ELECTRICAL AIDS
TO GREATER PRODUCTION

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PLANS, METHODS AND APPLIANCES BY WHICH INDUSTRIAL ELECTRICAL ENGINEERS ARE MEETING INCREASED DEMANDS FOR POWER

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PREFACE

Eighty per cent. of the power used in making munitions has to be applied electrically. The Great War has brought to the engineer in the industrial plant, to the chief electrician of such plants and to the consulting engineers at work in laying out and designing the electrical equipment for industrial work, many new opportunities.

Emergency power needs have been supplied, additions and alterations to wiring systems to carry added loads, extensions have been built, all with the general idea of helping to increase factory output and hold down factory costs.

The war indeed has emphasized the inherent economy and flexibility of electricity as a method of driving all classes of machinery and has stimulated greatly the application of electricity for lighting and power.

This volume is written out of the experiences of the men who have been engaged in this work. *Electrical World* from week to week has presented articles on application of electricity to plants, taking up the problems of installation and maintenance as well as the problems of layout and control.

In this volume, the best of this practice has been assembled to provide for the work of reconstruction now upon us a background of practical suggestions to help install, operate and maintain electrical equipment in different classes of industries.

The material has been chosen and edited, not to make a text book, but rather a practical handbook of methods, schemes and plans which can be lifted out and adapted to a wide variety of conditions.

For the information presented, *Electrical World* is indebted to the cooperation of scores of electrical engineers in industrial establishments; where permitted, individual credit has been given to the men who together have met so successfully the problems of applied electricity during the war and whose work forms the basis for the practical application in factories to help increase output and reduce costs under the normal conditions of peace.

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CHAPTER I

GENERAL POWER PROBLEMS OF INDUSTRIAL PLANTS

INDUSTRIAL APPLICATIONS OF ELECTRICITY

If it were possible to state in just one word what the great advantage is that has created the universal adaptation of electricity to practically every known industry, it might be summed up in the one word "control," says Dwight D. Miller, formerly with the engineering department of the Society for Electrical Development, Inc. This is true since by means of control not only is the highest economy secured, but also increased production within a given time and of a quality higher than possible to attain by those other methods of power application in which the possible degree of control is only nominal by comparison.

Notwithstanding the fact that the electrical industry had its inception in the production of light, still, owing to the limitation of space allowed, this subject must be passed over with the statement that there have been many and large increases in efficiency in the various lamps invented and manufactured from the time of the first open-arc lamp down to the highly efficient gas-filled tungsten-filament lamp of to-day. Up to recently the cost of lighting had steadily decreased, so that it is possible to obtain many times the candlepower for the same energy consumption, or the same candlepower at a greatly reduced cost for energy consumed.

In dealing with the subject of heat, atmosphere, time and temperature are the three controlling and essential factors necessary for quality production in quantity, especially in those processes involving high temperatures. The fact that these three factors are more easily and accurately controlled through the medium of electric heat than is possible with any method of combustion heating makes it a heating medium so far superior to others as to offset in many instances its higher first cost. This is at once evident when we recognize that heat produced from electric energy is produced at 100 per cent efficiency and is accomplished automatically under fixed conditions, beyond the effect of human errors consequent to manual control, while the utilization of the heat of combustion devices involves a large number of variables all of which either involve the human element in their control or are beyond its power to correct. The heat of electric energy is peculiar in that it can be generated in any quantity regardless of temperature. This feature is unique and renders its utilization much more flexible and its control nicer than is the case where the heat of combustion must be utilized. With given fixed electrical conditions, such as line voltage and resistance of the leads, electrodes and resistor material, the same amount of current will flow, automatically producing the same temperature to an exact degree, since it is governed by Ohm's law. With this law the human element has absolutely nothing to do, because as long as the voltage and resistance of the circuit remain constant the same current must flow *per se.*

In general the ratio of efficiency of application of heat of combustion to application of electric heat becomes greatly in favor of the latter as the higher temperatures are reached, because electric energy is always transformed into heat at 100 per cent efficiency, regardless of the temperature, so that only the heat losses due to radiation, conduction and convection must be taken care of. In the case of combustion heating, however, it is the lack of control of the factors producing the heat itself which prevents perfect combustion and, combined with the heat losses just mentioned, renders its efficiency of utilization much less. In fact, it is by no means rare to find coal or even oil-fired furnaces to-day whose thermal efficiency is no greater than 1½ per cent, which means that sixty-five times as much heat as is utilized in the useful work of heating is discharged into the atmosphere.

Much has been said regarding the high cost of electric heat—

that it is much more expensive than the various forms of fuel. This is true when viewed from a B.t.u. basis only. The crux of the whole matter, however, lies in the fact that the cost of heat energy alone, as compared with the entire cost of the finished product, is in many instances negligible. Many items enter into the total cost of production, of which heat energy is only one; so that, while electric heat may be more expensive, if by its use the other items (such as time required, labor, fire insurance, etc.) are cut in greater proportion, producing greater quantity as well as improved quality, it is evident that not only is electrically generated heat cheaper to use but also that its use is imperative in order to compete successfully with those using it in similar processes.

Probably no more striking and forcible example of the saving of both time and money effected by the use of electric heat can be found than in the case of repairing the interned German ships. Although there was a total of 109 ships damaged, which, if new cylinders and parts had had to be supplied, would have taken eighteen months to two years to repair, all these ships were placed in service in less than eight months by the use of electric welding. The estimated cost of repairs on the first ship amounted to $32,000, and the time required from ten to twelve months for completion. By means of electric welding the work was completed in fifty-two hours at a cost of less than $2,000 for the actual work done. Moreover, the cylinders withstood a test of more than 50 per cent in excess of their normal working pressure, although it is customary to test them up to an excess pressure of only 20 per cent. In many cases an electrode high in manganese was used which in itself supplied the proper tensile strength to the weld. Thus repairs were easily made in places which would have been extremely difficult, if not entirely inaccessible, had a method of welding which required a flux been employed.

Spot Welding Used Extensively. Another case in point is the manufacture of the all-metal automobile bodies by means of spot and arc welding. Indeed, were it not for the ease and rapidity with which welds are thus made, together with the strength obtained, many manufacturing processes which involve a complete and oil-tight junction of metals would be commercially impossible, the stock being too light and thin to permit of riveting successfully. In manufacturing small articles like window-sash pulleys, as is done at the American Pulley Company, Philadelphia, by spot and projection welding, many thousand welds are made per hour—in fact, just as fast as the operator can press a lever, demonstrating in a most striking manner both the flexibility and ease of control of the electric welder. Ship plates are pinned to the frames of the vessel by spot welding and later on are welded along the edges, practically fusing the plates into one another. In both of these applications heat is developed at the exact spot, to the exact degree and for the exact length of time only to effect a perfect junction of the metal. Where can you find a fuel-fired process so simple, so complete and so efficient in utilization of heat?

The practice of heating by induction is rapidly coming into use. In this case the material to be heated forms the short-circuited secondary of the transformer by which it is inclosed. While this method of heating is probably the most efficient of all now in commercial use in its practical application, it can only be used in connection with materials of uniform cross-sections, because with an uneven cross-section part of the piece may become superheated or even burned before the other part attains the desired temperature.

Industrial Heating. Lieut. Col. C. F. Hirshfeld, when head of the research department of the Detroit Edison Company, made some very interesting experiments with internal heating in connection with the baking of "japans." He says: "It is of particular interest to note that baking by internal heating is essentially an electrical method, and that it is far removed in every way from methods previously in use." In his paper on "Low Temperature Electro-Thermal Processes" he clearly demonstrates, by means of micrographs, that the surface coats of japanned articles baked by the heat radiated from electrical air-type heaters possess a much higher and more perfect gloss or finish, that they are denser, freer from crater holes and will weather much longer than is the case with those baked by hot-air convection currents of combustion heating. Moreover, the time of bake was reduced to two hours and forty minutes for the electric compared with five hours and thirty minutes for the combustion method.

He next experimented with inductive or internal heating as against electrical radiation and found that better results could be obtained with a bake of fifteen minutes and at a temperature of 338 deg. Fahr. (170 deg. C.) by internal heating than could be secured by means of external electric heating (radiation) using a temperature of 446 deg. Fahr. (230 deg. C.) for forty-five minutes. He says: "It seems probable that one coat baked in this way will prove the equal of two or three baked by the older methods. The effect of all this upon energy charges for a given weight of metal baked is perfectly obvious."

In view of the superior results noted above it is unfortunate that induction heating cannot be universally adapted to the baking of japanned articles. However, it is being successfully used in heating metal tires for wagons and rims for large automobile trucks, since in these cases the cross-sectional area is uniform. It is also being tried out in connection with electrically heated boilers. In this case a hollow brass casting forms the short-circuited secondary of the transformer and heats the water as it flows through. The casting is connected to the boiler in a manner similar to a gas hot-water heater of the circulation type.

By the use of automatic devices such as time elements with solenoid switches, etc., ovens can be automatically controlled and brought up to temperature before the operator arrives in the morning, so that there is no time lost in starting the day's work, or the bake may be completed and power shut off after the quitting time of the operator at night.

Many other examples can be given showing the advantages of electric heat in low-temperature processes, such as its use in connection with linotype melting pots, glue pots and hot tables of various kinds. Here the heating units are small, compact and easily so adjusted that heat is applied exactly in the location desired and accurately controlled either manually or automatically by the many devices already perfected for this purpose.

Electric Furnaces. Through the medium of the various electric furnaces now being rapidly installed by progressive companies, the entire metallurgical industry is much benefited. By the use of the electric arc the temperature range above zero has been practically doubled and made available for commercial uses. This has not only opened up a wide field for development in the electrochemical industry but has also already resulted in the commercial production of materials heretofore unobtainable or previously unknown, such as aluminum, calcium-carbide, carborundum and artificial graphite.

On account of the great heat developed in the electric furnace, reactions take less time and are more complete, hence the yield for a given time is increased. Because of the fact that the heat of the electric furnace is not dependent upon combustion, and can be used in a neutral or reducing atmosphere, it is a "clean heat," in that it is not contaminated by the various products of combustion. Thus both the time lost and the expense incurred in using deoxidizing agents are, to a great extent, done away with and the product is of a higher quality.

Not only has the electric furnace made tremendous strides within the past ten years in the steel industry both in connection with the melting and refining of steel and in its heat treatment, but it is now rapidly establishing itself in that other great allied branch—the non-ferrous field.

