutral grounded; and (b) a million volts, single-phase, with either one end or the neutral grounded. The transformer may be connected and used in other ways.

It is the potential above ground that is of chief importance so far as size, cost, and difficulty of design and construction are concerned. The total difference of potential in any source of high voltage above ground may ordinarily be doubled simply by duplication of the apparatus. Thus, 2,000,000 volts with neutral grounded might be obtained without difficulty by adding one unit with its exciting transformer to the present set. The same considerations hold good generally—it is the voltage above ground, that is, to the neutral point, that involves the difficulties.

The complete equipment comprises three main transformer units of 578,000 volts each, and an insulating exciting transformer and a million-volt terminal for use when two units are connected in series for a million volts to ground. The general arrangement in this case is shown in Fig. 1, and the scheme of connections in Fig. 2.

To obtain a million volts to ground the insulating transformer, line transformer, and million-volt terminal are placed on insulating stands in a large open oil tank which was already available. The line transformer is stripped of cover, tank, terminal, and other unnecessary parts and the transformer proper is placed in the large tank under oil.

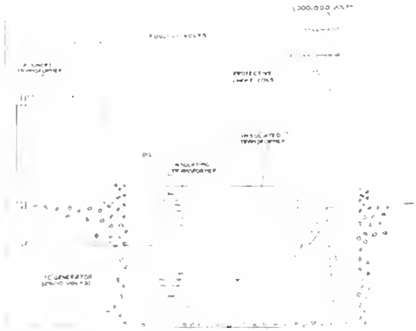

Fig. 1. General Arrangement of the Million-volt Testing Set, Showing the Main Transformer, Insulating Transformer, Line Transformer, and High-tension Bushing; the Latter Three Components Standing on Wooden Supports in a Tank of Oil

There are three main units which are identical and each is complete in itself. The normal rating of each is 60 cycle, 500 kv-a., 578,000/2500 volts.

One terminal is brought out through a high-voltage bushing. The other terminal is connected to a film cutout on a terminal board on the cover, and dead grounded. An ammeter and wattmeter may safely be connected directly in the high-voltage circuit at this point since it is at ground potential.

A voltmeter coil encircles the high-voltage coil stack at the bottom or grounded end and, having a ratio of 1000 or 2000 to 1 with the high-voltage winding, reads directly in kilovolts or half kilovolts. This coil also supplies the shunt circuit of the wattmeter and is grounded. The odd voltage of 578,000 was chosen to give exactly 1,000,000 volts, three-phase.

The insulating exciting transformer is used to excite the line unit when two main units are used in series for 1,000,000 volts to ground. The rating is 60 cycles, 500-kv-a., 2500 2500 volts. Its secondary is insulated for 500,000 volts working stress between primary and secondary, the whole transformer being immersed in oil in the large open tank.

The million-volt terminal is supported on an insulating stand at one end of the large open tank, the so-called "ground sleeve" being under oil and 500,000 volts above ground. The central conductor, cap, and two protective choke coils are 1,000,000 volts above ground. Except in length this terminal is almost identical with those used on the main units for 578,000 volts.

Two spiral choke coils of bare aluminum wire with parallel high resistances are used on all terminals, although not shown on the grounded unit in Fig. 1.

The sine-wave motor-generator set consists of a compound-wound, interpole, continuous-current motor rated 550 volts, 625 h.p., 900 r.p.m., and is direct coupled to two sine-wave, single-phase, 60-cycle generators rated 2300 volts, 500 kv-a. each.

The generators were especially designed for good wave form, the revolving field being of the round rotor type and wound like a direct-current armature, some of the coils being short-circuited to balance armature reaction. The two generators permit the use of two independent testing sets at the same time, one for 578,000 volts and one for 1,000,000

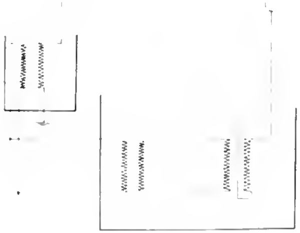

Fig. 2. Simplified Diagram of Connections of the Million-volt Set Shown in Fig. 1

Voltage control is entirely by generator field excitation and series-parallel armature connections.

Main Transformer

Figs. 3, 4, and 5 show the main transformer which is rated at 578,000 volts, 500 kw. The design is of the same type as that used for the past ten years for all sizes of testing transformers built by the General Electric Company, and in many respects resembles its standard power transformers, especially in sturdiness of construction and the use of the same type of core, coils, and insulation.

Fig. 6 shows an example of standard power transformer which closely resembles the testing transformers.

Fig. 3. Exterior View of the Main Transformer, 578,000 Volts. A similar unit stripped of cover, tank, and terminal is used as the line transformer

Fig. 4. Main Transformer Removed from its Tank; Front View, Showing the Tapered Major Insulation and the Extra-heavy Coil Insulation at the Top or Line End

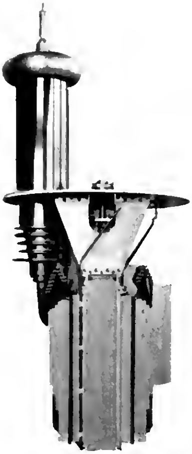

Fig 5. Main Transformer Removed from its Tank; Side View

Winding and Insulation

The low-voltage winding consists of a single helical coil wound in one layer on an insulating cylinder closely fitting the central core leg. Both terminals are brought out at the bottom.

The high-voltage winding is composed of 50 double-section disk coils, each double coil being taped with varnished cloth, the insulation increasing toward the top or line end. As shown in Fig. 4 the two upper groups of coils are heavily taped as units also.

In order to give a large radius to the upper corners of the coil stack, a thick, well-rounded wood ring or torus taped first with metal ribbon and then heavily insulated with varnished cloth tape is placed on top of the coil stack under the group taping and connected to the line terminal. This acts to prevent leakage over the major insulation and also as a static shield and arcing ring, the construction being virtually the same as in power transformers.

The size of the conductor, as well as the thickness of insulation between turns, sections, coils, and the group insulation, increases toward the top and is very heavy near the line terminal in order to avoid short circuits from high-voltage high-frequency line oscillations which, in a unit of this size, may be extremely severe.

The high-voltage winding contains about 30 miles of paper-covered aluminum strip.

All the coils are in the form of thin disks, wound one turn per layer, the winding being subdivided into 100 single or 50 double coils.

The high-voltage conductor has a current capacity many times normal, being good for at least 5000 kv-a., but the material and cross section were determined by mechanical and electrostatic considerations and not by conductivity.

It was desired to obtain the maximum insulation and uniformity of winding, thus disk coils of one turn per layer were chosen, as on power transformers.

The outside diameter of the finished coils being large, it was necessary to use a large conductor for mechanical reasons to give stability to the coil while winding and handling. The paper covering may also be applied more successfully to conductors of considerable size, and a large radius on the edges is desirable for better insulation. Aluminum was used instead of copper chiefly to reduce the weight of the individual coils and thus to avoid injury during handling.

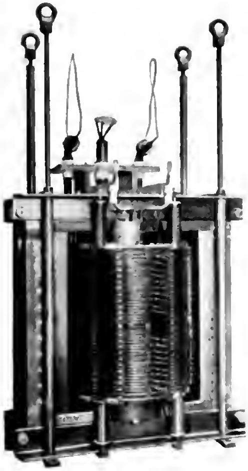

Fig. 6. A Standard Power Transformer, 25 Cycles, 2500 Kv-a., 100,000/6600 Volts, of the Same General Construction as is Employed in the 578,000-volt Transformer shown in Figs. 3, 4, and 5

The resistance drop and losses in the high-voltage winding are negligible as is obvious.

The internal capacitance between turns, sections, and coils is comparatively large as was intended, in order to distribute and reduce the dielectric stresses. The capacitance of the complete transformer is so great that the exciting current always leads the voltage and is much less than usual.

The calculated lagging magnetizing current is 46 amp. and the measured exciting current 33.5, corresponding to a leading current of 76 and an actual power-factor at zero load of 0.445 leading. This is for a single unit at 2500 volts impressed.

When two units and the exciting transformer are connected for 1,000,000 volts to ground the power-factor at the generator is 0.30 leading.

This is a favorable condition for the generator as the resultant current is greatly reduced and, being leading instead of lagging, the armature reaction is in conjunction with the field excitation instead of in opposition. The voltage wave-form, initially good, is distorted but little.

The actual capacitance being distributed in a complicated manner is difficult of calculation but a fictitious equivalent capacitance may be determined on the assumption that the internal capacitance is zero, and a condenser is connected in the high-voltage circuit at 578,000 volts, for one unit.

Fig. 7. Million-volt Terminal for the Line End of the Testing Set, Fig. 1

Fig. 8. 578,000-volt Terminal for the Main Transformer, Figs. 3, 4, and 5

On this basis the high-tension current is 0.33 amp. (normal full load = 0.865) and the equivalent condenser has a capacitance of 0.0015 microfarad. This is the capacitance of about 35 ft. of one-inch cable with paper insulation one inch thick.

The actual current at the grounded end of the million-volt connection with no outside load is nearly 0.5 amp., which gives some idea of the capacitance effect.

Major Insulation

The insulation between low- and high-voltage windings consists of a series of concentric insulating cylinders and oil spaces, provision being made for oil circulation. Moulded oil-treated pressboard shields of corresponding number and with similar oil spaces insulate the high-voltage winding from the core as shown in Figs. 4 and 5. The number of cylinders, shields, and oil spaces increases toward the top, the insulation being tapered according to the voltage stresses, the total thickness being roughly proportional thereto. This arrangement is often referred to as "graded insulation" but the expression is incorrect, as "grading" refers to the use of several dielectrics of differing specific capacitance in series, to equalize the voltage gradient, as in concentric structures such as cables, and is not employed here. The insulation is "tapered," that is, the thickness varies with the voltage.

High-voltage Terminals

The high-voltage terminals are illustrated in Figs. 7 and 8, and are of exactly the same design as the whole series of sizes used with testing transformers except for minor modifications made desirable by the extremely large size and high working voltage. The design of the whole series of sizes for working voltages of 50,000 to 600,000 was worked out expressly for testing transformers and standardized many years ago, so that intermediate or larger or smaller sizes may be calculated completely by empirical formulas with certainty that they will perform as expected.

Fig. 9. Spun Brass Cap. 50-in. Dia., Used at the Top of the High-voltage Terminals, Figs. 7 and 8, to Prevent Corona Formation

The terminals are of the filled type, the design being so efficient that corona is never shown, and the total length is a minimum.

Fig. 10. Cast Aluminum Sleeve, 715-lb. Weight, for Supporting the High-voltage Terminals, Figs. 7 and 8

The cap, Fig. 9, 50 in. in diameter, is spun from brass sheet and nickel-plated. The cast aluminum ground sleeve, Fig. 10, $46\frac{1}{2}$ in. in diameter, weighs 715 lb. The total length of the 578,000-volt terminal, Fig. 8, is 12 ft. $6\frac{1}{4}$ in., and the calculated arcing voltage 640,000. This is reduced somewhat by the projections on the transformer cover.

The 1,000,000-volt terminal, Fig. 7, is essentially the same except in length, which is 17 ft. $6\frac{7}{8}$ in.

Insulating Transformer

The insulating transformer, Fig. 11, is rated 500 kw., 2500/2500 volts, the secondary winding being insulated for a working voltage of 500,000.

Ordinary designs not being well adapted to the purpose, it was decided to use a form long in use for instrument current transformers, although the capacity of this power transformer is about 1000 times greater.

The core consists of two stacks of sheet steel rings 33 in. outside diameter and without joints. The primary winding is of flat strip wound on the rings torus fashion in one layer which exactly covers the inner surface, giving a smooth, hollow cylinder well adapted for insulation from the secondary winding.

The major insulation is in the form of a pair of wall bushings passing through the two ring-shaped cores and closely resembling the terminal of the main units. The center of the bushing is a brass tube, the secondary winding passing through this and across the ends, forming a large rectangle of circular section. The whole stands on a treated wood support and is immersed in oil in the large open tank, the secondary being directly connected to the low-voltage winding of the insulated line unit and in metallic connection with the core of the latter and the "ground" sleeve of the million-volt terminal, as shown in Fig. 1. The torus-shaped caps of the wall bushings are of cast aluminum and of excellent form to avoid corona. The reactance of 17 per cent is low for a transformer of this extreme rating and is practically negligible for all ordinary service since the actual load is far below normal, while the short magnetic circuit and freedom from magnetic joints give low losses and exciting current.

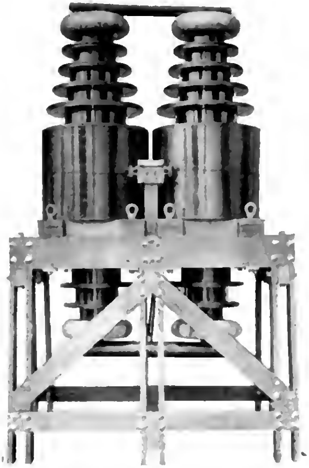

Fig. 11. Insulating Transformer Used to Excite the Line Transformer for Tests above 578,000 Volts

Assembly for 1000 Kv-a., 1,000,000 Volts to Ground

The million-volt to ground connection with a capacity of 1000 kv-a. is the most interesting connection, involving serious problems of design and construction, and is therefore shown in detail in Fig. 1. A large open oil tank, originally intended for experiments and tests under oil, was utilized for the insulating transformer, line unit, and million-volt terminal, each being mounted on an insulating support made of treated wood.

The tank is of boiler plate set in concrete and is 26 ft. long, 16 ft. wide, and 14 ft. deep, with semicircular ends, and holds 36,000 gallons of oil

Voltage Measurements

The reactance of the main transformer units at 500 kv-a. each is 6 per cent and the conversion ratio at the usual low loads thus gives a close approximation to the actual voltage. Full load is unlikely to be met with in testing practice. As a more accurate method, the voltmeter coil errors are less than 0.5 per cent at full load leading current and thus inappreciable at the usual loads of testing and experimental work. A sphere gap with diameter of one meter for each sphere is used for measurements up to a million volts above ground. This is designed in the form of swinging and sliding brackets, pivoted on the wall of the building, each bracket carrying a sphere, the axis of the spark gap being vertical. The two brackets or main frames hang in perfect balance at the ends of a silent chain passing over a sprocket mounted on ball bearings, and roll in a vertical direction on steel balls placed between V-shaped tracks of hardened steel attached to the main

Fig. 12. The Upper Arcs, Which Occurred at the Proper Place Between the Terminal Points, are of Several Successive Discharges Across a 9-ft. Gap Between Sharp Points, and Started by a Million Volts from Line to Ground. The lower discharge took place from the cap of the main terminal to a fence in the background. This accidental arc was photographed nearly end-on and does not indicate its length of 13 feet. The two strong lines near the arc show respectively the curved outline of the cap and the straight surface of the terminal by reflection from the arc. The location of this latter arc is shown in Fig. 13 at the points marked *A* and *a*

frames, and a $3\frac{1}{2}$ in. steel shaft mounted on ball bearings attached to the wall.

Adjustment of the gap length is by means of an endless rope, pulleys, and bevel gears which drive the sprocket on which the main frames are hung, and may be made while the apparatus is alive. The gap setting is indicated in millimeters on a large dial at the control board, the dial being operated by steel wires and bands connected to the main frames in a manner to avoid friction and backlash.