Many books have been written and the technical press for the last three or four years has contained a multitude of articles on the advantages of the electric furnace. Briefly, the whole subject may be summed up by saying that the use of the electric furnace enables commercial practice to approach very nearly the scientific accuracy of the laboratory, thus insuring not only certainty of production and duplication of results, but also production of a quality higher than can be commercially obtained by the use of combustion heating.

THE POWER PROBLEM OF THE MANUFACTURING PLANTS

Although power is an important factor in production, it receives very little consideration compared with other factors, points out Sydney Fisher, an electrical engineer who has been connected with large manufacturing companies in England and with two major war industries in this country. Power must be available in sufficient quantity when required, and its supply must be unfailing. Production must never be held up for power; in other words, power must be ever ready for production. These exacting requirements can be met in modern plants with electric service, and yet the cost of this vitally important factor in production does not amount, in many cases, to more than a few mills per unit of product. This has been made possible by the remarkable development of electrically operated equipment in late years.

Not only in the supply of motive power and power for lighting has electricity simplified production, but also in its application to production processes. Temperature control, so important in delicate heat-treatment operations, is a reality, and losses due to radiation, etc., are very small. The electric welding machine is used not only for welding, where it has eliminated many operations, but also in delicate heat-treatment operations where high local heating is required. It is also used in heating and clinching rivets, these operations being performed together. Electric plating and cleaning baths have greatly simplified operations which heretofore were difficult and expensive. The battery truck has made rapid transportation over short distances possible with economy in time and help. Scientific heat treatment has been made possible by the development of the thermo-electric couple for pyrometry. The telephone, the telecall, the fire alarm, all play a very important part in plant operation.

Efficient Operation and Reliable Service Chief Considerations. Reliable equipment is only one part of the problem, however—a very important part, to be sure, but not the all-important part. Enough power and continuity of service form the prime consideration of the power engineer, but over-equipment in any part of the system will result in poor operation and unreliability when the plant is in full swing. Efficiency and continuity of service can only be obtained through scientific selection and arrangement, careful installation and operation, and proper maintenance of scientifically designed reliable equipment.

The following suggestions, based on two years' experience in power work at one of the largest munition plants in this country, if not the largest, may be helpful to those engaged in present and future power work. Suggestions will be offered under the following headings: (1) organization, (2) selection of equipment, (3) inspection, (4) installation, (5) operation, and (6) maintenance.

The power engineer and the production engineer of a munition plant, or, in fact, any manufacturing plant, should each be responsible to the chief engineer. On no account should the power engineer be responsible to the production engineer. The production enginer is always afraid of an insufficiency of power. If allowed to have his way, complications will ensue.

Selection of Equipment. Generating equipment rated at 2300 volts, three-phase, 60-cycle, with 440-volt power and 110-volt lighting equipment, is without question the best system for industrial plants, in the writer's opinion. This is true from the initial-cost, operating and maintenance standpoints. The selection of generating, controlling, transmission, transforming and distributing equipment should be based on the assumption that a high motor load factor (90 per cent) will be maintained where possible and that the necessary synchronous apparatus will be installed at the load to bring the power factor up to 80 per cent at the transformer stations. This will result in the correct design of all branches of the system, insure subsequent efficient operation, reduce the possibility of breakdown to a minimum and reduce the cost of equipment.

Careful selection of motor equipment can be made without a large expenditure of time and money. Elaborate test equipment is not necessary. A young electrician carefully instructed and provided with several ammeters (0-15 amp., 0-75 amp. and 0-150 amp.) and with a suitable voltmeter can do all that is necessary. Records should be made of the minimum, average and maximum currents and the order and frequency of their occurrence. All peculiarities of the work cycle can be expressed in terms of current. The corresponding power output values can be obtained from a current-horsepower output curve plotted from manufacturer's data on efficiency and power factor at various loads.

The rated output of the motor should equal the average load demand. Peak loads not exceeding 150 per cent rated load and occurring at intervals for short periods may be taken as an overload. This apportionment of motor to load will insure a power factor of 80 per cent. The first two or three motors will have to be selected by well-based guesses. After tests have been made on these units the results can be used in making more scientific selections of the other units. At the plant on which the writer bases most of his opinions 400 motors aggregating 6000 brake-hp. were selected in this way. Careful study of the work cycle often results in the coupling of two drives on one motor with resulting adequate power for each and a high motor load factor.

When the load is intermittent and fluctuates, as in the case of drop hammer and heavy press drives, a high average load and consequent high power factor is unobtainable. In such cases use should be made of a synchronous motor fan or blower drive requiring sufficient reactive power to raise the power factor to 80 per cent. Where possible reactive power should be supplied at the load, thus increasing the generator, transmission-line and transformer capacity for useful average power and reducing equipment and transmission losses. The 2000-kw. turbo-generator unit is a good unit for industrial plants. Where the space is not too limited two such units are advisable, one of the bleeder type and the other of the mixed-pressure type, as they make the best use of low-pressure steam during winter and summer months respectively.

Control apparatus is pretty well standardized. In addition to standard exciter, generator and feeder panels, a station recording voltmeter, a power-factor meter, a voltage regulator and a ground detector (three-phase) will be found necessary. Power-limiting reactances are not a necessity even with time-limit relays, as the reactance of modern generators is sufficient to limit the current of the usual short circuit.

Combined turbine, motor-driven exciters are to be recommended for munition plants. Under normal conditions of operation the exciter is motor-driven. Should the speed of the motor drop below 95 per cent synchronous speed, the turbine automatically takes the load. This insures sufficient power for the station lighting in the event of a shut-down.

Fiber duct gives very good results for underground transmission. Manholes should not have perforated covers, should be shaped to the lay of the cable and should be made thoroughly waterproof. Should a circuit pass near furnaces or heated area, it should be run through a tunnel opening into a well-ventilated manhole at each end. Overhead transmission is less expensive and quickly installed but is easily tampered with.

Value of Several Motors to Each Machinery Group. Motor equipment should be selected on the basis of two or more to each group of machinery. This arrangement is more expensive, but is preferable for several reasons. For instance, a high motor-load factor is more easily obtained, a 42-hp. average load being better supplied by three 15-hp. motors, or one 20-hp. and one 25-hp. unit, than by one 50-hp. motor. Obviously when power requirements are uncertain and quick deliveries of small sizes are possible, a number of smaller sizes is better than a few large sizes. Furthermore, if the motor equipment is reduced to a few standard sizes (5 hp., 10 hp., 15 hp., 20 hp. and 25 hp.) fewer ''spares'' are required and the expense is less, the units being smaller.

With this arrangement, if many machines are idle or the duty is light, whole sections can be run on one of the motors, the others being disconnected. Another advantage of this arrangement, especially in a plant just being built or extended, is that operation does not have to be delayed by deliveries of equipment. If the generator capacity is small owing to slow delivery of units, loading up one motor in the section instead of having two or three running lightly loaded will relieve the station units of unnecessary reactive power load and hence increase the station capacity for the average power load. In the writer's experience a 20-hp. motor has taken the load of an entire group (33 hp.) for two hours, with the aid of an ordinary desk fan to keep it cool, while another motor in the section was being replaced. This is another reason why there should be more than one motor driving the group.

Money spent on circuit breakers to isolate circuits is by no means wasted. A short circuit at some remote point will shut down an entire feeder, perhaps the plant, unless some precautionary measure is taken. Overload relays are not desirable on individual motor circuits, however, unless steps are taken to study the work cycle and set them for the maximum current. Furthermore, they also must be inspected frequently, otherwise they will trip and shut down a group of machines, causing unnecessary delay. If a motor is carefully selected and fused for the maximum current, there should be no trouble. A 440-volt circuit is advisable for motor applications, as the copper for a 220-volt circuit is expensive.

In the opinion of the writer the incandescent lamp is best for lighting, 60-watt and 100-watt units providing general illumination being preferable for production work and 25-watt or 60-watt individual lamps for tool and assembly work. Vapor lamps, while they possess advantages as regards quality of light, are easily damaged and the maintenance is high.

Inspection and Installation of Equipment. Standard apparatus, such as motors, transformers, control equipment, etc., as supplied by reliable firms, are carefully inspected at the shop. Frequently, however, machines built to supply a less urgent order are supplied, and while they may be identical in design, they have different characteristics. In the writer's experience, three exciters specified for parallel operation were subsequently found to be over-compounded, flat-compounded and under-compounded respectively. The adjustment could have been made very easily at the shop but involved considerable time and expense after installation.

Tests for grounds in the fields of generators should be conducted. If the system is installed on contract, the layouts should be studied carefully and the sizes of bus copper and cable from generator through to motor should be checked. It is surprising how errors creep into a mass of detail. Occasionally 300-kva. transformers may be accidentally installed for 500-kva. service and the error not detected until the plant is in "full swing"; then the tar begins to drop and the bus copper changes color. Contacts of circuit breakers should be inspected with a thickness gage to detect poor contacts before they cause trouble.

While cable purchased from a reliable firm is guaranteed for a year, the reels should be meggered before and after being drawn through ducts. A megger test set is expensive, but it will be found invaluable in locating defects and ascertaining the condition of equipment. Transformer taps should be carefully checked, as phase reversal may cause considerable trouble when two transformer houses are tied together. While awaiting installation do not allow transformers to remain in the rain uncovered. The air gap and oil rings of motors should be inspected and the rotor should be tested to see if it binds. Compensator contacts should be inspected, as three-phase starting and single-phase running, due to a bad contact on the running side, is by no means uncommon.

The installation of generating, transmission and transforming equipment is usually and preferably placed in the hands of contractors. Curves showing daily progress in all branches of work should be plotted on one sheet and the contractor consulted to ascertain the cause of delay in any branch of the work. Installation should be constantly checked from drawings as defects do not come to light until the plant is in full operation, by which time the bills may be paid.

The power engineer should consult with the machinery layout department to determine the best grouping of machines from a power standpoint, and to eliminate short double-cross belts where possible and the arrangements which require excessive starting currents and needless constant expenditure of energy in overcoming friction. Sometimes chain drives are advisable. as they will transmit overloads. Motors are frequently regarded as underrated because the main drive of a belt, particularly on a damp day, is very inefficient. Excessive belt tension is frequently the cause of a seized motor bearing. A motor should be given a central position relative to the group of machines which it is required to drive, and the motor pulley placed under a girder if possible.

Operation of Equipment. Instruction cards should cover the operation and maintenance of every piece of equipment in the plant. No doubt should be left in the mind of the operator. Rules for starting, stopping and oiling should be very complete. Rules giving the method of procedure in case of shut-down can be drawn up to cover nearly every possible condition. A complete set of instruction cards will prevent shut-down, shorten the period of shut-down and place responsibility on the right person. A comprehensive set of signals (whistles and colored lights) should be in operation in the station, covering the starting and stopping of the main units and auxiliary apparatus.

Voltage regulators are a boon, but they fail sometimes. They may operate satisfactorily twenty-four hours a day for six months and then fail, causing the station to lose the load. Once in six months is once too often when a 10,000-hp. load is dropped and about 25,000 men are forced to be idle. At the plant where the writer is engaged periodic shut-downs were experienced until the regulator was made semi-automatic. If the regulator fails as now adjusted, the station voltage drops only to a certain value, which insures against dropping the load. This is done at a sacrifice of the automatic feature whereby the voltage is maintained constant under all conditions of load; hence the operator must adjust the generator and exciter fields when the load "goes off" and "comes on" at recess periods to keep the regulator on the line.

The field excitation of each generator should be adjusted so as to maintain the same power factor in each unit, as under this condition the station capacity will be a maximum. In some cases machines operate better at a lower or higher power factor. Sometimes it is desirable to raise the average power load of a bleeder turbine in order to obtain as much low-pressure steam as possible. Another precaution to take is to keep tie switches open when it is not necessary to have them closed, as the fuse capacity is doubled and the damage due to short circuits is thereby increased when they are closed.

Operators should be instructed to start motors with quick decisive motion. "Hobbing" should be discouraged, especially when belts are being put on. If the proper compensator taps are used, the acceleration will be such as to permit applying any belt without danger to the operator.

Where there are several motors on a floor one man should be detailed to start all of them so excessive starting current will be avoided. In addition, the man on the first floor should be instructed to begin starting motors at ten minutes before the starting time, the man on the second floor at eight minutes before, etc. Where the plant is all on one floor the same effect can be produced by starting the departments in succession with small intervals between. The station switchboard operator should be notified when synchronous motors are either started or stopped, as reactive power load suddenly thrown on the station may cause trouble.

Maintenance of Equipment. Maintenance men should be assigned to inspection when not employed in actual breakdown service. The importance of adequate inspection cannot be overemphasized. Systematic inspection brings defects to light before they reach the danger point.

Ground detectors should be installed in the generator field circuits and a three-phase ground detector in the main circuit. The station equipment should undergo a thorough inspection at short intervals which should include the inspection of oil-switch contacts and the timing of relays.

Duct lines should be inspected frequently, at which time manhole conditions should be observed and cables tested with a megger. Every feeder should be tagged in every manhole with a waterproof label. In addition there should be a diagram of each manhole showing the position of each feeder. A cable test set is not expensive and will be found very useful not only for locating grounds or other defects in cable but also for determining resistances all over the plant—magnetic chuck repair, pyrometric work, telephone work, etc.

Transformer houses should be roomy, well lighted, well ventilated and clean. The cause of water condensation anywhere should be investigated immediately. Transformer oil should be tested for water content at frequent intervals.

Motor inspection should be very thorough. Slip rings should be inspected for pitting and oil rings should be tested to see that they turn. More motors shut down because of seized bearings owing to the lack of oil and also to stationary oil rings than from any other cause. The adjustment of overload relays and circuit breakers at frequent intervals should also be checked periodically. Compensator contacts should be inspected and replaced when badly burned. When a motor has the appearance of being heavily overloaded, a search should be made for bad contacts on the running side of the compensator. The maintenance of compensators is usually very high but can be reduced by careful instruction regarding the proper method of starting and by systematic inspection.

The power engineer and his assistants, even though well organized and well fortified with departmental rules and comprehensive instruction cards, would do well to leave the office and stroll through the plant quite frequently. The power engineer should trust his assistants to the point of supporting them in a controversy. Furthermore, he should be safe in handing a problem to an assistant and then forgetting about it until the latter makes his report. However, a power engineer should not be too free in delegating responsibility to assistants.

LOW OVER-ALL COST AND CONTINUOUS PRODUCTION

Refinements hitherto unthought of in industrial engineering are becoming more and more justified to-day as material and labor costs continue to rise because of the abnormal conditions. Maximum output is paramount, but coupled with it are the prime requisites of lowest over-all costs and continuous productive facility. These spell economy; in fact, that word has become a slogan of the day. Inasmuch as induction motors play an all-important part in our industries to-day, some methods of purchase and installation will be given that have been suggested by A. P. Lewis, who was formerly electrical engineer of a large industrial plant in the middle West.

Things to Consider in Purchasing Motors. It will be observed at a glance that the scheme hereinafter described applies principally to the large users, but its adoption by engineers of the smaller plants will result in greater over-all economy of operation, though in a smaller way.

Certain assumptions will be made, in order to draw conclusions therefrom, and these can be varied to suit plants with any other status than that here considered. It will be taken for granted that it has been found advantageous to have a yearly contract for the purchase of motors, first, to benefit by a reduction in the price thereby given, and second, because the manufacturers will, under contract, hold for subsequent orders a small stock of motors in recurrent sizes—both features which are highly desirable to-day.

The next step in the usual procedure would be to get prices, characteristics, etc.; weigh one against the other and close the business with the logical manufacturer. This method will not, however, result in obtaining motors sure to fill requirements peculiar to existing conditions. So the commercial side of the problem will be passed by, for the minute, and the behavior of the apparatus already in use will be investigated.

In the electrical engineer's office of the plant involved access can be had to his "motor repair record," a card index giving the repairs required on each motor in the plant and extending over a period of years. The assembly of this data might be made as shown in Table I. This shows at a glance in the

TABLE I—SUMMARY OF MOTOR REPAIR REPORTS

Period January, 1916, to January, 1918, Number of Motors in Use About 850

Low Bearing	Dirty	Shorted Coils	Open Rotor	Re-wound	Worn-Out Shaft	Grounded	Open Stator	Loose Rotor	Miscellaneous
120	12	1	..	11	5	....	....	....	....
4	36	..	..	..	..	....	....	....	....
1	..	25	..	3	..	....	....	....	....
3	..	1	20	1	..	....	....	....	....
..	..	..	..	3	..	....	....	....	....
3	..	..	..	..	9	....	....	....	....
1	..	2	1	..	..	8	....	....	....
1	..	..	..	..	..	....	5	....	....
..	..	..	..	..	..	....	....	3	....
..	..	..	..	..	..	....	....	....	5
133	48	29	21	19	14	8	5	3	5
Per Cent:									
47	17	10	7	6	5	3	2	1	2

hypothetical plant of 800-odd motors where trouble is occurring in the motors and the proportion of each kind. A study of this record, which is an excellent criterion of future trouble, should certainly enable one to dissect a motor and see what particular manufacturer is turning out a machine which will reduce repairs to a minimum.

Fundamentally, the induction motor may be divided into its mechanical and electrical characteristics, the former, in this discussion, to include both mechanical repairs and those incidental to insulation trouble, and the latter only the value of electrical design. By a rather extended operation considering capital investment, cost of power, etc., an approximate figure can be obtained for the latter which permits the assumption that the values of these two divisions stand in the ratio of 90 per cent and 10 per cent.

Proceeding further with the subdivision of these two considerations, a final percentage weight list may be made up and percentages assigned as shown in Table II, column A. This column is arrived at by reference to the ''repair record'' and also by consideration of local plant requirements, such as difficulty of belt drives, dirty surroundings, vapors or acids present, any established duty cycle affecting temperature rating, starting conditions, value of power factor or efficiency predominant, etc.

TABLE II—PERCENTAGE WEIGHTS OF MOTOR CHARACTERISTICS WITH MANUFACTURER'S RATINGS

Item	A—	B—	C—	D—	E—
I MECHANICAL; total, 90 per cent.					
a. End bells; total, 52 per cent.					
1. Bushing construction, rings, etc.	12	12	10	9.5	11
2. Oil well, cover, etc.	10	10	9.5	9	10
3. Alignment, how made and retained	7	6	7	6.5	6.5
4. Holding bolts, size and number	5	5	5	4.5	3
5. Size and rigidity	5	5	4.5	4.5	4
6. Weight	3	3	2.5	2.5	2
7. Design for dust prevention	10	9	10	8.5	8
b. Stator; total, 26 per cent.					
1. Material and construction	3	3.0	30	2.5	2.5
2. Iron, how held	1	1.0	1.0	1.0	1.0
3. Ventilation methods	4	4.0	3.5	3.5	4.0
4. Open or closed slot	3	3.5	4.0	4.0	3.0
5. If open bridge, construction	2	2.0	2.0	1.5	1.0
6. Cell insulation	4	3.5	4	3.5	3.0
7. Coil insulation	5	5	4.5	5	4.0
8. Phase insulation	3	3	0.0	0.0	3.0
9. Terminal block	1	0.5	1.0	0.0	1.0
c. Rotor; total, 12 per cent.					
1. Shaft size in bearings	..	..	..	..	..
2. Bearing size	7	7	6.5	5	6.0
3. Bearings, center to center	..	..	..	..	..
4. Rotor insulation	2	1.5	1.25	1.25	2
5. Air gap, in inches	0.5	0.5	0.5	0.4	0.35
6. End-ring construction	2	1.5	2.0	1.75	1.75
7. Attachment of iron to spider	..	..	..	..	..
8. Attachment of spider to shaft	0.5	0.5	0.4	0.35	0.35
II. ELECTRICAL; total 10 per cent.					
a. Power factors	4	4	3.5	3.5	3.0
b. Efficiencies	3	3	3.5	3.5	4.0
c. Temperature rise on test:					
1. 75 per cent load	..	..	..	..	..
2. 100 per cent load	3	3	2.5	2.0	3.0
3. 125 per cent load, two hours	..	..	..	..	..
Total	100	96.5	91.65	83.75	87.45

Other points may be more important in certain plants. For the purpose of this discussion a plant will be considered with the following features desired or present. Continuity of operation (essential), cost of power low, a rebate given on purchased power for good power factor, dirt present in surroundings with high specific heat and causing a cutting action on bearings, difficult belt drives, variable load characteristics but no duty cycle, overload capacity necessary and severe starting duty.

The next step is to obtain complete data, from the manufacturers to be considered, on a line of motors within the ranges considered, with stock samples of several sizes. By inspection, averaging dimensions, weights and characteristics, each item of the competitive makes can have assigned to it its relative portion of the whole percentage of the item considered. For example, as bearing bushing construction carries a value of 12 per cent, the manufacturer whose design is best, all things considered, obtains full 12 per cent. The others fall below in direct ratio as determined by careful study. Proceeding in this way with all items and totaling each manufacturer's column, a result will be obtained which should show, all things considered, the motors which fill the requirements best.