The spheres are spun from sheet aluminum, so that the weight carried by the main frames is a minimum. The frames are of treated wood and extend about 16 ft. from the wall. A high resistance composed of a large number of carborundum rods is hung from the roof trusses and connected between the upper sphere and ground.

The design permits exact and delicate adjustment under full voltage and the arcing distance may be read directly from the dial without error.

Since there are three identical main transformers any one may be used as a potential transformer, thus giving an additional check. However, the voltmeter coils are the most accurate and convenient means of determining the high voltage, regardless of reactance, load, phase relations, or atmospheric conditions. The chief variable is the amplitude factor of the potential wave, or the ratio of the crest to the effective value which is determined by the spark gap or by an oscillograph or crest voltmeter. This variation is small because of the excellent characteristics of the generator and the low flux densities and high capacitance of the transformers.

The spark gap is useful also in indicating the presence of transient voltages which are not easily determined in any other manner.

The voltmeter coil is of the differential form composed of two coils in series. The errors of the two coils are of opposite sign and the relative number of turns are so chosen as to give a minimum resultant error closely approaching zero. Other forms might have been used, but the differential coil lends itself more readily to exact calculation and may be placed near points at ground potential.

Other Connections

(a) The two transformer units in series for 1,160,000 volts with neutral grounded, (b) three units in series for 1,500,000 volts with the ground one-third the distance from one end, (c) as well as 1,000,000 volts, three-phase are all simple connections involving no serious problems.

The whole outfit, while it contains some novel features and unusual refinements of detail, is designed along well-tried and standardized lines, especially to meet local conditions, the requirements of routine commercial tests, experimental and research work.

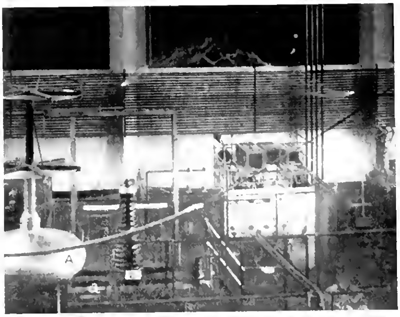

Fig. 13. Million-volt Nine-foot Arc Between Sharp Terminals. The arc shows faintly, due to second exposure of the photographic plate in daylight, and to poor focus. The letter *A* on the high-voltage terminal cap and letter *a* on the enclosing iron fence locate the ends of the arc shown in the bottom left-hand corner of Fig. 12

Results

Fig. 12 shows several successive arcs across a nine-foot gap between sharp points at a million volts to ground. In making this test, the voltage was brought up steadily until an arc was formed. The current produced a large drop in generator voltage which broke the arc. The generator excitation was immediately increased by means of the field rheostat so that the voltage rose with a rush, too fast to be read on the voltmeter, and restarted the arc. A repetition of this phenomenon caused several more arcs to form and break in quick succession. The arcs, combined with a voltage increase of about 10 per cent, set up violent oscillations culminating in a high-frequency arc from the million-volt terminal cap to an iron fence, about 13 ft. distant. This arc is shown in the lower left-hand corner of the picture and, being viewed nearly end-on, does not appear in its real length.

The outline of a portion of the terminal cap and cylinder is shown by reflection, and

Fig. 14 Several Successive 1,200,000 volt Arcs Between Points Spaced 11 Ft. Apart

Fig. 15 Two Successive 1,200,000 volt Arcs Between Points Spaced 11 Ft. Apart

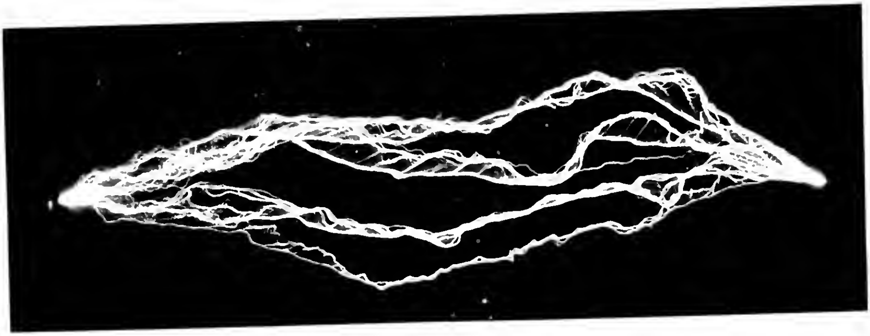

Fig. 16 A Record of Successive 1,500,000 volt Arcs Over a 14 ft. Gap

the actual position is given in the corresponding general view of the apparatus, Fig. 13. The nine-foot arc between points in Fig. 13 does not show clearly because the negative was exposed twice, once by daylight for the room and once in the dark for the arc and was not exactly in focus.

A resistance of about 525,000 ohms was in series with the main nine-foot arc, thereby limiting the current in this part of the circuit, but obviously there was no ohmic resistance to limit the discharge from the cap to the fence. As a result this arc was of explosive violence and of extreme brilliancy.

In another test at 1,000,000 volts to ground a discharge was formed from one of the choke coils located above the terminal cap, Fig. 1, to an iron pipe on the wall of the building. The spark distance was about 18 ft. and therefore, on the basis of voltage being proportional to length, represents an instantaneous potential to ground of about 2,750,000 volts.

Fig. 14 shows a series of eleven-foot arcs at about 1,200,000 volts between points with neutral grounded, and about 525,000 ohms in the circuit on one side of the gap.

Fig. 15 shows two successive arcs taken under the same conditions.

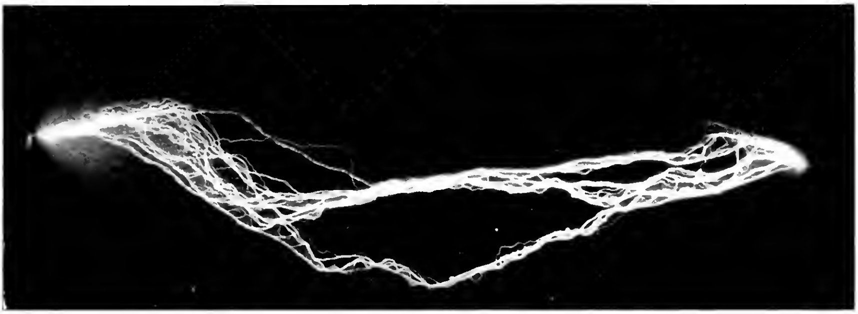

Fig. 17. Successive 1,500,000-volt Arcs over a 14-ft. Gap. The brush discharge before the spark took place shows particularly strong on the left terminal

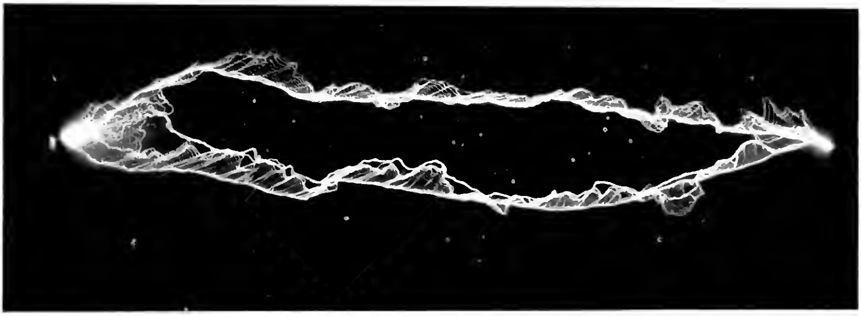

Fig. 18. Two Successive 1,500,000-volt Arcs Between Points Spaced 14 Ft. Apart. The left terminal is a million volts "above" ground, the right terminal is 500,000 volts "below" ground. Both terminals show brush discharge and two heavy spark discharges and about a dozen successive alternations of arc where the air currents have moved the arc in a direction parallel to the photographic plate

Figs. 16, 17 and 18 show fourteen-foot arcs at about 1,500,000 volts between points with about 400,000 ohms in the circuit on one side of the gap. Three transformer units were connected in series for this test, the grounded point being 1,000,000 volts from one end and 500,000 volts from the other end.

(To be Continued)

X-rays as a Means of Determining the Composition of Alloys

By T. S. Fuller

Research Laboratory, General Electric Company

"By determining the comparative X-ray absorption power of an unknown alloy, by matching the intensity of its X-ray image against the intensities of certain carefully prepared standards of the same thickness, and by correlating such data with that of knowledge common to metallurgists, it is possible to approximate closely the composition of the unknown." * * * Quotation from the following article.—Editor.

Since the discovery of X-rays by Röntgen, in 1895, the problem of the examination of metals by this means has been vigorously attacked by many investigators, and from many different angles, and a bibliography on the subject is to be found in connection with the report of the Symposium of the Faraday Society on Radiometallography[1]. A careful search of the literature on the subject, however, revealed only one description, that of Hadfield, Main, and Brooksbank[2], of experiments performed for the purpose of distinguishing the composition of different alloys by means of their different abilities to absorb the energy of a beam of X-rays.

Hadfield, Main, and Brooksbank determined the comparative absorption power of steel containing carbon 0.19, silicon 0.07, and aluminum 2.45; of pure iron containing carbon 0.03, silicon 0.01, and iron 99.9; and of steel containing carbon 0.55, chromium 2.79, and tungsten 20.4. The order of density on the radiograph print was, as expected, found to be the same as the order of their specific gravity.

W. E. Ruder[3] has very ably summarized the progress of metal radiography up to 1919.

It is the purpose of this article to outline an X-ray method which seems to offer very encouraging possibilities for quickly and easily arriving at the approximate composition of metals and alloys.

It was at one time supposed that the absorbing powers of different materials for X-rays were truly proportional to their densities, but as more and more data have been made available, it has been noted that dense substances are much more absorptive, for the same thickness, than light ones, and that the absorption increases rapidly with the atomic weight of the substance.

If this is true, the same thickness of every metal must have a more or less characteristic absorbing power, corresponding to that particular metal, depending upon its density and atomic weight, and resolvable by means of the intensity of the X-ray shadowgraph on a photographic film. By comparing such intensity of an unknown sample with those of carefully prepared standards, of known composition and the same thickness, taken on the same exposure, one is able to eliminate all but a few compositions having absorbing powers equivalent to the unknown; and by correlating these data with facts such as color, hardness, reaction to certain solutions, etc., of common knowledge to the metallurgist, he is able to determine very closely the composition of the unknown. The known standards may be either alloys of a definite thickness made to a definite composition, or composites of sheets of different metals piled one upon the other to a definite thickness.

TABLE I

ATOMIC WEIGHTS AND DENSITIES OF ELEMENTS INVOLVED IN THE INVESTIGATION

Element	Atomic Weight	Density
Aluminum	27.1	2.70
Copper	63.57	8.93
Lead	207.20	11.37
Tin	118.7	7.29
Zinc	65.37	7.1

The problem which inspired this investigation, and which has been successfully worked out by this method, may be considered as typical. A golden colored specimen made from rolled stock was taken as the unknown sample, and the problem was to determine its composition without defacement in any way. The sample had been treated with a chromate solution and lacquered.

The two common rollable alloys having a more or less golden color are copper-zinc and copper-aluminum. It was therefore

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[1] Trans. Far. Soc., Vol. 15, pp. 19-24 (1919-1920).

[2] Tran., Far. Soc., Vol. 15, pp. 74-75 (1919-1920).

[3] Year Book of Am. Iron and Steel Inst., pp. 352-368 (1919).

probable that the specimen under test was either a brass or an aluminum bronze, or a slight modification of one or the other.

Standards were next prepared and laid upon an 8 by 10-in. Eastman Duplitized X-ray film. The thickness of the unknown and all standards was 0.064 in. The edges of the samples and intervening spaces were blocked off with ⅛-in. sheet lead, and the whole section radiographed with a Coolidge tube using 10 milliamperes and 60 kilo-volts for 6 seconds. The focal distance was 15 inches.

The different series were radiographed separately, and the intensity of their images compared with that of the unknown; and finally for convenience all were radiographed on one film. The resulting composite radiograph is shown in Plate I.

Piles of copper sheets and zinc sheets one inch square were built up to 0.064 in. total thickness having varying proportions of the two metals (Samples Nos. *6* to *10*, Plate I) with limiting zinc contents of 1.3 and 17 per cent by weight (Table II).

A careful comparison of the intensities of the images on the film from which Plate I was made revealed the fact that the absorption power of the series decreased with increasing zinc content. A further comparison of this series with the unknown specimen, No. *5*, showed that the intensity of No. *5* lay between those of Nos. *8* and *9*; and therefore that if the unknown consists wholly of copper and zinc, its composition must lie between those of Nos. *8* and *9*, or, in other words, between 9.1 and 13 per cent of zinc by weight.

It is appreciated, of course, that the selection of an intensity comparable with No. *5* in a closely matched series like Nos. *6* to *10* is difficult, and may be somewhat a matter of opinion, but this can be accomplished with most series by suitable means.

The X-ray absorption powers of the other series of rollable golden alloys—those of copper and aluminum—are shown in Nos. *11* to *22*, Plate I. The aluminum content of the series ranges from 1 per cent in No. *11* to 14.3 per cent by weight in No. *22*.

As expected, the absorption power of this series is very sensitive to composition on account of the widely different densities and atomic weights of the components, and also that with the possible exception of No. *11*, containing 1 per cent aluminum by weight, all the images of this series are less dense than the unknown, No. *5*. Therefore, if X-ray absorption power be the criterion, No. *11* is the only member of this series to correspond with the unknown; and because 1 per cent of aluminum is not sufficient to impart to copper a golden color similar to the unknown, it follows that if the latter be an alloy of copper and aluminum it must contain aluminum in excess of 1 per cent, together with a metal of higher density and atomic weight to give the proper absorption power. The two most likely possibilities are lead, having a density of 11.37 and an atomic weight of 207.2, and tin, having a density of 7.29 and an atomic weight of 118.7.

Nos. *23*, *24*, and *25*, Plate *I*, depict the effect of the addition of lead to No. *16* (containing copper 96.6 and aluminum 3.4 per cent) upon the absorption power; lead being substituted for copper in No. *16* and being present in No. *23* to the extent of 2.1, in No. *24* to the extent of 6.4, and in No. *25* to the extent of 13.4 per cent. The absorption power of No. *24*, made up of copper 90.2, lead 6.1, and aluminum 3.4, as shown by its image, is very close to that of the unknown, No. *5*, and this mixture therefore appears as a second possibility in the scheme of analysis.

Nos. *26* to *32*, Plate I, show the effect upon the absorption power of the substitution of tin, the other probable element alloyable with copper and aluminum, for copper in No. *16*. The proportion of tin in these mixtures ranges from 1.3 to 38.5 per cent by weight. The mixture of this series, whose absorption power corresponds to that of the unknown, No. *5*, lies between Nos. *28* and *29*, i.e. between 9 and 13.7 per cent of tin, and this mixture therefore may be listed as the third possibility.

The absorption power of the copper-aluminum series is extremely sensitive to additions of lead or tin.

No. *33*, Plate I, is the X-ray image of a solid block of copper 0.064 in. in thickness, and No. *34* the image of a pile built up of copper sheets having a total thickness of 0.064 in.

The mixtures from which Nos. *1*, *2*, *3*, and *4*, Plate I, were made differ from the others which have been discussed, in that they are alloys made to contain the composition given in Table II, instead of piles of sheets. The only one of these whose absorption power approximates closely that of the unknown, No. *5*, is No. *4* which contains copper 90, aluminum 3.4, and lead 6.7 per cent. This composition is practically the same as that of No. *24*.

The mottled appearance of the lower right-hand corner of image No. *3* denotes heterogeneity of some sort, either holes in the casting or segregations of aluminum oxide. From the fact that the remaining section of No. 3 is darker than No. *29*, which contains slightly more tin, it is probable that the lack of homogeneity results from the latter cause, and that the oxidation of the aluminum has led to an abnormally high copper-tin content, which accounts for the discrepancy in the absorption powers of Nos. *3* and *29*.

Briefly, from a study of the X-ray absorption powers, as shown by Plate I, the compositions possible for the unknown, No. *5*, are:

(a) Alloy of copper and zinc having a zinc content between 9.1 and 13 per cent by weight.

(b) Alloy of copper, aluminum, and lead, having a composition about Cu-90.2, Al-3.4, and Pb-6.4 per cent.

(c) Alloy of copper, aluminum, and tin, having a composition of Cu-82.8 to 87.6, Al-3.4, and Sn-9.0 to 13.7 per cent.

(d) Alloy of copper, zinc, and tin, having a tin content less than that of No. *1*.

(e) Alloy of copper, zinc, and lead, having a lead content less than that of No. *2*.

To establish the identity of the unknown, No. *5*, in the problem under discussion, two additional comparisons must be made in conjunction with the X-ray absorption data. The two additional properties to be considered are natural color and appearance of the surface after treatment with a chromate solution. In the light of these, all but one of the five possibilities developed by the absorption data must be eliminated.

The alloy containing copper 89 and zinc 11 has a natural color, and a surface appearance after treatment with the chromate solution, closely resembling those of the unknown.

The color of the alloy containing copper 90, aluminum 3.3, and lead 6.7 is somewhat too red, both before and after treatment with the chromate solution.

The surface of both copper-aluminum and copper-zinc alloys containing considerable amounts of tin is whitened, instead of turning a golden yellow like the surface of the unknown, by treatment with the chromate solution.

The color of an alloy of copper and zinc, having a zinc content of 12.3 per cent by weight, and sufficient lead to give an X-ray

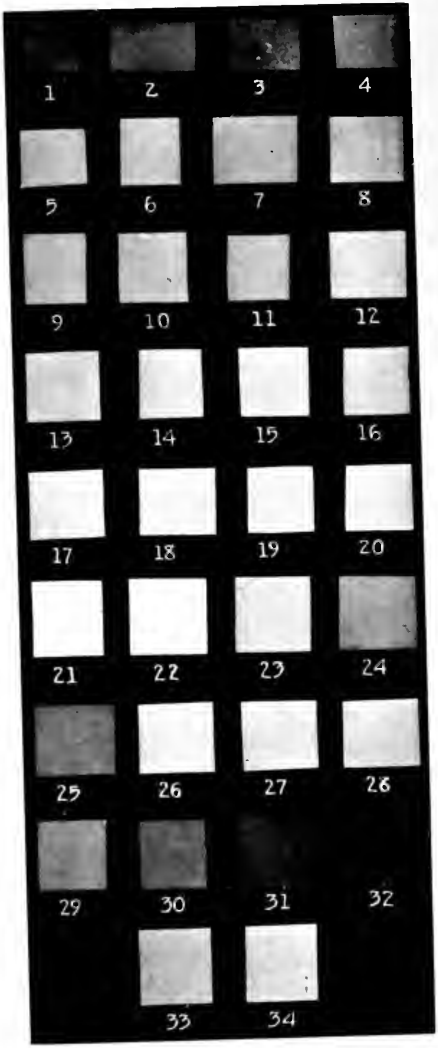


Plate I. Half-tone Reproduction of a Positive Made from a Negative Showing X-ray Absorption Power of Samples. Unfortunately, the fine gradations of shading in the radiograph cannot be fully reproduced in the process of making a half-tone.

absorption equivalent to that of the unknown, is too yellow, both before and after the chromate treatment, to match the color of the unknown.

Therefore, of the five compositions whose X-ray absorption power corresponds to that of the unknown, only one, the copper-zinc having a zinc content between 9.1 and 13 per cent, answers the added requirements of color matching. It has therefore been concluded that this is the composition of the alloy specimen.

By this time, interest in the method had reached such a point that it seemed justifiable

TABLE II

COMPOSITIONS BY VOLUME AND BY WEIGHT OF SAMPLES, THE RADIOGRAPHS OF WHICH ARE SHOWN IN PLATE I

No.	Alloy or Built up Section	Composition by Volume	Composition by Weight
1	Alloy	Cu — 72.5 Zn — 15 Sn — 12.5	Cu — 76.5 Zn — 12.8 Sn — 10.7
2	Alloy	Cu — 80 Zn — 15 Pb — 5	Cu — 81 Zn — 12.3 Pb — 6.7
3	Alloy	Cu — 77.5 Al — 10 Sn — 12.5	Cu — 85 Al — 3.4 Sn — 11.6
4	Alloy	Cu — 85 Al — 10 Pb — 5	Cu — 90 Al — 3.3 Pb — 6.7
5	**Alloy**	**Unknown**	**Unknown**
6	Built up Section	Zn — 1.6 Cu — 98.4	Zn — 1.3 Cu — 98.7
7	Built up Section	Zn — 4.7 Cu — 95.3	Zn — 3.85 Cu — 96.15
8	Built up Section	Zn — 11 Cu — 89	Zn — 9.1 Cu — 90.9
9	Built up Section	Zn — 15.6 Cu — 84.4	Zn — 13.0 Cu — 87.0
10	Built up Section	Zn — 20 Cu — 80	Zn — 17.0 Cu — 83.0
11	Built up Section	Al — 3.1 Cu — 96.9	Al — 1 Cu — 99
12	Built up Section	Al — 4.7 Cu — 95.3	Al — 1.5 Cu — 98.5
13	Built up Section	Al — 6.25 Cu — 93.75	Al — 2 Cu — 98
14	Built up Section	Al — 7.8 Cu — 92.2	Al — 2.6 Cu — 97.4
15	Built up Section	Al — 9.4 Cu — 90.6	Al — 3.1 Cu — 96.9
16	Built up Section	Al — 10 Cu — 90	Al — 3.4 Cu — 96.6
17	Built up Section	Al — 12 Cu — 88	Al — 4.1 Cu — 95.9
18	Built up Section	Al — 15 Cu — 85	Al — 5.2 Cu — 94.8
19	Built up Section	Al — 20 Cu — 80	Al — 7.2 Cu — 92.8
20	Built up Section	Al — 25 Cu — 75	Al — 9.5 Cu — 90.5
21	Built up Section	Al — 30 Cu — 70	Al — 11.8 Cu — 88.2
22	Built up Section	Al — 35 Cu — 65	Al — 14.3 Cu — 85.7
23	Built up Section	Pb — 1.5 Al — 10 Cu — 88.5	Pb — 2.1 Al — 3.3 Cu — 94.6
24	Built up Section	Pb — 4.7 Al — 10 Cu — 85.3	Pb — 6.4 Al — 3.3 Cu — 90.3
25	Built up Section	Pb — 10 Al — 10 Cu — 80	Pb — 13.4 Al — 3.2 Cu — 83.4
26	Built up Section	Sn — 1.5 Al — 10 Cu — 88.5	Sn — 1.3 Al — 3.4 Cu — 95.3
27	Built up Section	Sn — 4.7 Al — 10 Cu — 85.3	Sn — 4.2 Al — 3.4 Cu — 92.4
28	Built up Section	Sn — 10 Al — 10 Cu — 80	Sn — 9.0 Al — 3.4 Cu — 87.6
29	Built up Section	Sn — 15 Al — 10 Cu — 75	Sn — 13.7 Al — 3.5 Cu — 82.8
30	Built up Section	Sn — 20 Al — 10 Cu — 70	Sn — 18.5 Al — 3.5 Cu — 78.0
31	Built up Section	Sn — 30 Al — 10 Cu — 60	Sn — 28.2 Al — 3.5 Cu — 68.3
32	Built up Section	Sn — 40 Al — 10 Cu — 50	Sn — 38.5 Al — 3.6 Cu — 57.9
33	Solid	Cu — 100	Cu — 100
34	Built up Section	Cu — 100	Cu — 100

to carefully remove a few chips from the back of the name plate for a chemical analysis. This was done, and the alloy proved to be one of copper and zinc, containing:

Copper 89.30 per cent
Zinc 10.68 per cent

It is the opinion of the writer that the problem, the solution of which has been described in this article, is typical of those encountered every day by metallurgists in our various industries, and that the method provides a means, offering very considerable possibilities, for quickly and easily finding the approximate composition of many alloys.

By determining the comparative X-ray absorption power of an unknown alloy, by matching the intensity of its X-ray image against the intensities of certain carefully prepared standards of the same thickness, and by correlating such data with that of knowledge common to metallurgists, it is possible to approximate closely the composition of the unknown. Certainly, no one would deem it possible to arrive at the components of an alloy by such an X-ray method alone, but only by the consideration of all available facts.

Alloys composed of metals having widely different atomic weights and densities, such as copper and aluminum—or copper, aluminum, and lead—lend themselves to analysis by this method much more readily than those composed of metals having very similar atomic weights and densities, such as copper and zinc, although it is possible within certain limits to determine the composition of mixtures of these by such a method.

Facts well known to the student of X-ray phenomena, such as the abnormal absorption values of metals of atomic weights in the neighborhood of silver, and the maximum transparency of an element for each of its own characteristic radiations must be watched out for in such a scheme of analysis.

Closed Air Circuit System of Ventilation

By John G. Monson

Alternating-current Turbine-generator Engineering Department, General Electric Company

Since the time when generators were of open construction and the output per pound was small, the development of better grades of material, the adoption of higher speeds of operation, and the working out of detailed improvements in engineering design have resulted in the conventional turbine generator of today in which the output per pound and per machine has been increased to such an extent that the subject of ventilation has become of front-rank importance. In this connection attention may be called to the fact that, while the useful output of a generator is disposed of through a myriad of channels, the heat generated by the losses of the machine must all be disposed of at one location, viz., the power house. Operating engineers will find valuable information in the following article which describes in detail the new system of ventilation that in many ways is superior to the duct system.—Editor.

An article discussing the closed air circuit system of ventilation for cooling steam turbine generators was published in the General Electric Review, February, 1920, page 99. The system has been tried out in the General Electric Company's power station on a 40-cycle, 2-pole, 10,000-kw , 2400-r.p.m , 10,000-volt steam turbine generator, and has been demonstrated to operate entirely satisfactorily.

Because many of the large power stations are investigating this system with the intention of installing it on new units and also of changing over the ventilation of their present generators, the system will be described more fully, bringing out the useful points and the precautions that should be exercised in its installation and operation.

The closed air circuit system consists of the following parts as shown in Fig 1:

A rectifying or cooling chamber.

A louver cage where the air separates from the water

An eliminator chamber where any remaining free suspended particles of water are eliminated.

A pan for collecting and discharging the heated water.

Operation of the System

The exhaust air from the generator passes through a row of baffle plates which are installed to prevent water being squirted back into the generator in case any spray nozzles get out of order. The air then enters the washing or cooling chamber in which are located the necessary number of spray nozzles. Here the heated air comes in contact with the spray films and thoroughly mixes with the water vapors through the turmoil action produced by its velocity, in consequence of which its temperature is reduced to within a few degrees of the water temperature. The speed of the air through this chamber should be about 600 ft. per min. Directly below the cooling chamber is a somewhat larger space surrounded with off-set boards, or plates, forming a louver. In the louver compartment the cooled air is separated from the water by gravity. When leaving this chamber the air scrubs against the louver plates which are always wet on the inside by the water sprays from the cooling chamber above. The scrubbing assists in cooling and is helpful in removing most of the suspended water particles from the air before it enters the eliminator chamber. The speed of the air through the louver cage should be comparatively low, about 300 ft per min., if space is available. The eliminator chamber is a space large enough to reduce the air velocity to about 200 ft. per min. and is supplied with eliminator plates to remove the last vestige of free water particles from the air The air then re-enters the generator.

The space occupied by this system is relatively small compared with the old system of taking air through ducts from outside the station and then discharging it outside. The foundation directly under the generator is usually provided with a space which is occupied by the inlet and outlet air duct pipes. This space can be utilized to advantage for installing the air rectifier as shown in Fig. 1, thereby simplifying the station arrangement and furnishing much more room.

As the whole ventilating system is totally enclosed, impurities cannot enter except, possibly, when opened for inspection or repairs and even then whatever dirt might enter would be removed by the water. It should not be necessary therefore to clean the generator so frequently, thereby maintaining longer operating periods at less expense.

All high-speed machines that discharge their ventilating air to the atmosphere are more or less noisy, but with this new system the noise should be reduced to an unobjectionable tone and volume.

Amount of Water

The quantity of water required to remove the heat of the generator losses from the outgoing air is approximately four gallons per minute, per kilowatt of loss, for one degree Centigrade rise of the water, and it varies inversely with the rise of the cooling water. In the installation referred to, the temperature rise of the water is five to seven degrees Centigrade which results in a considerable saving in the amount of water used as compared with the old system where the water from the washer was heated only about two degrees.

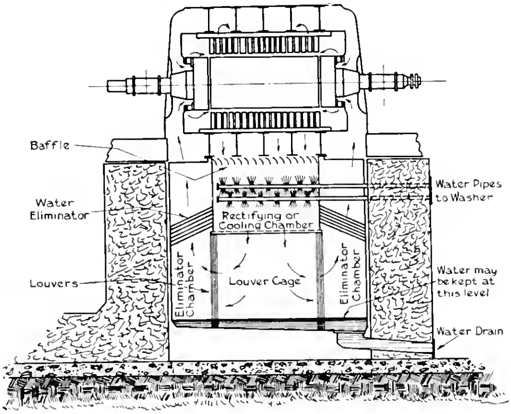


Fig. 1. Diagram Illustrating the Closed Air Circuit System of Ventilation, for Cooling Steam Turbine Generators

The Spray and Feed-Water Arrangement

The number of spray nozzles depends upon the amount of water necessary for cooling the generator, and is based upon the maximum generator losses; but the arrangement of these sprays in the rectifying or cooling chamber should preferably be in two or more rows, each forming a separate section one above the other with feeder pipes to each having separate valve connections so that any section of sprays may be made inoperative when a less amount of water is needed, as when the generator is operating under fractional load or the intake water is of a low temperature.

It is advisable at all times to run the generator at a fairly constant temperature thereby lessening the repeated expansion and contraction of the generator materials, especially the windings. The working life of the machine should be materially increased by a reduction of the relative movements of the various parts.

The quantity of water can be automatically regulated by electrical and mechanical arrangements for varying the supply to the spray nozzles, in accordance with prearranged temperature limits, or be controlled by thermostats placed in the space where the heated air leaves the generator. With such automatic regulators the generator will operate at fairly constant temperature for different loads, and be entirely independent of surrounding atmospheric conditions, and the quantity of water used will be reduced which is especially desirable in places where water is not plentiful.

Air Free from Water

The air flow is vertically downward from the generator and through the spray chamber into the louver cage, so that the water spray air mixture has to drop straight downward with the air flow. As the speed of the mixture is reduced in the louver cage to approximately 300 ft. per min., the water will drop by gravity to the bottom allowing the air to pass out at right angles from the cage into the eliminator chamber, and here the direction of the air is changed to vertically upward. If the air, after leaving the louver cage, carries any free water particles these will be removed by the eliminator plates. The low velocity, vertical flow, louver, and eliminator plates effectively remove all free water from the air before it re-enters the generator.