The cost of the machines has been intentionally left out of the tabulation, because the difference in price of standard motors to-day is small in comparison with repair expense, which may be of the order of 50 per cent of the first cost. Engineers may well insist in this case that over-all economy is established by the reductions of repairs, particularly where it is considered that a repair charge on a motor costing less money than another could be taken as a carrying charge on the higher-priced machine. For example, if the repairs, as shown in the record (Table I), cost $7,500, and these could have been reduced 50 per cent by paying $20 apiece more for the motors and obtaining a better design, it is evident that there would be available $3,775 to cover interest charges on the extra investment of $17,000. At current interest rates the extra investment would have earned roughly 15 per cent. These figures are not exact and only exemplify the possibility of saving considerable amounts by judiciously purchasing motors to fill a required service.

Installation and Maintenance. Certain fundamentals should be specially recognized in making motor installations—namely, that their life is determined by two things, bearing and insulation deterioration. Low bearings are usually caused by tight belts, dirt cutting the bushing or obstructing the proper flow of the lubricant, and vibration resulting from improper design of gear drives. Insulation deterioration may result from several causes—overloading with resultant heat, dirty ventilating ducts restricting heat dissipation, chemical action on insulation resulting from oil seepage or presence of harmful vapors, and precipitation of actual conducting dust in and around coils. The elimination of these or similar causes cannot but reduce repair costs.

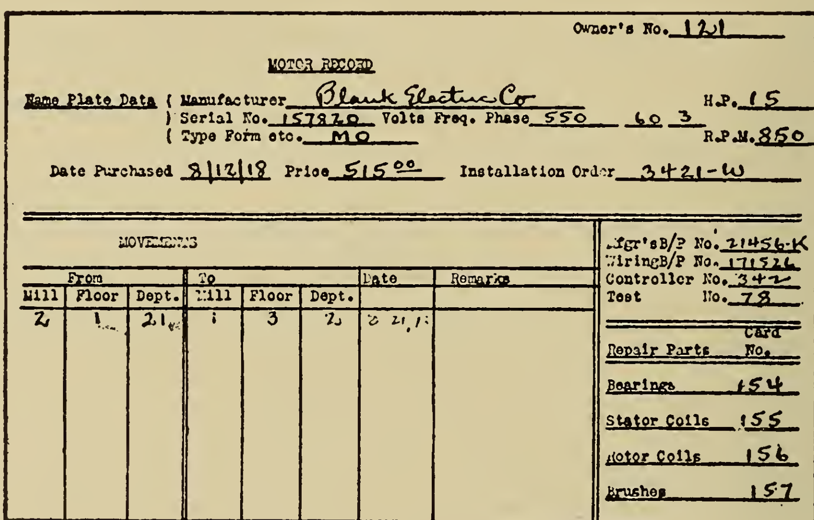
Tight belts should be avoided by installing drives with long centers and by furnishing millwrights with the necessary instruments, tools and tables of tensions to fill any probable requirement and then insisting on their intelligent use. Dirty bearings and oil wells are the most common source of trouble. Frequent inspections and periodical washings with gasoline help. Engineers should insist on carefully designed dust rings, oil-well caps which cannot be removed and which close by gravity, and should consider the use of ball bearings, which practically remove the chance for catching dirt and require only repacking in grease every few months or so.

Vibration on gear drives is always present in greater or less degree. Its transmission to the bearings of induction motors can result in nothing but trouble. A machine driving through gears should be installed on as solid a base as possible and then have interposed a flexible coupling between it and the pinion shaft. Engineers who make the statements that their gear drives with pinions on motor shafts are satisfactory lose sight of the fact that the statement is a comparative one and that often a satisfactory drive can be made more satisfactory by the use of a flexible coupling at these points.

Insulation deterioration from overloading can be prevented only by the proper use of fuses or relays and more particularly by a careful study of the load characteristics. If insulation is failing because of dirt lodging in the air ducts and a consequent retention of heat, dust-proof or inclosed motors may be the solution of the trouble.

They may cost 30 per cent more than open motors, but one repair against the open motor may make up the difference, to say nothing of the cost of continual inspection required on the open motor to keep its ventilating ducts in proper condition. Vapors present in the air may also require the use of motors depending on radiation rather than convection for heat dissipation.

A common source of insulation failure results from the improper oiling of bearings, the well being filled above the shaft clearance, whereupon it runs down the end bell and ultimately works into the winding. An overflow should be provided well below this point and the oiler equipped with a pump filler of which the nose can enter the well cover and the body be placed below to catch the discharge from the overflow pipe. In this way the well can be filled with no loss and the oil running out used again if it is in proper condition. At least it cannot get into the windings. In machine shops the writer has found a dust precipitation, consisting of iron particles and oil, in open



Owner's No. 121

MOTOR RECORD

Name Plate Data (Manufacturer Blank Electric Co H.P. 15
) Serial No. 157820 Volts Freq. Phase 550 60 3
(Type Form etc. MO R.P.M. 850

Date Purchased 8/12/18 Price 515.00 Installation Order 3421-W

MOVEMENTS

From			To			Date	Remarks
Mill	Floor	Dept.	Mill	Floor	Dept.		
2	1	21	1	3	2	[illegible]	

Mfgr's B/P No. 21456-K
Wiring B/P No. 171526
Controller No. 342
Test No. 78

Repair Parts	Card No.
Bearings	154
Stator Coils	155
Rotor Coils	156
Brushes	157

FIG. 1—MOTOR RECORD

motors that will actually break down on 440 volts with conducting points an inch apart. The residue is evidently dust as no gritty feeling is noticed. Inclosed motors are the remedy for this persistent trouble.

Intelligent inspection is the surest way to prevent failures in induction motors. The number and kind of inspections, of course, depend on local conditions. The inspectors should, however, be equipped with certain necessary data and should have considerable mechanical experience. A table of proper fuse ratings or overload settings, air-gap feelers or gages and bearing feelers should be provided. Their proper use anticipates trouble and allows adjustment before production is curtailed. The inspector should also be provided with means for taking oil samples and, if necessary, renewing oil in poor condition. Insulation resistance readings are desirable at frequent periods; complete rewinding may be avoided where this resistance is low by carefully washing the insulation in gasoline, drying in a vacuum and impregnating with an insulating varnish. The repair record previously referred to in this article should serve as a guide

TEST RECORD

Card No.____

Owner's No. 121 Machines Driven Planer

No. of Machines One

Amount of Shafting None

Date 8/15/18 Name of Tester John Smith

Temp. of Room 88° F Is this Normal? Plus

Temp. of Motor ________ F Is this normal? Yes

Operating Conditions. Dirt Vibration Oil Seepage, etc. ____

Insulation Resistance ________ Stator or Field ________ Rotor or Arm ________

NO-LOAD TEST

Idle with what ________

V_1 ____ V_2 ____ V_3 ____ I_1 ____ I_2 ____ I_3 ____

W_1 ____ W_2 ____ Total W ____ P.F. ____

LOAD TEST (over 1/2 hr. Period)

What Running ________

V_1 ____ V_2 ____ V_3 ____ I_1 ____ I_2 ____ I_3 ____

W_1 ____ W_2 ____ Total W ____ P.F. ____

OTHER CONDITIONS

What Running ________

V_1 ____ V_2 ____ V_3 ____ I_1 ____ I_2 ____ I_3 ____

W_1 ____ W_2 ____ Total W ____ P.F. ____

Recommendations and Remarks ________

Fig. 2—Test Record

showing what to look out for and inspections be directed accordingly, experience dictating the number and kind, together with desirable notations to be kept.

Properly kept motor records are a valuable asset to the engineer responsible for maintenance as well as statistical reports, etc. With properly kept records available, he is at once aware of the investment involved therein, the number and size of motors in the plant, the stock available for emergency use, the connected horsepower by department, building or floor, and has therein a ready reference for determining any repair parts required as well as the tabulated load characteristics of motors in operation.

STARTING AND CONTROLLING DEVICE Card No. 342

Description Manually Operated Drum Controller

Manufacturer's Data 15 hp 550 V 12 amp Serial No 35672 M

Date Purchased 8/12/18 Cost 78.00

Repair Parts	Card No.
Fingers	727
Contacts	728

Fig. 3—Starting and Controlling Device Record

Five form cards are all that is necessary to file these data and to have as elaborate a cross index at hand as is necessary in the average plant. Fig. 1 shows a preferred form of motor record card, which is filled in as far as possible at the time the motor

REPAIR PART Card No. 154

Description Pulley-End Bearing Bushing

Manufacturer Blank Electric Co.

Manufacturer's Identification

Bushing Type #16322 S

Our Stock Code No BB 15-1-121

Fig. 4—Repair-part Record

is purchased, additional information being entered as it becomes available after receipt of motor and its installation. The various headings and items on this card need no elaboration. On the reverse side thereof is the repair record of the particular machine, which shows the date, kind and cause of the trouble and identifying means for determining the cost, such as the order number. This form (Fig. 1) refers to three other forms—the test card (Fig. 2), the control card (Fig. 3), and the repair-part card (Fig. 4).

The test card contains such data as are necessary to study intelligently the load characteristics of the motor in question. On the reverse side of this card is a brief description of the method of drive together with pulley or gear sizes. The control card describes the starting or controlling device of the motor, with repair parts for it, and with space on the reverse

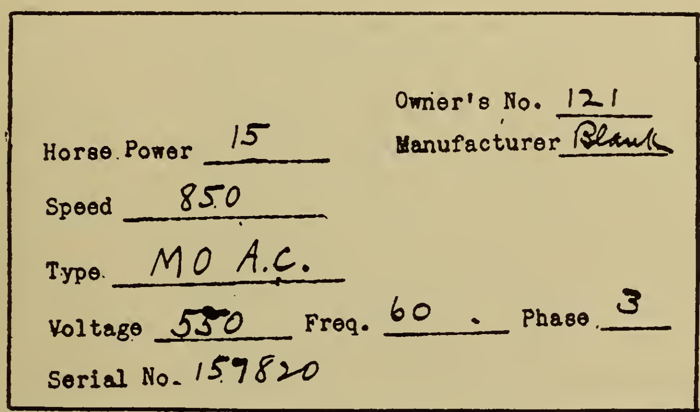

Owner's No. 121
Horse Power 15
Manufacturer Black
Speed 850
Type MO A.C.
Voltage 550 Freq. 60 Phase 3
Serial No. 157820

Fig. 5—Digest of Motor-record Information

This card may be used as manufacturer's mill, department, horsepower or speed classification to locate any motor if any of its characteristics are given, and it also enables total connected load records to be kept for any desired portion of plant.

side to show any changes in its location. The repair card contains sufficient information to identify properly the repair part in question, permits prompt ordering of replacements, saving laborious investigation, and the stock code number allows the stock clerk to pick out immediately from his bins a given bushing or coil, provided that he knows the motor it is to be applied on.