Dampers and Fire Protection

It will not be necessary in the closed system to install dampers for fire protection or for preventing condensation of moisture when the machine is at rest. However, to provide against temporary failure of the water supply, it is advisable to have dampers so arranged that (1) the outgoing air from the generator can be discharged at the top of the armature spider, (2) the bottom discharge can be closed to the spray chamber, and (3) at the same time air can be let into the generator from the basement.

Fire Protection

In the case of an internal fire the oxygen in the air is consumed, thus the fire may be extinguished although a small flame may continue for a time sufficient to cause some injury to the winding. Therefore, it is advisable to provide for an extinguishing agent such as steam, water, or a non-combustible gas. If steam is used, special care should be taken that only a sufficient amount is turned on, about one-half pound per cubic foot of air space in the system; otherwise, the excess pressure may burst the generator lagging, also the heat may injure the insulating materials. If water is used, pipes with small holes should be fitted inside the end shields surrounding the winding. When necessary the water can be sprayed all over the end windings where the fire generally occurs.

Danger Signals

The closed air circuit system cannot operate without water being supplied to the rectifier any more than the bearings can operate without lubrication For this reason an alarm device should be installed to announce danger of overheating in case the generator should happen to operate above normal temperature because of heavy overload, improper operation of the cooler, or internal fire. Such an alarm device can readily be installed, and consists of thermostats mounted in the outgoing air duct between the generator and cooler (two are usually installed as a check on each other) which would by electrical connection ring a bell at any predetermined temperature. The thermostats should be tested at intervals. For an assumed condition, the data given below illustrate the method of determining the temperature for which the thermostats should be set.

	Deg. C.
Temperature of water supply	31
Temperature rise of water leaving	6
Temperature difference between leaving water and leaving air	3
Temperature rise of air passed through generator	25
Temperature allowance for contingency	5
Temperature at which alarm should be given or thermostats set	70

If the temperature of the supply water, or the rise of the air passing through the generator differ from the foregoing, the temperature alarm should be changed an equal amount.

Alternating-current generators are built with either of two kinds of insulating material; that is, Class A for 105 deg. C., and Class B for 125 deg. C. actual temperatures in accordance with the A. I. E. E. Rules. Therefore, the class of insulating material used on the windings, the full-load temperature rise of the generator, and the condenser water temperature determine the possibility of using the condenser water for cooling the generator. The operating internal temperature of any machine is that indicated by the hottest temperature detector imbedded in the windings. After obtaining from test for full load the rise of the hottest detector and the temperature rise of the outgoing air, it can be readily determined if the class of insulation used in that particular machine will permit of the condenser water being used for cooling purposes. Part of the condenser water can be used provided its temperature is several degrees lower than that of the outgoing air in which case the cooling chamber has to be constructed differently. The condenser water can be used in the upper row of spray nozzles and arrangements made for collecting and removing this water again before it enters the lower strata of spray nozzles where the cold water is used. By this arrangement the hot outgoing air from the generator could be cooled to within a few degrees of the condenser water by the upper strata of spray nozzles and the air temperature still further reduced by the lower strata of spray nozzles. This will economize the amount of cool fresh water used. It would make a more complicated rectifier and should only be employed where water is scarce, or where it is desired to recover the heat in the air. For example, if the generator is provided with Class A insulation, for which the temperature of the air should be about 55 deg. C., and the condenser water to the spray nozzles is say 120 deg. F., or 45.5 deg. C., and we use such a quantity of this water as will heat up 5 deg., then 45.5 plus 5 plus 3 is 53.5 deg. C., hence the benefit would be practically negligible unless the condenser water has a lower temperature. With Class B insulation, and 65 deg. C. outgoing air, the benefit would be greater. Attention is called to this point to show how it can be determined if this kind of cooling water is suitable for a particular installation.

Another way to economize in the amount of water would be to use part of the cooling water over again and then mix with it sufficient make-up water to keep the temperature down to a proper value, especially during such times as the temperature of the water supply is low or when the machine is operating under fractional load.

The same water may be used continuously provided it is cooled, which may be accomplished by the use of a cooling tank or by forcing the water through pipes immersed in cold water of a quality not suitable for the generator spray cooler due to its containing salt or impurities that would clog the spray nozzles or cause a slimy substance to collect in the rectifier. If the water is pumped from a river or lake it should be screened or strained to remove most of the impurities A self-cleaning strainer is the simplest because the cleaning is done by opening a valve, which is but a moment's work and which may be done at regular intervals without shutting down the generator

Saving in Generator Maintenance

It is a well known fact that the air washers generally used do not remove all the impurities, but let the worst kind of these—such as carbon dust, greasy or oily substances—pass into the machine. Very few persons have even a vague conception of the amount of air passing through a generator in a single day. Approximately seven million pounds will pass through a 30,000-kw. machine during twenty-four hours' operation, that is, the quantity of air per hour is about equal to the weight of the generator. Therefore, if only an extremely small percentage of dirt is present in the air entering the generator an amount will soon be accumulated that will clog the air passages around the ends of the windings, fill up the air ducts, prevent proper ventilation, and thereby cause excessive heating. This accumulated dirt substance in the windings may actually be set on fire by means of a spark from static electricity or other sources, even causing minor explosions. Frequent inspections and cleaning have therefore been found imperative but this performance is expensive and slow for it requires dismantling of the generator. In the closed system there will be no dirt worth mentioning, and the expense of cleaning will be greatly reduced.

Condition of the Air Entering the Generator

In the present mode of ventilation, where air washers are used for cleaning and cooling, and the air is supplied from the outside, the humidity of the air entering the generator is about 100 per cent (the same as in the closed circuit system) when the air temperature outside the station is above freezing. If this temperature is below the freezing point then the water-mist particles will freeze, slip by the eliminator plates, and be carried into the generator where they melt causing the water to run over the leads and windings, which may result in short-circuits and burnouts. Another bad condition is encountered during the hot summer months, when the air is warm with high humidity. This air when drawn in and passing through the washer is cooled below the saturation point, but part of the mixture it carries is changed into a fine mist resembling fog. Water vapor carried in this form by the relatively high air velocity cannot be removed by an eliminator of reasonable size, and therefore is drawn into the generator and deposited inside the shields where it soon forms into drops. The dripping of this water into the windings and its collection at the bottom where the leads are brought out from the generator is likely to produce disastrous results. Such conditions as those mentioned will not occur in the closed circuit system as the outgoing air from the generator to the washer will always be warm, and the humidity about 30 per cent after leaving the generator

Air Velocity and Dimensions of Cooling Chamber

The air velocity through the cooling chamber will differ to some extent with the manufacture of air conditioning apparatus, such as different water pressures, number of nozzles, size of openings in nozzles, cost, etc. Such data should be obtained from any reliable air washer company. There is one important point which should be emphasized, that is, the transfer of the heat from the outgoing air to the water will be the same for all velocities provided the air is in contact with the water the same length of time, and the amount and the fineness of the water is the same. In other words, if the air velocity is low a shorter distance for air travel may be used than when the velocity is high. Velocities below 300 ft. per min. are not recommended for at such speeds the air travels in parallel lines, therefore part will not come in contact with the spray films. With higher velocity the air is set in a turmoil and therefore will mix better with the spray. If too high a velocity is used, say 1000 ft. per min., then the length of the air travel or cooling chamber will be rather long and the rectifier unnecessarily deep.

Velocity Through Louver and Eliminator Chamber

The air velocity through the louver compartment should be such that practically all the fine suspended water will readily separate from the air. After passing through the scrubbing plates and entering the eliminator chamber the air velocity should be still further reduced, in fact so much so that any free water suspended will drop to the bottom and run off. If the velocity here is sufficiently low then no eliminator plates will be necessary, but as this condition may not be met at all times it is recommended that these be installed for greater safety.

The information that should be furnished the air conditioning companies when requesting a quotation on an air cooler for the closed system should give the amount of air in cubic feet per minute necessary for the generator, the generator losses that must be removed, the maximum and minimum water supply temperatures for the washer, also the quality of the water with regard to impurities.

The foregoing description and comments apply more particularly to the closed air circuit system when located directly under the generator, that is, having a vertical air flow. This type will probably be utilized mostly in new installations. Other locations and arrangements may be used, especially for machines already operating in stations. Most large power stations are now using horizontal air washers taking air from the outside of the building, or the basement, etc. For convenience, and for saving expense, it may not be deemed advisable to make many changes, therefore a way of obtaining a closed air circuit ventilation is to reconnect the outgoing air duct from the generator to the air washer where it stands. On other units which have not yet been supplied with air washers, but may be in the future, and the foundation does not allow sufficient room directly under the generator, then an air washer of either a horizontal or vertical type may be installed in a convenient place, preferably near the generator in order to make the ducts short. It has been found that the heat transfer through the sheet iron walls of a duct is considerable when there is a large difference of temperature between the inside and outside of the air duct. If the temperature drop is large, which is readily ascertained from tests by thermometers inserted at different places in the duct, then it is advisable to lag the duct with heat insulating material such as is used around steam pipes, etc. This would apply especially to that part of the duct next the generator where the outgoing air duct is surrounded with the ingoing air to the generator.

Control Equipment for Electrically Propelled Japanese Fuel Ship "Kamoi"

By R. O. Dunham

Railway Equipment Engineering Department, General Electric Company

The author describes in considerable detail the control equipment of the first twin screw ship to be propelled by synchronous motors. This ship was built for the Imperial Japanese Navy and can be operated either manually or through the master controller.

Since this article was written, the ship and its equipment have successfully passed the builders' trial. A six-hour full-load run was made and followed by ten standardizing runs; two runs at 80 r.p.m. of the motors; two runs at 106 r.p.m.; two at 116; and four at 123 r.p.m. The ship was then turned through a complete circle with both motors full-speed ahead and the rudder at 35 deg.; through a complete circle with one motor stopped and the other motor at full-speed ahead with the rudder at 35 deg.; and then through a complete circle with one motor running full-speed ahead, the other full-speed astern and the rudder at 35 deg. The ship was reversed from full speed ahead and the motors stopped in eleven seconds and synchronized with the generator at 40 r.p.m. astern of the motors in eight seconds more. The ship was run for an hour from a 625-kw. auxiliary unit and the propellors turned at 55 r.p.m., giving the ship a speed of about 7½ knots. The whole propelling equipment functioned in such a manner that the ship was accepted by the representative of the Japanese Navy at the end of the trials.—Editor.

The first ship in the U. S. Navy to be propelled electrically was the collier *Jupiter;* she was equipped with twin screws driven by induction motors. The first twin screw ship in the world to be driven by synchronous motors is also a fuel ship—the *Kamoi*, which was built by the New York Shipbuilding Corporation for the Imperial Japanese Navy.

The propelling machinery of the *Kamoi* consists of one 6250-kw., 2300-volt, 3-phase, 40-cycle generator driven at 2400 r.p.m. by a direct-connected Curtis type steam turbine and two 4000-h.p. synchronous motors which are direct connected to the two propellers and drive them at 120 r.p.m. In addition, a 625-kw., 750-volt generator is provided which, in emergency, can be coupled to one of the exciter turbines and used to drive the two propelling motors at low speed. Two 500-kw., 3-wire, 225-volt turbine-driven direct-current generators supply the current for excitation and control as well as for driving the auxiliaries.

The operation of the propelling motors is controlled through the operation of the equipment contained in the control panel; the alternating-current control group and the direct-current control group. On the panel are mounted the electrical relays, instruments, master controller, governor control switch, the two motor rheostats, generator rheostat and the manual levers for operating the control groups. The two control groups contain the alternating-current contactors for completing and for reversing the line circuits and the direct-current contactors for completing the field circuits.

Control Panel

The control panel, Fig. 1, is a structural steel cell faced on the front with a steel plate. The instruments are of the flush type and are set into holes cut in this plate and are bolted to it. With the instruments there are mounted two protective relays and the ammeter in the neutral of the generator which indicates any leakage current to ground. There is also a test switch for checking the operation of the relays and the switch which carries the control current to the master controller. Fuses, removable from the front of the panel, are provided for the lighting circuit and for the potential circuit of the generator field temperature indicator.

The handwheel of the operating mechanism for the generator and motor field rheostats is mounted in about the center of the panel with the center of the handwheel about 30 inches from the floor line. The three rheostats are all operated by the same handwheel and for adjustment of the fields to give unity power-factor any rheostat may be disconnected from the handwheel through the operation of its clutch which is located above.

In normal operation the contactors are controlled by the master controller. The closing of the contactors is controlled through the manipulation of the two reverse levers and the field lever. Each reverse lever has three positions: ahead, stop, and astern. Operation of one lever energizes the line contactors for the port motor and operation of the other lever energizes the contactors for the starboard motor. The field lever, when operated, energizes the contactors in the field circuits of the generator and motors. The field lever has an "off" and three operating positions.

The turbine speed control switch is located above the master controller. This switch, through control of the governor motor, causes the turbine governor setting to be changed and thus varies the turbine speed. The switch has three positions: increase, off, and decrease. It is returned by a spring from the "increase" position to the "off" position but may be placed in the "decrease" position. When the switch is placed in the "decrease" position, the governor motor causes the setting to be decreased to the low speed setting which is approximately one-quarter speed. For lower speeds than one-quarter, the turbine throttle must be operated.

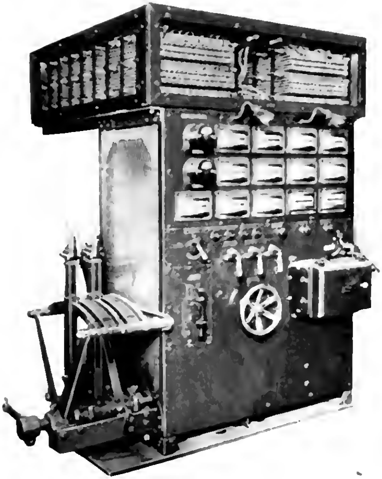


Fig. 1. Control Panel, Front View

Three-position voltmeter and ammeter switches are provided which enable the operator to read the voltage across and the current in the three phases.

The generator and motor rheostat dial switches are mounted at the back of the panel and are so arranged as to be operated by the rheostat handwheel. The unbreakable punched steel resistors for the three rheostats are mounted in a frame which is located on top of the main panel and connected through cables to the dial switches. Fig. 2 shows the back of this panel and clearly shows the connections between the resistors and the dial switches.

Three levers are used for manually operating the contactors; they correspond to the three master control levers, there being one field lever and two reverse levers. The field lever closes manually the same contactors that are electro-magnetically closed through the operation of the master controller field lever, and the reverse levers close manually on the corresponding points the contactors closed electro-magnetically through the operation of the reverse levers on the master controller.

Mechanical interlocking is provided between the manual levers and the master controller so that unless the manual levers are in the "off" and "stop" positions the master controller levers cannot be operated, and unless the master controller levers are in the "off" and "stop" positions the manual levers cannot be operated. Interlocking is also provided between both the manual field and reverse levers and the field and reverse levers of the master controller. Unless the field lever is in the "off" position, the reverse levers cannot be moved from one position to another. The field lever can, however, be moved with the reverse levers in either operating position or the "stop" position.