Each one of the cards mentioned is filed in its order, and information thereon is kept up to date by the proper coöperation of the records department, the testing department and the operating or maintenance department. The arguments in favor of a system similar to this are many, and even in a smaller plant the time saved and the valuable information accumulated by the tabluation of this data are surprising to one not accustomed to the system.

Conclusion. The preceding discussion is the result of investigations and studies in a plant using several thousand motors and covers many years' experience with troubles incidental to their operation. The repair record is merely typical, to illustrate the point of the discussion. The motor record is substantially one which is in very satisfactory use to-day.

PREVENTING INTERRUPTION OF PRODUCTION

The importance of an adequate uninterrupted supply of motive power is appreciated by all production engineers. In many cases, however, it is given comparatively little consideration in the press of routing, machine layout and other problems, because the latter are of relatively greater importance to the production engineer. The inevitable result is motor breakdown and consequent interrupted production when production problems are supposed to have been solved and the plant should be taking its full load. Many engineers play very safe and install more than enough motor-power equipment. This is particularly true in the case of munition plants where the supply of money is plentiful.

There are two objections to this overcautiousness, however, says Sydney Fisher, process engineer, Bridgeport Brass Company. One is the fact that the available supply of motors is relatively low; hence the rating should approximate closely the actual requirements, as otherwise labor and equipment many have to wait for power. The other objection involves the operating difficulties that inevitably result from over-motoring, particularly where the equipment is of the alternating-current type and the reactive power is an important consideration. The writer has been called in on two cases where the reactive power demand has greatly exceeded the average power demand, hence causing a breakdown of transforming transmission equipment. The design of the motive-power equipment of the plant should be placed in the hands of a competent electrical engineer to whom all layouts of machinery requiring power should be submitted for the selection and location of the motor or motors and for any recommendations he may see fit to make.

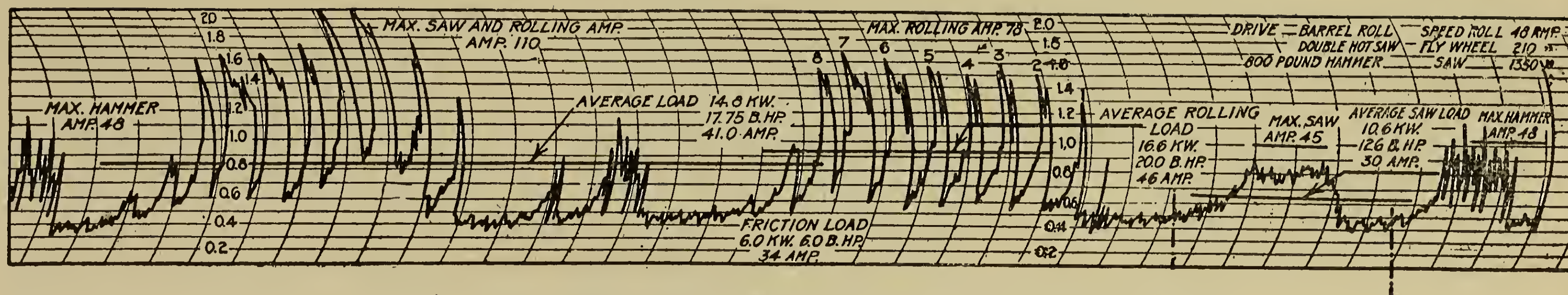


FIG. 6—LOAD VARIATIONS ON MOTOR DRIVING BARREL-ROLLING MILL

The motor is rated at 25 hp. and 244 volts, and it drives a hot roll, an 800-lb. drop hammer and a double hot saw 36 in. in diameter

The following suggestions on the selection, installation, operation and maintenance of motor equipment are based on experience at three munition plants. For group drive and individual drives requiring constant speed the three-phase, 60-cycle squirrel-cage induction motor is without question the most desirable type of motor for industrial work. It is of very simple design and very rugged, two factors which make for ease of construction, without resulting low cost and large supply and low maintenance respectively. This motor will take sudden load variations up to 200 per cent of its rated full-load torque with a comparatively small variation in speed and with small temperature rise. This type of motor is very satisfactory for drop-hammer, punch-press and upsetting-machine drives, the load on which is very variable.

Fig. 6 gives the load variation on a 25-hp., three-phase, 60-cycle squirrel-cage motor driving barrel-rolling equipment consisting of a hot roll, an 800-lb. (362.9-kg.) drop hammer and double hot saw 36 in. (91.4 cm.) in diameter. This motor has operated for more than a year during three eight-hour shifts per day without breakdown.

Four hundred and forty volt motors are very satisfactory, the cost of wiring to serve them being much lower than that for 220-volt motors. As to speed, the 1200-r.p.m. motors are cheaper, but they give considerable bearing trouble, particularly with belt drive. Therefore 900-r.p.m. motors are more satisfactory.

The question of group versus individual drive is a very important one. Production engineers who have had the bitter experience of trying to get maximum production with a poorly designed, badly maintained motor equipment are apt to decide in favor of the individual drive. Instead of judging any type of drive hastily, however, it would be better to consider the relative merits of a well-designed group drive and an individual motor drive for the same group of machines. To illustrate how this can be done consider Fig. 8. The load curve shown is that of a drive which has operated without breakdown for eighteen months prior to this writing and may be considered a good design. An individual motor drive for the same group of machines might be determined from the data given on the curve as follows:

The peak-load 26.1 brake-hp. labeled "Work arrives, machines take load,'' is doubtless due to all twenty machines taking their maximum load simultaneously, hence the combined friction and cutting load per machine would be (26.1 — 5) ÷ 20 = 21.1/20 = 1.05 brake-hp., 5 hp. being the line and countershaft friction load. To make the equipment flexible enough to cover possible changes of spindle speed, rate of feed and depth of cut, it would be advisable to provide 25 per cent reserve capacity, hence twenty 1.25-hp. motors would be the equivalent of the group drive. It should be noted here that the diversity factor which

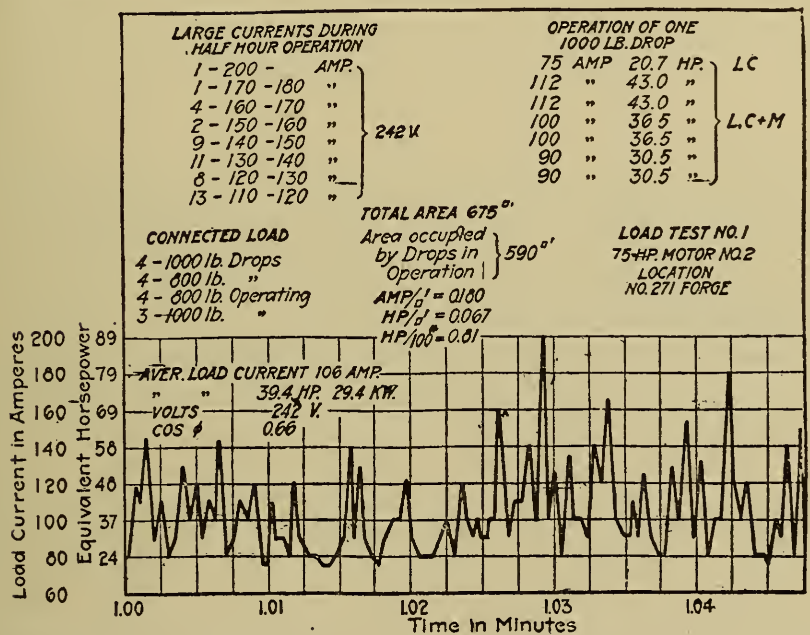


FIG. 7—LOAD FLUCTUATIONS ON A MOTOR DRIVING A GROUP OF DROP HAMMERS

exists with the group drive, but is absent in the individual drive, would cover small changes of spindle speed, rate of feed and depth of cut on about half the machines in the group.

Comparing the cost of the motor equipment in both cases, exclusive of cost of wiring, which would be considerably greater for the individual drive and take a greater length of time to install, one 20-hp. motor with compensator would cost $460, whereas twenty 1.25-hp. motors with starting switches at $102 would cost approximately $2,040. A small factory having forty such groups would require approximately forty 20-hp. motors for group drive and 800 1.25-hp. motors for individual drive. With the large order balances now carried by the large electrical companies, it is probable that a better delivery would be obtained on forty 20-hp. motors than on 800 1.25-hp. motors.

Regarding the relative cost and time of delivery of shafting, hangers, pulleys, belting and counter-shafting required for the group drives and the change gears required for the individual drives, both involve steel and labor, two items which are at a premium at the present time.

Power Factor with Group and Individual Drive. The average power demand of the group drive is greater than that of the individual drive, owing to a continuous friction load required by shafting, belting, etc. The friction load varies from 25 to 35 per cent. On well-designed drives, however, the power factor is relatively high and the reactive power demand correspondingly low. For the individual drive the average load per motor is lower, there being no shafting, belting, counter-shafting, etc., and no diversity factor. This low average load coupled with the inherently low power factor for small motors results in a low total power factor.

In the case of large plants with a central power station where process steam and steam for heating are in great demand the additional power demand for friction is very desirable, while the high power factor makes for high turbine efficiency. Where an outside power supply is depended upon, the expense of power for friction is of course undesirable; on the other hand, additional expense is usually incurred by a low-power-factor load.

The relative ratings of transformers, cables and generators required for each type of drive might be compared as follows:

Kw._g — Group kw. (approximately 80 per cent power factor).
$\text{Kva.}_g = \text{kw.}_g \div 0.80 =$ group kva.
$\text{Kw.}_i = 0.75\ \text{kw.}_g$ (assuming 25 per cent friction load)
$=$ kw. for individual drive (approximately 60 per cent power factor).
$\text{Kva.}_i = \text{kw.}_i \div 0.60 = 0.75\ \text{kw.}_g \div 0.60 = 1.25\ \text{kw.}_g$

$$\frac{\text{Kva.}_g}{\text{Kva.}_i} = 1.25 \div 1.25 = 1.$$

Inasmuch as the required capacity of generators, cables and transformers determined by the kva. load is practically the same in both cases the initial investment of this equipment and time of delivery do not differ. The maintenance of motor equipment is unquestionably higher with individual drives. This, of course, is inevitable with such a large number of units each operated by an employee whose chief consideration so far as the motor is concerned is to close and open the switch as required. Of course, breakdown of the motor involves only the shutdown of the machine which it drives, whereas shutdown of a group motor entails the shutdown of every machine in the group. Serious shutdown of a group motor should be a rare occurrence, however, if (1) the drive is carefully designed, if (2) adequate inspection of motor equipment is maintained, and if (3) an efficient maintenance force is available.

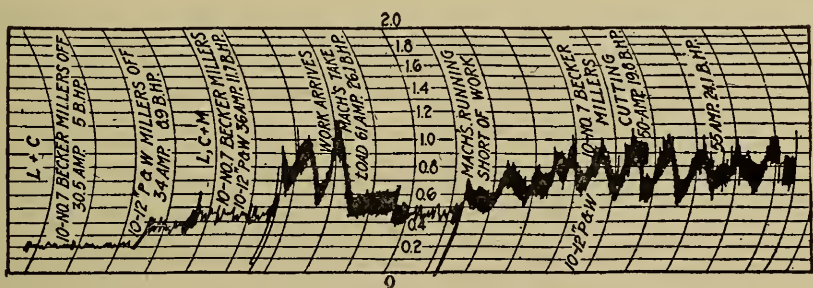


Fig. 8—Load Fluctuations in Receiving Mill

The motor is rated at 20 hp., 238 volts; the length of the line shaft is 126 ft. Twenty-two belts are used, 50 per cent of which are crossed and 100 per cent are double. L.C. and M. per sq.ft. = 0.0102; L.C.M. and M. per sq.ft. = 0.0173; L. and C. per ft. of line = 0.04; L. and C./L.C. and M. = 0.43; L. and C./M. = 0.75; power machining ÷ power L.C. and M. = 0.70; maximum demand ÷ average demand = 1.22. L.C. is line and countershaft friction load, M. being machine friction.

The common method of ascertaining the size of motor required is to add the power requirements of the machines driven, as given in the manufacturer's catalog, and apply what is commonly called a load factor. This more or less hit-and-miss method usually results in the selection of motors either too large or too small. A glance at the load curve in Fig. 8 will suffice to show that the power required to overcome machine friction is only about 25 per cent of the total power demands, the greater portion of the power being required for machining. In other words, power demand is determined by the class of work done on the machine. It is a function of (1) the spindle speed and rate of feed, (2) the depth and width of cut, and (3) the diversity factor, which depends on the length of cut and the number of machines per operator.

Careful consideration of item 3 is of the utmost importance. For instance, even with the same conditions of operation as regards spindle speed, rate of feed and depth of cut, a larger motor is required for a cut 12 in. (30.5 cm.) long in the direction of feed than would be required for a cut 2 in. (5.1 cm.) long, because a larger number of machines would require power simultaneously. Similarly a one-machine-per-operator condition would require more power than a two-machine-per-operator condition, since the number of machines cutting at the same time would be greater. The effect of the diversity factor is illustrated in the curve shown in Fig. 8. The peak load occurred immediately after the arrival of the work and was evidently the result of all machines operating simultaneously, being considerably higher than the peaks during normal operation.

Two ammeters (0-50 and 0-150), the characteristic curves of stock sizes of motors (10, 15, 20 hp., etc.) and a few typical machine groups to experiment on should provide sufficient data for the motor layout design of most of the common machine-tool groups. A synopsis of the data needed and of the method of calculating the motor-characteristic curves is given below:

1. Efficiency and power factor at half, three-quarters, full and one and a quarter times full-load output for standard sizes of 220-volt, three-phase, 60-cycle, 900-r.p.m., constant-speed induction motors. These data were obtained from the motor-manufacturing company's price book.
2. No-load input and no-load current values, obtained by test on standard motors.

Method of Procedure:

1. Input-output curves were plotted from above data, 1 and 2. Input = output ÷ efficiency.
2. Efficiency curves were plotted from input-output curve, which supplied values of efficiency below half full load.
3. Load-current curves were obtained by substitution in following relation:

$$P = (1.732 IE \cos\theta\ E) \div 746.$$

$$I = (746 \times P) \div (1.732 E \cos\theta\ E) = [746 \div (1.732 \times 240)] \times [P \div (\cos\theta \times E)]$$

$$= 1.795 \times (P \div \cos\theta \times E).$$

I = load current.
E = line volts (240 volts).
$\cos\theta$ = power factor given by manufacturer.
E = efficiency given by manufacturer.
P = power output (hp.).

Four points were obtained by calculation, using data No. 1 and a fifth point from data No. 2.

4. Power factor curves were plotted using four points from data No. 1. An additional point was obtained by substituting no-load current and no-load power input in $\cos\theta$ = watt input $\div \sqrt{3}EI$.

The use of the ammeters and the characteristic curves are demonstrated by the data given on Fig. 7. These data were obtained from a test on a 75-hp. motor driving a group of drop hammers and were subsequently used to design six similar drives.

Good judgment is a very valuable factor, of course. Accurate data obtained from a few careful experiments and applied with good judgment will result in economy of time and capital and will assure continuous and satisfactory operation. It is desirable from an economic and operating standpoint to design for an average load which is not less than 90 per cent of the rated load of the motor. Advantage should be taken of the overload capacity of the motor in every case. In this connection a chain drive should be used for the main drive, since the pulleys supplied by motor manufacturers apparently (from the experience of the writer) are not designed to transmit the overload which the motor is capable of carrying without slip.

Inspection and Maintenance Service. Assuming that the motors have been carefully laid out, they should run without shutdown if given a reasonable amount of care. By care is meant adequate inspection to locate the cause of trouble before it reaches the danger point and immediate attention by an efficient maintenance force to correct the cause. It is the policy of many plants to expect machine operators and floor foremen to report the cause of breakdowns, but such practice does not bring satisfactory results since machine operators and foremen are responsible for production and that is the chief subject in which they are interested. They have neither the inclination nor the time, if they are attending to their work properly, to keep track of service equipment. It is eminently the function of the service department to see that its equipment is kept in proper shape to insure continuity of service, and this can only be done by an adequate inspection force. This does not necessarily mean an increase in the service force, as the work of an efficient inspection force will result in an elimination of trouble to such an extent that the maintenance force will have ample time for inspection work and may, therefore, ultimately replace the original inspection force.

Adequate inspection is maintained in one of the biggest munition plants in this country, and breakdowns, particularly of motor equipment, are very rare. This inspection work is carried on almost exclusively by maintenance men; hence, comparatively speaking, the cost of inspection in this case is almost negligible.

The inspection of motor equipment should include the observation of the following items:

Motor.

1. Oil supply.
2. Freedom of oil rings.
3. Application of gap gage to air gap.
4. Main-drive belt tension.
5. Slip-ring surface.
6. Speed test.
7. Motor temperature.
8. Observation of conditions in shop which would affect the operation of motor.

Control Apparatus.

1. Condition of make-and-break switches.
2. Condition of overload release on compensator.
3. Examination of compensator contacts, particularly on the running side.
4. Inspection of overload relays (timing, damping, etc.).
5. Oil supply in compensator.
6. Temperature of compensator—no-voltage-release coil.

A frequent cause of motor shutdown is defective starting and control apparatus. This is largely due to careless manipulation of the former and improper adjustment of the latter. It is essential, therefore, to provide comprehensive instructions covering the starting and stopping of motors, and to train one of the machine operators on each floor for this work. Most of the trouble is caused during noon hour when motors are "hobbed" in order to place the belts. "Hobbing" is prolific of more breakdowns than any other cause with the possible exception of seized bearings resulting from excessive belt tension or lack of oil. If a motor accelerates too rapidly to permit placing a belt safely, the compensator taps should be adjusted to cause a lower acceleration.

An efficient, enthusiastic maintenance force is one of the biggest assets that an industrial plant can have. The word enthusiastic is by no means misapplied as the conditions under which these men have to work and the rapidity with which they have to work are very trying. Properly directed, an enthusiastic force will correct a shutdown in jig time.

The training of an efficient maintenance force is largely a matter of personal contact of the chief electrician or electrical engineer with his men. An hour or two per week given to instruction of the men in the fundamental principles of electrical engineering and their practical application will accomplish wonderful results.

The electrical engineer should draw up a logical method of procedure to determine the cause of motor breakdown. This has been found to be a great time saver as compared with the usual hit-and-miss methods employed by the average electrician. Such a method of procedure might be framed as follows:

Test temperature of motor by hand.

1. If temperature of frame, including bearing, is uniform, examine fuses or relays; replace blown fuses and examine relay timing adjustment and damping device.

Start motor and stand by.

2. If temperature of bearing is abnormal, look in oil chamber. If full of oil, examine oil ring to see if it revolves freely. Reset relays or replace blown fuses. Jerk starting lever and observe motor shaft and chain or belt. If there is no motion, there is a seized motor bearing. Call for emergency motor.
3. If temperature of frame is uniform but abnormal, replace blown fuses or reset relays and start motor. Take speed of motor. If speed of motor is less than full-load speed, motor is overloaded. Inquire of floor foreman about changes in operation

and look for seized shaft bearing. If either is the cause, notify chief electrician immediately.

Suggested Procedure in Case of Breakdown. In case of motor shutdown the following method of procedure is to be followed unless the cause of shutdown is immediately apparent.

Overheating of a three-phase motor is frequently caused by running single-phase, one phase being broken by a bad compensator contact on the running side; therefore examine compensator contacts on the running side and rectify if necessary.

The reason for the various steps should be carefully explained and every effort made to get the men to memorize the instructions.

The cost of delay in the event of breakdown can be substantially reduced by installing two motors per section and providing an auxiliary jack belt so that either section can be driven from the adjoining section. By doing this and providing extra cooling for the motor operated the writer has managed to keep a large portion of the machinery in similarly divided sections running until a new motor could be installed. A 20-hp. motor in one case carried 32 hp. for four hours, suitable additional ventilation having been provided as mentioned above.

In conclusion, decide on the best make of motor and install it throughout. This will substantially reduce the number of spares and spare parts to be kept on hand. As a result the investment in stock parts will be minimized, repairs can be made easily and less delay will be caused when there is a breakdown.