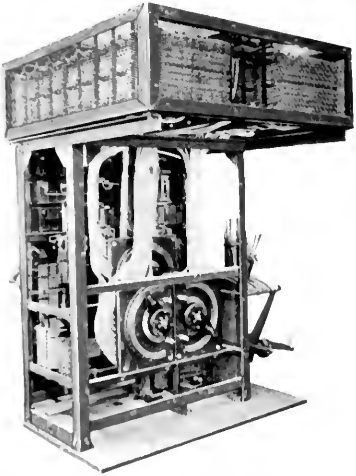


Fig. 2. Control Panel, Back View

Control Groups

The two control groups are very similar in construction consisting of structural iron frames in which the contactors are mounted. The reversing contactors are mounted in the alternating-current group. Five contactors are provided for reversing the phases of each motor. One of the five is closed in both ahead and astern operation while two more are closed for ahead operation and the other two for astern operation.

A-C. Control Group

The reversing contactors are all alike being air break contactors of the type developed for ship control work. These contactors are of large capacity and are designed for 2300-volt service. In the operation of the *Kamoi* equipment, the full load current is only 785 amperes and the contactors are not called upon to open the circuit at full voltage for the generator field contactors are opened before the reversing contactors.

Fig. 3 shows the alternating-current control group with the enclosing grille work removed and with the arc chute removed from one of the contactors. When the contactor is closed the main current is carried from the top terminal to the two cast fingers in contact with the top terminal block through the two sets of heavy braided copper shunts to the lower terminal. The two pairs of front tips of the contactor are in parallel with the back tips and carry their proportion of the current; as the two paths through the front tips are of higher resistance the current flowing is only a small part of the total current. As the rear contacts open the front tips are called upon to carry all of the current and as they open the blowout coils in the arc chute are cut into circuit and force the arc out through the chute until the circuit is ruptured. In normal operation a large solenoid, in lifting its armature, forces the contacts closed. In manual operation, rotation of the cam shaft causes the cams through operation against rollers on the armature, to close the contactors.

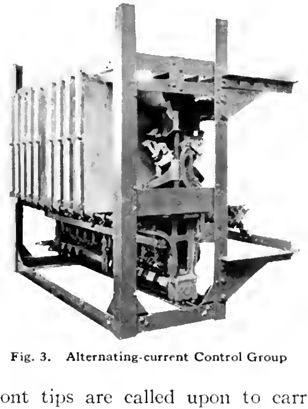


Fig. 3. Alternating-current Control Group

Mechanical interlocking between the contactors is provided which prevents single-phase operation due to the opening of one of the contactors. Two of the three contactors, necessary for operation either ahead or astern, cannot be closed without also closing the third. To prevent any contactor from staying closed, due to possible welding of contacts, a mechanical knock off is provided which through the rotation of the cam shaft forces open any contactor which might have stuck closed.

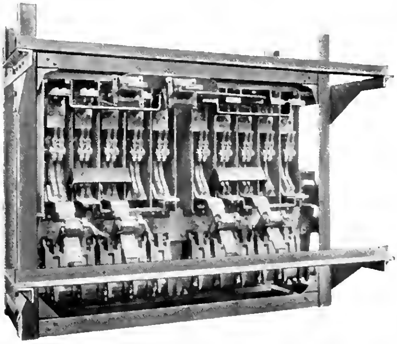


Fig. 4. Alternating-current Control Group, Back View

Fig. 4 shows the back view of the alternating-current control group with the enclosing screens removed.

D-C. Control Group

The four motor field contactors and the four generator field contactors are all mounted in one group; the direct-current group is very similar in construction to the group containing the reversing contactors. Figs. 5 and 6 show front and back views of this group. The contactors used to close and open the field circuits are rated at 450 amperes direct current and 250 volts. All of the contactors are provided with powerful magnetic blowouts which insure that, when the contact tips part, the arc between the contacts is ruptured.

The two motor field contactors for each motor are mechanically tied together and operate as one. They are not provided with discharge resistances for the voltage kick obtained when the circuit is broken is no greater than that which the motor fields are designed to stand during induction motor operation. The two contactors are mechanically tied together to prevent one from opening ahead of the other and thus allowing the kick from the motor field to be transmitted to the auxiliary apparatus or lights which might be connected to the same exciter which is furnishing the field current

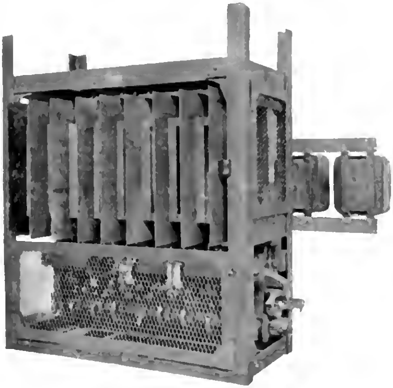


Fig. 5. Field Contactor Control Croup

One of the generator field contactors has a discharge contact so connected to the field circuit that when the contactor opens a discharge resistance is cut in across the generator field. The control is so arranged that this contactor opens ahead of the other contactors, and, therefore, resistance is always inserted across the generator field when the circuit is open.

Operation

The operation of the equipment is briefly as follows: The ship is ready to start with full steam pressure at the turbine and the turbine turning over at one-quarter speed (controlled by the governor). With the exciter running and with its voltage adjusted to 225 volts, with the necessary auxiliaries running, and the control and field switches closed on the d-c. switchboard; then when the order to start the ship ahead is given, the operator first places the reverse levers of the master controller ahead, then pulls the field lever to the first point. The movement of the two reverse levers ahead closes certain contactors in the a-c. group, connecting the two motors to the generator. The movement of the field lever to the first point energizes those field contactors in the d-c. group which put double voltage, 225 volts, across the generator field. The motors start as induction motors and come up to a speed corresponding to the generator speed. When a steady speed is obtained as indicated by the propeller speed indicators, the operator moves the field lever to the second point which closes the motor field contactors putting 113 volts across the motor field to pull the motors into synchronism with the generator.

After the motor line currents have dropped due to the motors being in step with the generators, the field lever is pulled to the running point. On this point, certain of the field contactors open and another closes which puts normal voltage (113 volts), across the generator field. The generator speed should now be increased through the operation of the turbine speed control switch until the desired motor speed is obtained.

To reverse either or both motors, the speed control switch should first be placed in the decrease position and the field lever thrown to the "off" position. Then the reverse lever or levers of the motor or motors to be reversed should be thrown to the reverse position and the field lever again pulled on in the same manner as when starting from rest. Operation through the use of the man-

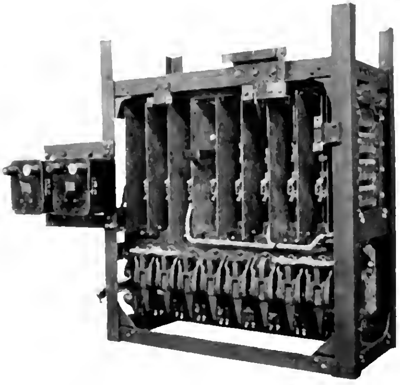


Fig. 6. Field Contactor Control Group, Back View

ual levers is exactly the same as described, except that the manual levers are used instead of the master controller levers.

After the ship has been started, with approximately normal field on motors and generators, the fields of the machines should be adjusted to give unity power-factor. To do this, the generator field rheostat may be disconnected from the rheostat handwheel and the motor fields decreased or increased together until the minimum reading is obtained on the motor ammeter or the minimum kilowatt reading is obtained on the generator wattmeter. The generator field rheostat should then be connected to the handwheel and the three fields adjusted in accordance with the excitation and generator field temperature indicators. The generator and motor field current should be adjusted so that the excitation is as low as possible without causing the motor to drop out of step. The generator field current should be kept low enough to keep its temperature below 300 deg. F. as shown by the generator field temperature indicator.

The instruments provided on the control panel make it possible for the operator to read the line current through both motors; the generator voltage; the kilowatt load on the generator; the motor and generator field currents; the turbine and propeller speeds; the generator field temperature; the degree of excitation on motors and generators; and the leakage to ground through the generator neutral.

Protective Relays

The protective relays provided are designed to protect the generator both against grounds and unbalanced loads. A current transformer in the generator neutral supplies current for actuating the ground relay. If the leakage to ground exceeds 7.5 amperes, the ground relay is tripped and, in tripping, energizes a tripping coil on the generator field contactor and causes it to open, thus taking voltage off the generator. If the load on the phases is unbalanced more than 50 per cent, the induced voltage in the generator field causes a current to be set up in a reactor which trips the balanced relay and opens the generator field in the same manner as when the ground relay is tripped.

Conclusion

The equipment is so mounted in the engine room that the operator is near the turbine and faces forward when facing the control panel. The control groups hang below the deck on which the control panel is mounted and the manual operating rods extend from the panel directly through the deck to the control groups.

The *Kamoi*, with its electrically propelled equipment and with the type of control described, can be made to respond immediately to any order which may be received from the bridge. The speed with which orders can be executed should make the ship very easy to handle under all conditions.

The Edisonian Year 1922

By C. L. CLARKE

CONSULTING ENGINEER, GENERAL ELECTRIC COMPANY

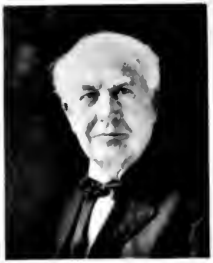
Mr. Charles L. Clarke—who was the first chief engineer of the parent Edison Electric Light Company, and of the local Edison Electric Illuminating Company of New York, where the Pearl Street station was erected—was asked to write a brief description of the Edison celebrations recently held in New York City. We feel sure that his account will be read with interest by our many subscribers.—EDITOR.

1882

THE year 1922 has borne special witness to the abounding public esteem, reflected from all walks in life, in which Edison, the great inventor, perfector and introducer of his inventions into practical use for the beneficial service of mankind, is held. For this is the year that noteworthily marks the 40th anniversary of the starting in commercial operation, on September 4, 1882, of his first electric lighting central station system with the central station at 257 Pearl Street, New York City, which was so comprehensively complete and perfect in all essential details that its operation was successful from the very first. From that day the bringing of the incandescent electric light into the home, the office and the shop, and eventually into the street, began.

The carbon filament lamp, possessing the fundamental features of high resistance and moderate illuminating power combined with economy, which survive in the lamps in use today, had been invented by Edison on October 21, 1879, and he had made the other inventions essential for an electric lighting system to compete successfully with gas lighting. But to the people they were still mainly on paper or in an experimental stage in the laboratory until the starting of the Pearl Street station brought them to fruition in the public eye.

The awakening was sudden and great—so sudden that only a few years later the lamp was in use by the many thousands, and so great that today they are to be counted in the many millions. An illuminating account, in this commemorative year, of the beginning and growth of the Edison lighting system with statistics has been published by the National Electric Light Association in Bulletin No. 9, IX, September, 1922, pages 515 to 536. And the end is not only not in sight, but apparently reaches beyond the boundary of reasonable human imagination and prophecy.



1922

For all this the people are grateful and would not be denied the privilege of manifesting their appreciation of the debt they owe to Edison or let the year pass by without some public recognition of this feeling, which formulated itself into a reception and banquet in his honor at The Commodore under the auspices of The New York Edison Company on the evening of September 11th "in commemoration of forty years of Edison service in the City of New York." Men of public affairs, leaders in law, finance, commerce, public utilities and the industries, associates of Edison in pioneer days and other guests assembled to the number of six hundred. The key and freedom of the City of New York were presented to him, and addresses were delivered recounting his achievements and the resulting good to the world. Edison's reply to the assemblage, and through it to all men, so reflects the impress of his character—truly modest, with trustful reliance upon the helpful goodwill of others—that his words, here quoted, should be read, and their import may well be remembered and taken to heart.

"Mr. President Hulbert: I thank you sincerely for your courteous presentation of the freedom of the city, and will you kindly convey to his honor, Mayor Hylan, and to the honorable board of aldermen of the city of New York, my deep-felt appreciation of the distinguished honor conferred on me, of which I am very proud.

"This commemorative celebration has a deep personal significance to me, for the Pearl Street station was the greatest adventure of my life. It was akin to venturing on an uncharted sea. No precedents were available. I felt the sense of a great responsibility, for unknown things might happen on turning a mighty power loose under the streets and in the buildings of lower New York. However, I kept my own counsel.

"Thanks to the faithful co-operation of my unfailing companions, the Pearl Street station was carried promptly to the point of successful operation. The later development of the industry is a matter of history.

"As I look around this assemblage my thoughts run backward to those days; although Father Time has laid his silvery fingers upon us the memory of our early struggles at Pearl Street affords a pleasant retrospect. It is natural as I sit tonight surrounded by so many of my old friends and fellow workers, there should be mingled with my joy something of sadness as I think of the men whose companionship we no longer share.

"If there be some addition through my work to the resources of human welfare, that benefit has accrued largely through my good fortune in being favored with the devotion of associates willing to throw their all into the melting pot. I have never ceased being grateful to the Edison men whose friendship I have enjoyed ever since the morning fifty-three years ago when I landed here from the Boston boat.

"To the wider circle of friends I must express the fullest appreciation of the encouragement that has enabled me to perfect various inventions, and is notably embodied in the splendid public utilities bearing my name of which The New York Edison Company is typical. I would think more highly, perhaps, of the little I have done if I did not feel it to be only a promise of what lies before. There is still much to be done in the promotion of human happiness and comfort."

Such was the Great Inventor's message of thanks for helpfulness from others in the past coupled with the inspiring injunction to all to keep on in the work, "to be done in the promotion of human happiness and comfort."

In addition to the commemorative celebration of September 11th, and especially that the people as a whole might in a worthy sense participate in doing honor to Edison on this anniversary year and also gain a better understanding of his work as well as that of others creatively prominent early in our electrical era, a Museum of Edisonia and Historical Exhibit of Electric Lighting, under the auspices of the Association of Edison Illuminating Companies and the Edison Pioneers, was opened to the public from October 2nd to the 21st, at the Grand Central Palace, New York City.

Here was exhibited great collections of electric lamps of all sorts arranged in historical order, early electric generators and motors, measuring and indicating instruments, models of central stations, etc., connecting the names of such early inventors as Elihu Thomson, Brush, Stanley, Sprague, Wood and others with that of Edison in the field of extending the use of electricity for light and power. The American Institute of Electrical Engineers, universities of learning, corporations and individuals contributed from their collections to make this a great exhibition which was visited by many thousands and commanded at once their earnest and informing interest. Among the most prominent exhibits was Edison's "Jumbo" generator No. 9,* which was the first generator to be started in commercial operation at the Pearl Street Station and is the sole survivor of its kind.

Thus has this Edisonian year greatly been celebrated. Edison's ways have been the ways of peace; his achievements have redounded to the happiness of all peoples. Amid the confusing aftermath of the World War encouragement for future good may still be sought in such works as those of Edison, symbolizing, as they do, that master appeal for a better civilization by our great poet Longfellow:

Were half the power, that fills the world with terror,
Were half the wealth, bestowed on camps and courts,
Given to redeem the human mind from error,
There were no need of arsenals and forts.

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* The "Jumbo" generators at the Pearl Street Station were originally driven by Porter-Allen engines, but defective speed regulation when the generators were connected in multiple with the busbars soon led to the substitution of Armington & Sims engines in their place. For this reason we find the exhibited "Jumbo" equipped with the later and not with the original engine.