POWER FACTOR CORRECTION—AN URGENT NECESSITY

Most of the larger electric systems are already overloaded, and something has to be done immediately if further demands for power are to be fulfilled. This was particularly true late in 1918, Will Brown of the Electric Machinery Company, says because it was difficult, if not almost impossible, to obtain new generating apparatus and distributing equipment, and also because the fall lighting load was beginning to overlap the power load, leaving no margin of capacity for growth of load. Furthermore, every one had been warned that fuel would be scarce that winter, so power production was further limited. That there had been a shortage of electric power for some time is a fact well known to the industry. The two-hundred-million-dollar emergency power bill was a belated effort by Congress to remedy the situation.

Since power is the basic necessity of all war industries, it behooves every one interested in its production and use to consider how it is going to be secured in quantities which are desired. Of course, the usual methods of economizing here and curtailing unnecessary waste there can still be followed; but something more must be done, and that is to consider how poor power factor is limiting power and how it can be improved. The reduction of power factor has become particularly serious since the war, probably because of the fact that much alternating-current equipment has been installed and not operated at the best loads.

How a Whole Community May Be Affected. As an example of how a community and its power company has been affected by low power factor, the general power representative of one large central generating station in the East, writes as follows under date of August 30, 1918: "We now have a shortage of capacity both in generation and transmission, and in order to meet the demands of war industries, we are asking our customers to comply with our contract requirements of 80 per cent power factor. We have been making tests of our larger customers' operating conditions with an improvement in power factor in mind."

What is true of this company, which serves New Jersey's enormous war industries, is true of companies throughout Pennsylvania, Ohio, New York, Illinois, Indiana and other manufacturing states.

Power factor is a subject confronting not only the power producers but also the users, first, because if the user doesn't help to improve power factor he cannot get the power, and, second, because improving power factor is going to make it possible for him to get more work out of the equipment he has already installed. This is something that many industrial plant engineers have not stopped to consider, and still it is vital to maximum production. The details of the benefits to the producer and user will be discussed later, but what has been said should be sufficient to point out that coöperation between industrial plants and power producers is vitally essential now before any more time passes.

Plans cannot be definitely outlined for such coöperation since the conditions differ so in different localities, but it might be suggested that representatives of central-station companies and the industries they serve might find it mutually beneficial to discuss plans of power-factor improvement. Having more engineering information back of them, the central-station engineers might point out to the industrial-plant engineers how power factor is going to benefit the user and how they go to work to locate the causes of poor power factor and improve it. Consulting engineers might be invited into such conferences and left to give the advice necessary to correct conditions where the industrial plant is not well equipped with electrical engineering talent. At any rate, there is an opportunity for coöperation, and not much time or money will have to be expended in getting results, as the remedy can be applied at once.

It is a curious fact that many men view low power factor as an abstract evil that is causing the "other fellow" lots of trouble. They readily admit the importance of high power factor, but cannot seem to realize that they themselves are helping to make matters worse—that right in their own plant power is being wasted and money is being lost. Hundreds of central-station officials write that the greatest obstacle to power-factor improvement is indifference. At Niagara Falls indifference on the part of a large user was responsible for a large lawsuit, involving more than a hundred thousand dollars—all for wattless current. Indifference is keeping many induction motors runnings at poor power factor when it would be just as easy to run them at good power factor.

In the past large central stations which had excess power to sell were not over-particular about anything but load factor. The times are different now. Electric power is going to be sold and used under restrictions as to power factor. Central stations are by no means anxious to impose penalties, but they may be forced to do so if those who cause poor power factor do not correct conditions. This does not mean that the average cost of power is going to be increased; on the contrary, it is very likely that this will tend to decrease certain power rates. The power user who operates his plant so that his power factor is kept relatively high will actually be receiving a bonus in the way of reduced rates.

However, rates based on power factor are only a means to an end, and if the customers once realize how big an economy they can secure by a little attention to motor operation they will never again turn to old haphazard methods, and when added to this is the very present possibility that power in some cases cannot be secured at all unless power factor is improved, surely the power customers will get busy and improve their loads.

There is one thing encouraging about the situation; nine times out of ten when the discovery is made of what is really causing poor power factor it is possible to make considerable improvements without any additional apparatus. There is always a better way of using equipment now installed, and the advantage is that the remedy can be applied at once.

Picture of Waste from Low Power Factor. To visualize the losses brought about by low power factor, imagine a great hill of junked electrical apparatus—alternators, transformers, oil switches, thousands of miles of copper wire, lying tangled all over "no man's land." That's about what it means when we say in cold engineer's English that low power factor cuts down the capacity of generating, transmission and distributing apparatus. Alongside of this first hill is a second hill, smaller it is true, but very formidable. Here are piles of steam engines, gas engines, waterwheels and steam turbines that are giving no service at all. This is the condition that exists when we say that part of the capacity of prime movers is wasted because of low power factor. In addition to this there is another waste that cannot be shown as a piled-up hill of wreckage, but it exists nevertheless. It is the lowered efficiency at which all prime movers are forced to operate when they are working at part load.

Turn now to a water-power plant. Over the giant spillway thousands of tons of water is pouring, all wasted because the wheels can be operated only at part gate, this in turn being due to the reduced rating of the generators caused by poor power factor. The water can't be stored, the generators can't carry any more current, and so all this water power is going to waste just when it is needed most. Every kilowatt of I^2R loss means burning a certain amount of coal. The I^2R losses at 70 per cent power factor are more than twice as large as the I^2R losses at unity power factor (same power delivered in both cases).

Then try to imagine the accidents and shut-downs happening every day due to overheating of conductors and consequent break-down of insulation. Low power factor is indirectly responsible for much of this contributory damage. Overloaded apparatus means work for the troubleman. Break-downs are more serious to-day than ever, as the time involved in making

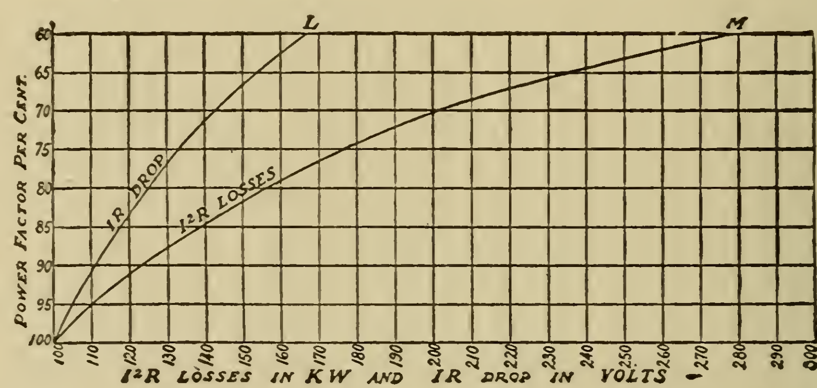


Fig. 9—How Power Factor Affects I^2R Loss and Potential Drop in Conductors

repairs is greater because of the shortage of spare parts as well as the shortage of men to do repair work. A shutdown due to a burn-out to-day is likely to result in considerable loss in plant production.

Every motor on such a system is working under the handicap of poor voltage regulation, and sometimes it doesn't work at all. Furthermore, poor power factor is usually an indication that alternating-current apparatus is working considerably below rating. This means that maximum use is not being obtained from equipment and is particularly serious because every productive hour counts to-day as never before. Imagine the carloads of material—iron, copper, steel, etc.—and the skilled labor as well—which could be released for other work if by some magic the power factor of the peak load on all electrical systems could be raised to 100 per cent!

Evil effects of low, lagging power factor are too well known to need much discussion. But it is one thing to understand statements in a general sort of a way and quite a different thing to be brought rudely up against the facts themselves.

Typical Examples of Effects. Here are typical examples of things that are now happening:

Case 1.—"We designed a line, 22 miles (35 km.) in length, 22,000 volts, for a certain kilowatt load, at 80 per cent power factor. After the load was connected, including a very large hoist, we found the power factor during the hoisting period would drop as low as 50 per cent. This doubled the kva. in the line and made regulation so poor that the hoist could not be operated. We must practically double our line capacity in order to take care of the wattless currents."

Case 2.—"At a certain power station we had three generators, giving service to the town, and one large power customer with a connected load of 300 hp. in induction motors. This customer's load factor is 80 per cent and the power factor is 60 per cent. At our request customer installed a synchronous condenser, receiving 10 per cent discount on his net bill. This resulted in raising the power factor to 85 per cent and enabled us to carry day load on two units, whereas it was previously necessary for us to run all three units to handle this load."

Case 3.—Hodenpyl, Hardy & Company of New York state that on some of their large contracts, particularly in Ohio, they have allowed a better rate for energy consumed at specified high power factor. This has had the effect of inducing customers to install corrective apparatus, and in a number of cases where contracts approximated 10,000 kw. or more customers immediately installed synchronous condensers at their own expense.

The isolated plant which generates power for its own use is equally interested in providing for high power factor. This should be considered when apparatus is installed and also when planning methods of operating machines and motors.

Causes of Poor Power Factor. While certain types of alternating-current apparatus are undesirable in point of power factor, they have not been generally developed commercially or if they have they are not used extensively. Therefore the usual cause of poor power factor is not so much the result of poor design as it is of poorly planned installations. This is evident from the fact that most commercially developed induction motors produce a power factor as high as 90 at full load and never much lower than 65 in the smaller sizes and lower speeds. On the other hand, however, if the motors are incorrectly applied to the machines (that is, if the average load is much less than the rated load of the driving motor), the power factor will be considerably lower than it would be if the motor were properly loaded as shown by the curves in Fig. 10. Thus it may be seen that unless careful attention is given to diversity of load in grouping machines and to actual power requirements, very low power factor may result, especially since it is usually the practice to provide a liberal margin of power instead of to depend on the overload capacity for carrying peaks. What is true of induction motors regarding power factor is also true of nearly all alternating-current apparatus—the farther below

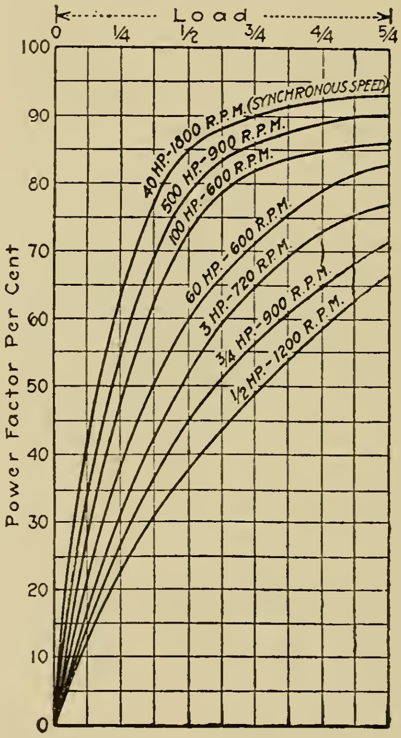


FIG. 10—PROBABLE POWER FACTOR WITH INDUCTION MOTORS

rated load it is operated the lower the power factor produced. Single-phase arc furnaces are also productive of low power factor even when working at normal rating.