The Electrical Equipment of Mill No. 8 of the Riverside Division of the Riverside and Dan River Cotton Mills

By George W. Robertson

General Superintendent, Riverside and Dan River Cotton Mills

As the equipment of these cotton mills is mostly standard apparatus, the author tells the greater part of the story in the illustrations.—Editor.

This mill which is located on the Dan River is of particular interest to both cotton mill and electrical engineers, not only because it is completely electrified and contains what is probably the greatest number of looms ever installed under one roof but also because it concentrates in one building the long-chain dyeing, beaming, slashing, web drawing, tying, weaving, and wet and dry finishing processes for a group of mills, on both sides of the river, which are now devoted solely to the preparatory processes for the new mill.

Fig. 1. Mill No. 8 Riverside Division, Riverside and Dan River Cotton Mills, Danville, Va.

The Riverside mills equipment includes more than 144,000 spindles and No. 8 Mill contains 5040 looms, the product consisting of chambreys, cheviots, drills, ginghams and plaids. The new four-story building, see Fig. 1, is 810 ft. long and 144 ft. wide, each floor consisting of twenty-nine full bays and two smaller end bays, the three upper floors being devoted entirely to weaving.

On the second floor there are 1728 Draper looms arranged in rows across the building, see Fig. 2, each individually driven by a ½-h.p., 1800-r.p.m., 550-volt, 3-phase, 60-cycle loom motor with individual motor control. On the third floor there are 1152 Draper and 540 Crompton and Knowles looms while on the fourth floor there are 1620 Crompton and Knowles looms, see Fig. 3, arranged lengthwise of the building. The arrangement of the looms and their control is very compact, see Fig. 4, with wide passage ways at the sides of the floors to facilitate the handling of materials.

These loom motors are totally enclosed and are equipped with waste packed bearings, indestructible type rotor windings, specially insulated field coils and a tapered shaft extension on which an oil tempered steel pinion is secured by a nut and lock washer. The motor is mounted on the loom bracket, see Fig. 5, and direct gear drive is used.

The feeder circuits for the motors are installed on the ceiling of the floor below and brought up through the floor to a fuse box, provided with a three-pole snap switch, and through flexible metallic conduit to the motor terminals.

For current distribution the motor-driven looms are divided into nine sections, each of which has an independent main feeder controlled by an oil switch in the power station. These sections are subdivided in the mill into groups of not more than 72 looms, each group being fused in a wall cabinet in the weave room. There are no switches in these

Fig. 2. 1728 Draper Looms Individually Driven by ½-h.p. Loom Motors

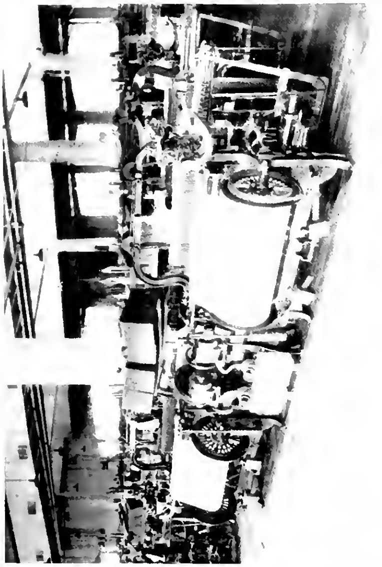

Fig. 3. 1620 Crompton and Knowles Looms Individually Driven by ½-h.p. Loom Motors

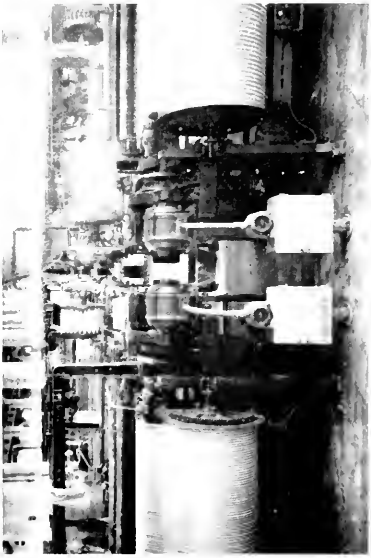

Fig. 4. Arrangement of Draper Looms showing the Close Spacing of the Motor Drives

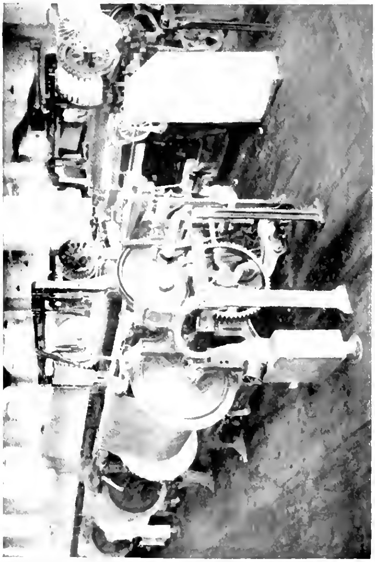

Fig. 5. ½-h.p., 1800-r.p.m., 550-volt Loom Motor with Snap Switch Control and Fuse Box

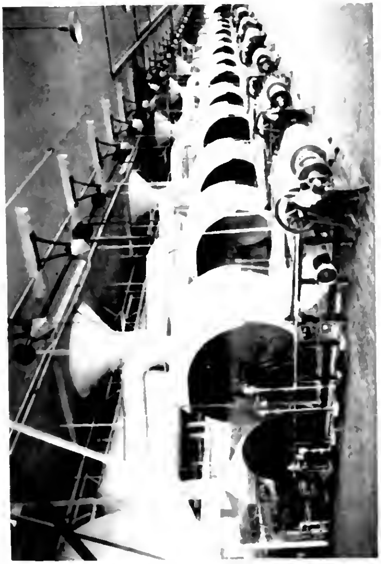

Fig. 6. 18 Slashers Driven in Two Groups by 60 and 30-h.p. Motors Belted to Counter Shafts

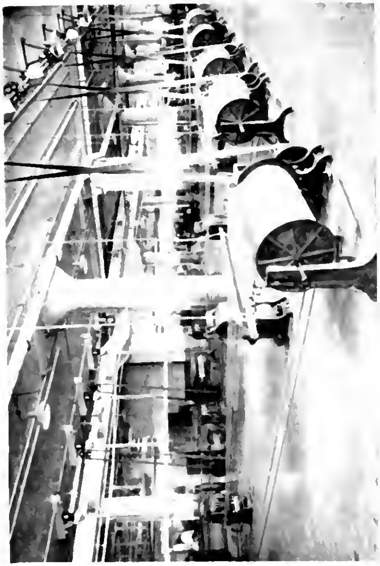

Fig. 7. Ten 56-in. Beamer Frames Group Driven by 30-h.p. Motor

Fig. 8. Steam Power Station with two 3000-kw., one 1500-kw. and one 1250-kw. 3600-r.p.m., 600-volt, 3-phase, 60-cycle Turbine Generators

Fig. 9. Arrangement of Switchboard and Oil Circuit Breakers in Power Station

cabinets, the operating control of the separate looms being effected by means of the individual snap switches.

The slasher room contains a battery of eighteen slashers, see Fig. 6, driven in two groups by motors mounted on the ceiling and belted to the counter shafts, and ten 56-inch beamer frames, see Fig. 7, which are also group driven. Back of the group of slashers, individually motor-driven warp tying-in and drawing-in machines are installed.

Fig. 10. Arrangement of 14 Feeder Lines Carried on Roof Beams of Covered Bridge from the Power Station to Mill No. 8

On the same floor is the finishing room where the close control of the varying speeds required of some of the machines is secured by the use of 230-volt direct-current motors; current for these being supplied by means of two 75-kw. motor-generator sets. All the alternating-current motors operate on 550-volt circuits.

There are two power stations, one a hydro-electric station with one 200-kw. and one 350-kw. horizontal shaft waterwheel generators operating at 300-r.p.m. under a $10\frac{1}{2}$-ft. head. The other is a steam station equipped with two 3000-kw., one 1500-kw. and one 1250-kw. turbine generators, see Fig. 8, operating at 3600 r.p.m. Two exciter sets are used, a 25-kw. turbine-generator set and a 50-kw. motor-generator set.

Both power stations generate current at 600 volts, 3-phase, 60 cycles and the control is centered in the main switchboard, see Fig. 9, in the steam station.

Spanning the river between Mill No. 8 and the steam power station is a steel and concrete bridge 980 ft. long, over which section beams are carried to the new mill and the finished cloth transported back to the shipping point, by means of storage battery trucks with trailers.

Fig. 11. Arrangement of Compensator with Relays for Slasher Group Drive Control

The bridge also carries all heating and manufacturing steam lines to the mills across the river from the power station, and fourteen feeder circuits, see Fig. 10, in metallic conduit for both power and lighting.

Feeder distribution in the mill is also accomplished with metallic conduit, see Fig. 11, with safety switches and fuses at all control points. In all more than 65 miles of metallic conduit have been installed.

The lighting supply is distributed at 115 volts from three single-phase transformers located at the mill end of the bridge and about 2700 Mazda lamps with reflectors are used.

The Possibilities of Electrical Precipitation in the Chloride Volatilization Process*

By Thomas Varley

Metallurgist and Superintendent United States Bureau of Mines Experiment Station,
Salt Lake City, Utah

and by H. W. Clark

Formerly Electro-metallurgist United States Bureau of Mines Experiment Station,
Salt Lake City, Utah

We have already described the Cottrell process of electrical precipitation (Nov., 1921) and a number of its applications, particularly those with reference to the precipitation of fumes from furnaces for treating tin drosses (Dec., 1921) and dust from cement mills (Feb., 1922), and the cleaning of blast furnace gases (July, 1922). In the following article the authors describe the possibilities of electrical precipitation in the chloride volatilization process. In the event that the electrical precipitator for this service proves a commercial success, and from the tests described this seems probable, the result will be far reaching as extensive changes from what is now considered standard practice may be looked for.—Editor.

The History of the Volatilization Process

In ore dressing hydro-metallurgy and pyrometallurgy, advantage is taken of certain characteristic features or performances of various minerals and their behavior in both mechanical and chemical treatments, as a means of isolating one or more minerals from waste materials. The volatilization of metals as chlorides and their recovery as fume is a natural development from chloridizing roasting in which salt has been largely used as a chemical reagent.

Chlorine as a metallurgical reagen for extracting metals from their ores has been used almost exclusively for the recovery of gold and silver. It was during the treatment of ores of this character, which contained probably small amounts of copper and lead, that notice was made of the fact that certain percentages of the minerals in the ores were lost. At first there was no explanation of why this loss occurred, but several investigators fully proved that it was due to the minerals being volatilized.

Volatilization may be defined as the art of separating or isolating certain metals from worthless gangue by means of halogen agents, these agents usually being salt and calcium chloride. Advantage is taken of the fact that in the process of heat treatment the chlorine is liberated from the halogen salts and a concentrated atmosphere of chlorine vapors are passed over the roasted charge of ore at elevated temperatures. Suffice to say that, under proper conditions, the volatilized metals pass off through the furnace into properly devised chambers, and are condensed by some suitable means, and the metal value subsequently recovered. The affinity of various metals for chlorine is well known and the following re-action readily takes place. Many physical chemists have studied the process and find that certain metals perform much differently than do others. Croasdale states that the chemical formula would be probably as follows where sulphur was either present in the ore or added with the charge:

$$Cu\,S + 2\,Na\,Cl + 2O_2 = Cu\,Cl_2 + Na_2\,SO_4$$

$$Pb\,S + 2\,Na\,Cl + 2O_2 = Pb\,Cl_2 + Na_2\,SO_4$$

In 1903 Stuart Croasdale, one of the pioneer investigators of this process, together with Edwin C. Pohle, took out U. S. Patent No. 74,712, which was the first patent ever granted in which the complete volatilization of metals was used as the major part of a process. A company was organized by Mr. Croasdale and his associates, and plants were operated both in New Jersey and Denver, Colorado.

Fume Recovery

The chemical re-actions and the pyrometallurgy of the process seemed to be entirely satisfactory. The principal difficulty encountered was the recovery of the chloride fumes. Various types of devices were tried, and perhaps the best description of the difficulties encountered is furnished by Mr. Croasdale as follows:

> "Since the metals volatilized as chlorides were recognized as metallurgical losses, and as such were kept at a minimum by roasting at low temperatures, no special apparatus was devised for their recovery beyond the ordinary dust chambers. These were considered essential by all metallurgists when roasting fine ores in the White-Howell or Stetefeldt type of furnaces. In some instances it was recommended that steam be injected into the dust chambers, which, on condensing in the cooler parts of the flue, would carry down with it the solid matter from the furnace gases. Little or no distinction was made between flue dust and fume.

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* Written for the General Electric Review and published by permission of the Director of the United States Bureau of Mines.

"It is true that water sprays and other forms of water condensation had been recommended, but the only place that I know where this method reached a commercial application was at the Holden Lixiviation Works, Aspen, Colorado. Here we had a volatilization loss of about 10 per cent of the silver as chloride from the Stetefeldt furnace. A large chamber was built beyond the usual dust chambers, and this was filled with a checker work of wooden fence pickets which were sprayed with water. Considerable silver was saved in this manner but the recovery was not complete.

"Bags of textile material had already been used for the recovery of zinc oxide. This method had been recently introduced for the recovery of fumes from lead blast furnaces, and was recommended by Chanute for the recovery of metallic chloride fumes. It was generally recognized, however, that bags were impracticable for the collection of metallic values from the corrosive acid gases resulting from either oxidizing or chloridizing roasting operations.

"In connection with fume recovery, it is interesting to note* a forerunner of the Cottrell precipitator, patented by A. O. Walker, of England, and which is described as follows:

> " 'He collects the fine particles of metals suspended in the fumes by means of a discharge of high potential electricity from metal points or edges, or other projections, situate in the flue passage, chamber or other receptacle, and so placed that the current of air or gas containing the finely divided material or metallic vapour is carried or passes in close proximity to the discharging points. The discharge from the points electrifies the air or gas and the charged air or gas then acts on the finely divided matter, causing it to cohere, condense and deposit.'

"This process is said to have worked very efficiently but evidently it never advanced beyond the experimental stage.

"For the collection of fumes we naturally installed bags first. Both cotton and woolen fabrics soon disintegrated from the corrosive action of the acids in the fumes, and this system had to be abandoned temporarily. We then tried water condensation in every conceivable form. Towers filled with gravel and heavily sprayed with water were useless, even when the gravel was reduced almost to the fineness of sand, and we reached the capacity of our fans to force the furnace gases through the towers. The same was true with filters of textile fabrics sprayed with water. The copper chloride fumes were particularly difficult to collect.

"Finally, we made a tower in which we placed a number of superimposed horizontal burlap filters. These filters were placed about one foot apart and water was sprayed on top of each filter. A positive blower of the Root type was placed in the flue system ahead of the condensing tower. This blower was lined with lead to preserve it from the corrosive action of the fumes. When in operation, the gases were forced through the lower filter in the condensing tower. In doing so a certain amount of water was held on top of the filter and the gases formed a bubble at each mesh in the burlap. Each bubble collided with its neighbors so that the gases not only passed through the wet filter but through two or three inches of water foam on top of the filter. Water gauges were placed on the side of the tower so that the depth of water held on top of each filter could be observed and regulated. While it was possible to hold a depth of eight to ten inches of water on top of each filter, a depth of two inches was found to be more than sufficient since more agitation was produced.

"After passing through the first filter and the water on top of it, the gases reunited to pass through the second filter and the water on top of that, in the manner just described, and so on through the tower.

"It took seven or eight of these filters to collect all of the copper chloride fumes. We had the satisfaction of stopping the fumes eventually but our apparatus became too difficult to manage and was impracticable.

"By this time our funds were exhausted and we were forced to cease operations, but before giving up entirely we decided to try some more experiments with textile fabrics for the collection of fumes. We built a small gas-fired furnace and connected it with a woolen bag. The fumes, before entering the bag, were so thoroughly cooled in a long flue that practically all of the corrosive sulphuric acid was condensed and the bag then recovered the fumes successfully without apparent injury. We were never able to continue this demonstration on a large scale and over a long period of time, so it is yet undetermined how long the bags would give service."

The Cottrell Electrical Precipitator

The advent of the Cottrell electric precipitator about 1914, which was first installed at some of the important smelting plants in the western states, revived the idea of volatilization. Inasmuch as the precipitator worked very well on blast furnace gases, it was thought that it could be successfully used as a means of precipitating the volatilized chloride fumes evolved in the process mentioned. Such being the case, about 1918 the United States Bureau of Mines Inter-Mountain Experiment Station, in co-operation with the Department of Metallurgical Research, University of Utah, installed what was then considered a preliminary set of Cottrell treaters.

It was clearly demonstrated that this means of precipitation was successful, so that early in 1919 the semi-commercial installation, which is described later in this article, was installed.

Numerous types of ores of the oxidized and semi-oxidized variety have been experimented with in amounts varying from a few pounds in the small scale experiments to several tons in the larger experimental plant, and these have all indicated that the metal values in these types of ores could be readily recovered by this method, whereas by water concentration and flotation treatment it was impossible to make satisfactory recoveries of the metal content.

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* Eissler's Metallurgy of Gold (Ed. 1895).

Semi-commercial Laboratory Installation of Cottrell Precipitator

The results obtained in the small scale laboratory tests were so alluring that the Bureau officials, and the Director of the School of Mines and Engineering, University of Utah, decided it would be worth while to build a semi-commercial size plant to demonstrate further the commercial possibilities of the process. Through the efforts of Thos. Varley, Metallurgist in charge of the station, the following described plant was built in the old power house of the University early in 1919.

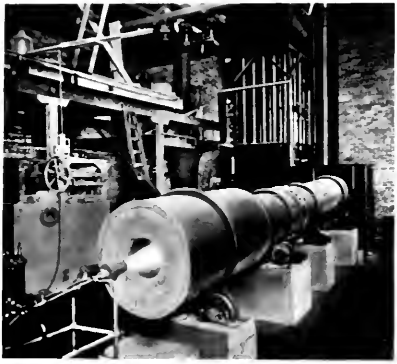

Fig. 1. Volatilization Kiln (cement type) Used in Large Scale Volatilization Tests

The furnace is a horizontal cylindrical kiln similar to those used in cement mill practice and is illustrated in Fig. 1. The kiln installed is 20 ft. long with an inside diameter of 13 in. for the last 15 ft., and 21 in. for the first 5 ft. from the fire end. A four-inch nose ring is placed at the end to give a deeper bed of ore and hold the ore in the hottest portion of the kiln for a longer time. The kiln is fired directly in the open end by means of a high-pressure Hauck oil burner using 34 deg. Baumé gas oil. It was also fired successfully on a short test with powdered coal, but in all probability this would require a combustion chamber.

The ore is fed into the cold end of the furnace by means of a water-cooled worm feeder discharging 3 ft. from the end, giving the ore a travel through the kiln of about 17 ft. The driving mechanism of the kiln is such that any desired speed can be obtained, thus making it possible to keep the ore in the kiln as long as is desirable. The temperature is regulated by control of the burner.

The cold end of the kiln extends into a sheet-iron cooling and settling chamber where the heavier particles carried from the kiln are deposited. From this settling chamber the gases pass through a short horizontal flue into a second settling and distributing chamber, where the greater part of the remaining dust particles are given up without the gases losing any great amount of the metal chloride fume. From here the gases pass up through a flue and discharge down through the Cottrell precipitator.

The precipitator is constructed in two units, each with a capacity of 1500 cu. ft. of gas per minute, making a total capacity of 3000 cu. ft. per minute. The units are 17½ ft. high and 1½ ft. square, and their arrangement is shown in Fig. 2.

Each unit receives the gases from a 15-in. pipe into the top chamber of the treater. The gases pass from the top to the bottom chamber through 20 tubes each 8 ft. long and 6 in. in diameter. The gases pass from the bottom chamber into the stack through an 18-in. exhaust fan. The connecting pipes are arranged with a slide damper so either one or both treaters can be used at any time.

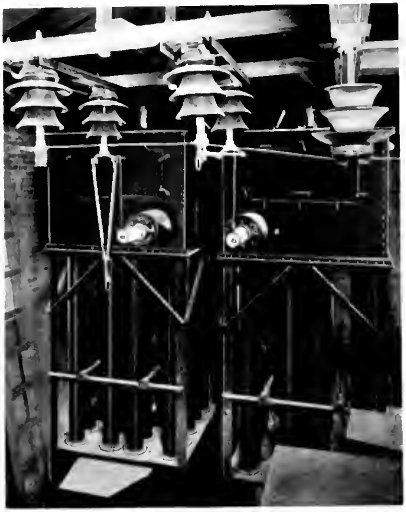

Fig. 2. Cottrell Precipitators Used in Large Scale Tests

The fume is removed from the bottom hopper through a spout at the bottom arranged with a slide gate. Hand-operated mechanical knockers are provided for both the positive and negative electrodes. When the electrodes are knocked the fume falls into the hopper below.

The discharge electrodes are made of No. 16 Chromel wire and are hung in the center of the tubes. The wires are kept taut by 20-lb. weights suspended on the lower ends as shown in Fig. 3. A metallic grid, which is securely anchored to two porcelain bushings, is placed on the suspended wires at the bottom to prevent the swinging of the electrodes. The grid is adjustable so each electrode can be centered in its individual tube.

The precipitation transformer is rated at 5 kv-a., 220-440/100,000 volts. The rectifier disk is 30 in. in diameter and is driven by a 3-h.p. synchronous-induction motor. The collector shoes of the rectifier are adjustable so that both the portion of the wave rectified and the position of this portion of the wave can be varied at the operator's will. The transformer and rectifier are shown in Fig. 5.

The control switchboard is arranged so the potential applied to the treaters can be varied from zero to 100,000 volts. The controlling is done on the primary of the precipitation transformer by means of an autotransformer and a rheostat. A milliammeter is placed in the high-potential line between the rectifier and precipitator to measure the current supplied to the precipitator. This meter also indicates whether the correct polarity is applied to the treater.

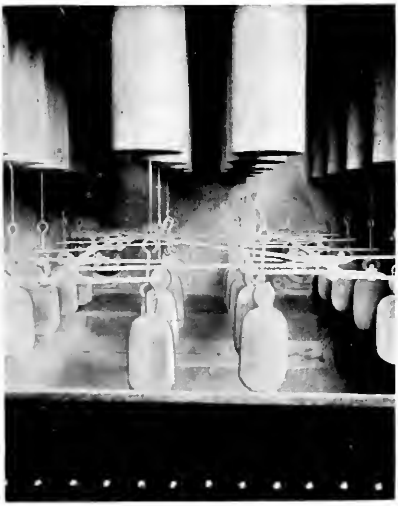

Fig. 3. Bottom of Precipitator Tubes, Showing Discharge Electrodes, Weights, and Steadying Grids

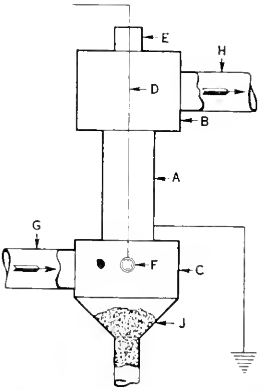

Fig. 4. Diagrammatic Elevation of a Cottrell Electrical Precipitator Showing the Fundamental Parts

Operation of the Cottrell Precipitator

The operation of the Cottrell precipitator is illustrated schematically in Fig. 4. The pipe *A*, or collecting electrode, terminates in headers *B* and *C*. The discharge electrode *D* is suspended axially in the pipe, is insulated from it at *E*, and is held taut by weight *F*. Gases enter from flue *G*, pass through pipe *A*, and leave through the outlet *H*. When the current is on and the precipitator is in operation, the charged particles are deposited on electrode *A*. The deposited particles are dislodged from the electrodes by means of rapping devices which deliver a sharp blow on the pipe, and the collected material falls into the lower header or hopper *J*. If of a liquid nature, the material may run down the surface of the electrodes into a sump or other suitable receiver.

Tests of Cottrell Treater

The volume of gases and the weight of solid matter per cubic foot carried by them is measured before and after passage through the treater. From this the efficiency of the treater is calculated.

The volume of gases is measured by means of pitot tubes in both the supply and discharge pipes. The weight of solid matter per cubic foot is determined by means of small extraction thimbles. A small quantity of the gas is drawn from the flue through this thimble which is kept heated above the boiling point of water, so that it will not absorb moisture from the gases and become clogged up quickly. Care is taken that the sampling tube is near the point of average gas concentration, and that the velocity of gases entering the sample tube is the same as that of the gases passing the sample tube. The volume of gas passing through the thimble is measured, and the solid material collected, weighed, and the concentration of solid matter calculated.

Test runs with both copper and lead-silver fumes in all cases indicated a complete clearance or efficiency of 99 per cent. This efficiency is several per cent higher than is usually obtained in commercial treaters. This is probably due to the more careful adjustment of discharge electrodes with respect to the tubes, and to more sensitive voltage regulation keeping it as near the critical point as possible.

Laboratory Tests

Tests of the Cottrell precipitator indicated that the collection of fumes from all ores treated by this method was satisfactory. Quantitative efficiency measurements were made of the precipitator when operating on lead-silver, and copper fumes. From tests on ores containing small amounts of gold, platinum, and mercury fume, assays indicated practically a complete precipitation of these metals. In one case where no platinum was detected in the crude ore, an appreciable amount was detected in the fume. This proves that not only the base metal fumes but also the rarer metals can be collected by the Cottrell precipitator. From the results of quantitative tests of the precipitator at this laboratory sufficient data can be obtained for the design of commercial plants.

The velocity of the gases permissible in the treater to obtain a reasonably high precipitation efficiency can be determined for each particular ore. The highest concentration of fume in the gases which can possibly be obtained is desirable. The nature of the fume and its concentration of say two, three, or four grains of solid matter per cubic foot should be quite definitely known in the design of a plant. If only two grains per cubic foot can be carried, the precipitator will necessarily be twice as large as if four grains per cubic foot is carried—if the plant is to treat the same tonnage of ore and efficiently recover the same tonnage of fume.

Plant at Salmon City, Idaho

The Pope Shenon plant at Salmon City, Idaho, was built with a crushing capacity of 200 tons daily. The volatilization equipment installed was not designed to treat this tonnage, but was of sufficient size to obtain data for the design of a plant capable of handling this amount.

The rotary kiln installed is 26 ft. long and has an internal diameter of about 3 ft., see Fig. 6. It is lined with fire brick laid flatwise, with an inch of Sil-o-cel between the brick and shell. The kiln slopes nine inches in its length toward the discharge end. It can be rotated at various speeds depending on the tonnage treated, temperature, etc.

The kiln is fired by fuel oil through a burner of the type developed by the Riverside Portland Cement Co., at Riverside, Cal. Air for the burner is supplied at about two pounds pressure by a positive pressure blower.

The gases on leaving the kiln pass into a reinforced concrete dust chamber which is intended to settle out the dust carried from the kiln. Two inverted U-tubes are mounted on top to assist in cooling the gases before they reach the precipitator. The gases pass through the U-tubes back into a separate section of the dust chamber and then into the treater proper.

The precipitator is of the vertical-pipe updraft type. The precipitating tubes are 36 in number and are 8 in. in diameter and 16 ft. long. They are made of No. 10 gauge iron with lap welded seams. The discharge electrodes are of No. 12 iron wire. These are held in place by the usual centering devices, and are held taut by 40-lb. weights hung on the bottom end of the wires. The usual arrangements for knocking the discharge and collecting electrodes are provided.

The precipitator was not designed for this plant, but was purchased from another mining company before it was installed. It was designed for a capacity of 6000 cu. ft. of gas per minute, with a tube velocity of 8 ft. per second. It so happened that the furnace can operate on this amount of gas without excessive velocities.

The direct current is furnished by a modern precipitator transformer, rectifier, and switchboard. The transformer is rated 220/75,000 volts, 10 kv-a.

The rectifier is of a standard type driven by a 3-h.p. synchronous-induction motor.

Fig. 5. Transformer and Rectifier Used to Supply Current for Large Scale Laboratory Tests

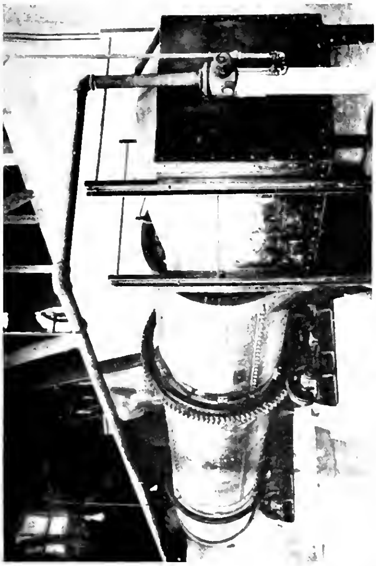

Fig. 6. Volatilization Kiln at a Commercial Size Copper Plant

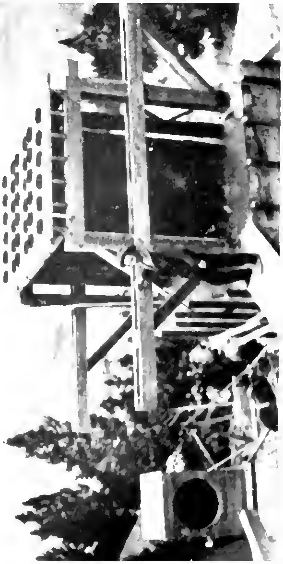

Fig. 7. Cottrell Precipitator Under Construction at a Commercial Size Copper Plant

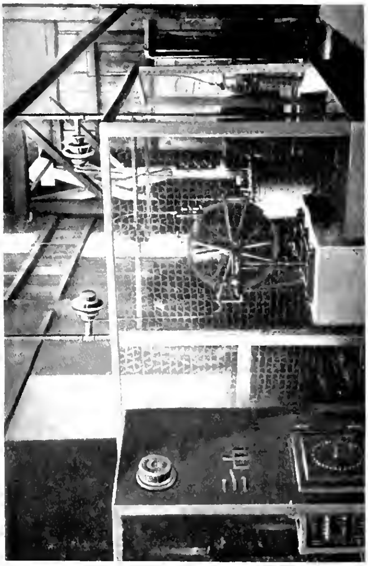

Fig. 8. Electrical Precipitator Equipment at a Commercial Size Copper Plant

The rectifier is adjustable as to the position of the arms and the distance between the two arms of each pair. The control gearing is so arranged that the electrode positions can be adjusted while the rectifier is in operation.

The transformer and rectifier is controlled by a switchboard of standard design. It contains switches for controlling the primary circuit of the transformer, voltage regulator, series resistance, rectifier motor, and a circuit breaker to interrupt the power supply in case of short circuits in the high-tension system.

The high-tension voltage is regulated by a combination of series resistance and potential regulator. The stabilizing resistance provided will give a total drop of five per cent in eight steps. The actual regulation is done with the motor-driven hand-controlled regulator. The regulator is of a special type having a range of 25 per cent variation for both buck and boost. It is equipped with a high-speed motor so that changes in voltage, no matter how large, can be made almost instantly.

A sphere-gap voltmeter is provided for the measurement of the high voltage. This is of standard design with micrometer adjustment of the spheres.

A milliammeter is installed on the high-tension direct-current line between the rectifier and the treaters. This serves several purposes: first, to indicate the amount of current flowing to the treaters; second, to indicate proper polarity of the treater current; and third, as an indicator of trouble in the precipitator proper. Disconnecting switches are placed so as to physically disconnect the treater from the high-tension circuit when it is desired to work in the treater. This is an extra precaution in the interest of "Safety First," as the rectifier outfit is shut down at such a time.

Plant Operations

The ore treated carries from 5 to 15 per cent copper in the form of carbonates and sulphides. The long distance from smelters and consequently high freight rates makes it possible to ship only the very highest grade ore at a profit. Laboratory experiments as described in the foregoing had indicated that this ore could be treated commercially by this process. The management decided to erect a plant for a commercial trial.

Tests were carried out at this plant during the summer of 1920 to demonstrate the process on a commercial scale. The tests were made by Dr. R. H. Bradford of the Department of Metallurgy of the University of Utah, assisted part of the time by H. W. Clark, formerly of the U. S. Bureau of Mines, R. A. Perry and others.

It was first necessary to adjust the operation of the kiln so that a tailing with sufficiently low copper content could be obtained. After several weeks' work the kiln speed, rate of feed to the kiln, flame conditions, etc., were so adjusted that 35 tons per day assaying 6 per cent copper could be treated in the kiln with a tailing of less than 0.5 per cent copper.

The fume of all these runs was caught by the electrical precipitator with visual clearance at all times. When these tests were run no equipment for measuring the solid matter in the gases was available, so that quantitative tests of the amount of solids carried by the discharge gases could not be made. Past experience indicated that when complete visual clearance is obtained more than 95 per cent of the solids are removed by the treater. The weight of fume collected checked very closely with the amount driven off from the ore indicating that very little was lost. The grade of fume was also very satisfactory, carrying nearly 50 per cent copper, and only a very small amount of insoluble matter. The fume collected was stored for future reduction, except quantities which were reduced in a small oil-fired foundry furnace. In the future the reduction will be made in a small reverberatory furnace which is now under construction.

The reductions produce copper bullion, and calcium chloride as a slag. The latter is re-used as a chloridizing agent in the kiln. Hence the only chlorine needed in the process is that required to make up for unavoidable losses. The tests indicated that 50 to 75 per cent of the chlorine can be recovered in the slag. The complete tests demonstrate that 90 per cent of the metal values in the ore can be saved by the use of this process. With the enormous deposits of ores in all parts of the country, amenable to this process, it should be only a matter of time until there are larger numbers of these plants in operation.

General Considerations

If the chloride volatilization process proves to be a commercial success, the future developments for electric precipitators for service at such plants will be interesting. The fume collecting device will be the important feature at a plant of this kind and probably will vie with its already indispensable use at smelting plants and cement works. At these plants as a collecting device, its use was primarily to stop the pollution of the atmosphere in the vicinity of plants, but it is usually a fact that the value of the products recovered pays handsomely on the money invested in the equipment.

In a smelting plant or cement works, the value of the products recovered in the treaters is only a small portion of the total value of the products made by the plant, while at a plant treating ore by the chloride volatilization process the whole product would be recovered in the treaters. The primary use of the precipitators here is to recover the greatest value possible from the gases heavily laden with valuable metals.

This will necessitate especially devised treaters considerably larger than those used in present practice. These changes may be in the arrangement of electrodes, collecting hoppers, gas passages, materials used for construction, and location with respect to the remainder of the plant in order to make the cost per unit capacity less than is now the case.

Probably even more important than the reduction of cost per unit capacity is the increase of efficiency of the precipitators for use in connection with the recovery of chloride fumes. This is due to the enormous value of the material collected. For instance, at a plant treating 500 tons of 5 to 6 per cent copper ore per day, the treaters will collect the equivalent of 50,000 lb. of copper, worth, at 20 cents per pound, $10,000. An increase in efficiency of one per cent would mean a saving of an additional amount of copper worth $100, which for the year would mean a saving of $36,500. This saving per year would justify an increased cost of approximately $200,000 to effect the increase of one per cent in the efficiency of the precipitator. This fact will affect the design of treaters for this service and it is probable that higher efficiencies will be obtained than are now thought justifiable for the present uses. Thus it will be seen that gold and silver ores would probably have to be even more carefully handled.

Lower voltages and closer electrode spacing may be one of the developments. This tendency may result in the discarding of the pipe type treater and the substitution of the plate type with horizontal gas passages, and more stable electrode systems will likely be used. This may include more rigid suspension devices for the discharge electrode and the substitution of rigid rods or pipes for the wires now used. This will make it possible to operate the treater at a point nearer the critical voltage than can be done with suspended wires which are subject to swinging and vibration. This feature is another which will tend to promote the use of the plate type treater as rigid discharge electrodes made of pipe are very readily adaptable and are absolutely free from the vibration experienced with stretched wire electrodes.

Changes in the interest of higher efficiency will not be confined to treater design only, but will affect the design of electrical apparatus for this service. The electrical rectifier which will enable the treater to operate at a point nearer the critical voltage will undoubtedly be used. The kenotron rectifier has possibilities in this direction. From a theoretical standpoint it is possible with a rectifier of this type, due to the smoother form of the rectified wave, to more closely approach the maximum voltage value with the average voltage than is possible with the mechanical rectifier. An increased cost of installation and operation of a kenotron will no doubt be justified for service in the recovery of chloride fumes if by its use the efficiency of the precipitator can be increased.

In conclusion it may be said that the Cottrell precipitator has immense possibilities in connection with the development of the chloride volatilization process of metal recovery, and its development for this service will no doubt result in extensive changes from what is now considered standard practice.

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.

Corona

Corona Voltmeter.
Bul. of Hyd. Pr. Comm. of Ont., Sept., 1922; v. 9, pp. 275-280.
(Illustrated description of a device developed by J. B. Whitehead.)

Electric Conductors

Electrical Characteristics of Steel and Iron Wire.
Elec. Wld., Oct. 21, 1922; v. 80, pp. 872-874.
(Tabulated and graphic test data are presented.)

Electric Distribution

Electrical Power Distribution in the Steel Industry. Beitman, B. T.
Assoc. Ir. & St. Elec. Engrs., Oct., 1922; v. 4, pp. 721-724.

Electric Drive—Steel Mills

Electrification of Steel Works. The Electric Driving of Reversing Rolling Mills.
Beama, Oct., 1922; v. 11, pp. 689-693.
(Describes equipment manufactured by the English Electric Company, Ltd.)

Electric Transformers—Testing

Testing Transformers for Characteristics. Gooding, R. F.
Elec. Wld. Oct. 28, 1922; v. 80, pp. 935-938.
(Describes equipment and methods required.)

Electrical Machinery—Temperature

Overloaded Generator. Phillips, H. M.
Power, Oct. 24, 1922; v. 56, pp. 642-644.
(Practical methods of determining generator temperatures in the plant.)

Electroplating

Electrolytic Deposition of Iron for Building Up Worn or Undersized Parts. Kellogg, David R.
Am. Mach., Oct. 19, 1922; v. 57, pp. 611-612.
(Extract from paper before American Institute of Mining and Metallurgical Engineers.)

Frequency Changers

Operation of Frequency Changers. Smith, L. M.
Assoc. Ir. & St. Elec. Engrs., Oct., 1922; v. 4, pp. 701-719.

Heat Treatment

New Type Automatic Temperature Regulator and Its Application to Heat Treating Furnaces. Newcomb, R. W.
Am. Soc. St. Treat. Trans. Oct., 1922, v. 3, pp. 98-102.

Insulation—Testing

Insulation Failure—A Pyroelectric Effect. Hayden, J. L. R., and Steinmetz, Charles P.
Elec. Wld., Oct. 21, 1922; v. 80, pp. 865-868.
(Investigates the phenomena of breakdown in solid insulation.)

Radiotelephony

Method of Eliminating the Carrier Wave in Wireless Telephony. Heather, R.
Elec. Rev. (Lond.), Oct. 13 1922; v. 91, pp. 510-511.
(Shows diagram of connections and explains its action.)

Refractory Materials

Refractory Materials for Electric Furnaces. Searle, Alfred B.
Beama, Oct., 1922; v. 11, pp. 664-670.

Ship Propulsion, Electric

Rewinding a Main Drive Motor on a Dreadnought. Solberg, T. A.
U. S. Naval Inst. Proc., Sept., 1922; v. 48, pp. 1529-1538.
(An account of repairs to one of the main motors of the U. S. S. *Tennessee*.)

Steam Boilers, Electric

Electric Steam Generators and Their Application. Gregory, P. S.
Elec. News, Oct. 15, 1922; v. 31, pp. 37-39.
(From a paper before the American Electrochemical Society, Montreal, September, 1922.)

Wattmeters

Polyphase Wattmeter Connections—I. Staubitz, L. P.
Power Pl. Engng., Oct. 15, 1922; v. 26, pp. 1003-1005.
(Serial.)

NEW BOOKS

American Fuels. Bacon, Raymond Foss, and Hamor, W. A. 2 vol., 1922, N. Y., McGraw-Hill Book Co., Inc.

Bearings and Bearing Metals. 120 pp., 1921, N. Y., Industrial Press.

Engines and Boilers. Eyrie, Thomas T. 234 pp., 1922, N. Y., The Macmillan Co.

Hydraulics. King, Horace W., and Wisler, C. O. 237 pp., 1922, N. Y., John Wiley & Sons.

Liquid Fuel and Its Apparatus. Ed. 2. Booth, William H. 308 pp., 1922, N. Y., E. P. Dutton & Co.

Mastering Power Production. Polakov, Walter N. 455 pp., 1921, N. Y. Engineering Magazine Co.

Railway Electric Traction. Carter, F. W. 412 pp., 1922, N. Y., Longmans, Green & Co.

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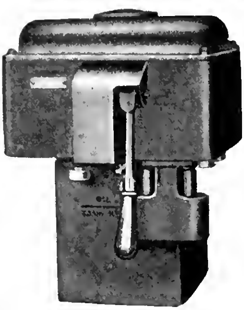

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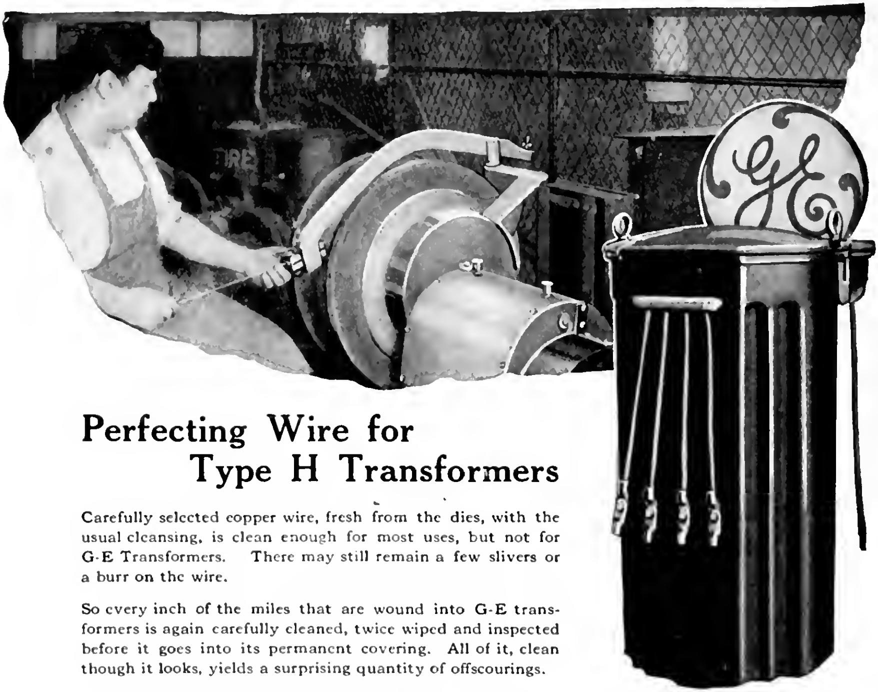

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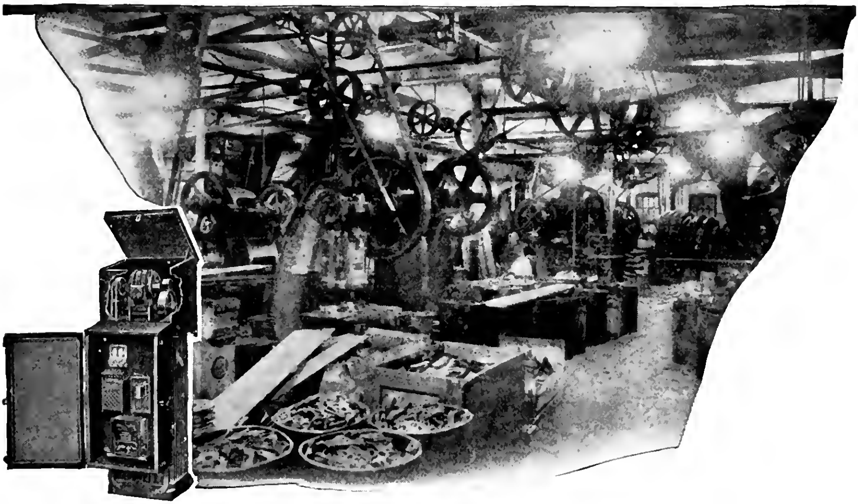

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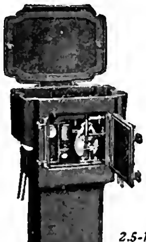

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Fabbrica Lampade Itala, Milan
Societa Edison per la Fabbricazione della Lampade, Ing. C. Clerici & Co., Milan

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International General Electric Co., Inc., 23 Waters St., Yokohama, P. O. Box 174
Shibaura Engineering Works, 1 Shinhamacho Shibaku, Tokyo
Tokyo Electric Co., Ltd., Kawasaki, Kanagawa-Ken

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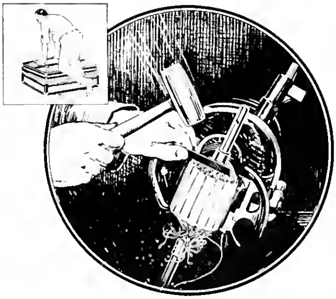

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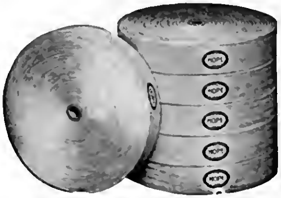

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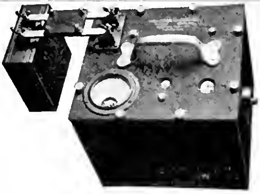

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