Some engineers argue that individual drive is best because then motors can be selected for a definite load and can hence be operated at the best power factor as well as the best efficiency. Others maintain that the advantage which can be taken of diversity makes group drive preferable because such a large margin of rating does not have to be provided for peak loads. Each argument has something in favor of it, but it will usually be found that the average load on a well-applied group-drive motor is closer to the motor rating than is the case with an individual-drive motor, so the resulting power factor must necessarily be better for group-drive motors.

The application has a great deal to do with the results, however. Among the principal breeders of power-factor troubles are hoist motors, which draw a large current in starting, and individual drive motors that require large amounts of power in starting and carry flunctuating loads. For instance, with reciprocating pumps it is not uncommon for the load to vary from zero to full load periodically. Meanwhile almost as much current is drawn from the line at part load as at full load.

In textile mills where many small induction motors are driving individual machines there is also apt to be low power factor. This typical example comes from an official of the Titusville (Pa.) Light & Power Company:

Several years ago as manager of a central station I made a contract with a new silk mill for power at a rather low rate. Instead of group drive, which we thought the mill owners would use, they installed some 350 or 400 ½-hp., three-phase motors, one to each loom. After a loom was started it required very little power to keep it in operation, resulting in a 35 per cent power factor and a 35 per cent load factor during period of operation, fifty-four hours per week.

We ran a special circuit from our plant to a substation at this mill, which was situated close by, and installed in the substation three 100-kva. transformers. When the mill was not in operation and no energy was being used, our instruments showed that the silk-mill circuit was using in capacity and core losses 25 kva., about 5 kva. of which was core loss, the rest being due to the low power factor of the unloaded transformers. As there were some motor-driven fire pumps connected, it was impossible to cut out the circuit during the time the mill was not in operation.

Since then I have endeavored, wherever it is possible to do so, to place large power customers on synchronous converters or synchronous motor-generator sets. It is usually possible to do so as most manufacturing plants desire variable-speed motors.

Low power factor may also be produced by using direct-connected induction motors to drive low-speed machines like compressors. At Punxsutawney, Pa., for instance, there is a certain railroad shop where four 100-hp. induction motors were driving air compressors. These reduced the power factor at the plant to 65 or 70 per cent, causing considerable trouble owing to insufficient fuse capacity and excessive overload at the power house. These power users have now installed synchronous motors which float on the line and correct the power factor. It would have been much better from all standpoints if the original compressor motors had been of the synchronous type.

Where direct-current power is required it has often been the practice in the past to use direct-current generators driven by induction motors. These always give considerable trouble because of the reactive (wattless) component they produce. The following extract from a report concerning the Jamestown (N. Y.) Light & Power Company describes a case in point:

> There was a certain large power consumer who had ordered a 200-hp. induction motor-generator set. We immediately showed him that he could improve his power factor by installing a synchronous motor-generator set. He changed his order and took a synchronous motor of a larger capacity, which gave a surplus beyond the actual power required and gave a lot of condenser capacity for power-factor correction. We gave him a better rate for this, which made him see that he could afford to pay the additional cost of the motor. He is glad that he made the change.

How Lagging Power Factor Works in a Circle. Lightly loaded transformers introduce considerable reactance in a circuit. Here we can see the effects of lagging power factor working in a circle. When power factor is low, excessive current must be carried and this necessitates larger transformers. These transformers in turn, when lightly loaded at off-peak times, tend still further to lower the power factor on that feeder circuit. Many of these oversized transformers scattered over a system have considerable to do with lowering the over-all power factor.

Regarding this cause of low power factor, the Penn Central Light & Power Company states:

> We have had several cases of trouble with power transformers caused by low power factor, the transformers being overloaded in kva. while the actual output in kw. was far below the transformer rating. We have also experienced some trouble with overloaded lines due to highly inductive loads.

While poor power factor is usually a result of negligence in planning the installation, it was caused during the war to a great extent by the inability to secure the right size of motor for an installation. Since the principal problem before manufacturing plants was to produce quickly, they installed larger motors than necessary where it was difficult to secure the right size, being willing to invest more money and forego the better efficiency and power factor of the correct motor for the more expedient method.

In other cases poor power factor has resulted because of change of load due to change in use of machines. This has no doubt contributed considerably to the poor power factor now obtained, since many plants changed their business entirely to engage in war service, utilizing their old equipment, but for entirely different duties.

Even those which have not changed their ordinary business may handle such totally different products one month from what they do another that the average loads on the motors, and consequently the power factors, will be considerably altered. The improper use of starting and speed-control devices may also cause poor power factor.

What to Do When Poor Power Factor Is Evident. When it becomes evident that there is a condition of bad power factor something should be done to discover the real sources of trouble. To locate the individual causes will take time but will not involve the use of many or expensive instruments. This last task is really up to the industrial plants, although they might be instructed how to conduct tests by the local central station if they are not well enough equipped with electrical engineering help to undertake them alone.

Plants which have separate feeders to each motor with ammeters, voltmeters and wattmeters, etc., permanently installed on each circuit can determine the power factors of their motors so readily that these will be passed over. Many plants, however, have feeders running to different distributing panels and have no instruments on each individual motor. In such cases portable test sets can be quickly rigged up at small expense and arrangements made so they may be connected in circuit without interrupting service. This detail can be left to each individual's ingenuity, although one or two methods which might be used will be mentioned.

For example, arrangements can be made for connecting test sets to the jaws and hinges of the motor's main switch, and then when everything is in readiness for making the tests the main switch can be opened and readings taken. Instead of clamping the testing cables to the switch jaws, they might be attached to the end contacts of blown fuses inserted in the regular fuse clips. Of course, in such cases fuses rated to protect the motor should be included in the test circuit, and in any case the instruments must be of such size that they will not be injured.

Since load surveys should be made periodically, it would be advisable to arrange the main switches for ready connection of the testing equipment. For the same reason the testing equipment should be assembled permanently in portable form. As power factor is so closely associated with the load factor of motors, it will usually be satisfactory to test only for load to see if it is near the rating of the motor, unless there is some question as to whether the motor is the proper type to use. To obtain records which will be suitable as a basis for making changes, graphic charts should be taken, and preferably over a period which will include all ordinary fluctuations.

Such records will not only indicate which motors are responsible for the poor power factors but will also give a basis for replanning the motor drives. Although at first it may be necessary to select the size of motor on the basis of the power requirements as given by the machine manufacturer, it would be advisable finally to determine the nature and magnitude of the load by careful tests and then readjust the motor drives to agree therewith.

The power factor of other apparatus than motors can be determined in a similar manner.

How to Correct Power Factor. If the poor power factor seems to be due to some inherent characteristic of the apparatus operated, about the only remedy is to have the manufacturer adjust it or else provide some corrective apparatus such as synchronous motors, synchronous condensers or static condensers. When time is limited these remedies are particularly effective, as they may be applied without interrupting service. In view of the fact that synchronous motors can now be used for various applications[1] as well as power-factor corrective purposes, it is well to bear them in mind when making new installations and decide whether they should not be installed in the first place. Since most cases of poor power factor are due to poorly planned induction-motor drives, the remedy is to make use of load records in reapplying them. From such records it can be determined whether individual or group drive is best and which machines should be grouped together. The selection of group or individual drive and the grouping of machines depends on so many factors that they will not be discussed here, but the reader is referred to other articles which have appeared in different issues of the *Electrical World.* In this connection the writer (Will Brown) emphasizes, however, that care should be exercised in selecting the type of motor to use and then so to apply the motors that they will operate as near rating all the time as possible. Sometimes substituting a smaller motor for a large one and equipping it with a flywheel to help carry the peak loads will improve power factor.

Individual motor drive can often be carried too far. There are times when improvement can be brought about by combining a number of machines to be driven from the same line shaft. In some cases a synchronous motor of liberal capacity, either belted or directly coupled, could be installed to drive the line shaft. This would serve the double purpose of providing ample power to carry the load over all peaks and providing additional condenser capacity at periods of light load for supplying magnetizing kva. to the rest of the system. Whatever slight losses or inconvenience might be caused by the belts and shafting would be more than offset by the decreased I^2R losses throughout the plant. The result would be better voltage regulation and possibly a better rate for maintaining higher power factor.

It is interesting to note that numerous plants have been saved from power-factor troubles by the use of synchronous motor-generator sets. Many central-station companies have induced customers to install synchronous motors of sufficient kva. rating to maintain at all times a power factor of 90 per cent leading (or lagging) while driving the direct-current generators.

[1] For applications to which synchronous motors are suited see section on Motors and Control.

How to Encourage Power-Factor Improvement. Decreased efficiency itself is not always a sufficient spur to make the plant owner look for a remedy. The possibility of not getting any power at all unless correction is made may wake up some indifferent power users. On the basis that poor power factor is usually caused by underloaded motors another inducement can be advanced—that improving power factor will release equipment to take on new loads caused by growth in business. Possibly a penalty for low power factor is needed to make some factories act. Plant owners would discover that they could put in smaller motors and move the old motors up to larger loads, and thus really save money on original motor costs. They would also obtain a better rate for good power factor. The power-factor penalty clause would not remain as a fixed charge against factory production, but would bring about increased savings both to the power customer and to the central station supplying the power.

CHAPTER II

DISTRIBUTION, TRANSFORMATION, SWITCHING, AND PROTECTION

EFFECTIVE DISTRIBUTION OF FACTORY POWER

Notwithstanding the efforts made to direct careful attention to the problem of motor application in factory work, there is every likelihood that distribution circuits for supplying the motor and lighting equipment in many factories will not receive the necessary consideration unless special thought is given to them by the management. It is reasonable to expect that in a new plant the distribution circuits will usually be planned with due care to meet the initial needs. The typical factory, however, and more particularly the machine shop, requires continual rearrangement of machinery, and the tendency of the electrical department, in meeting calls for hurried changes in positions of motors, is to utilize as far as possible the existing wires in the various sections of the plant. One natural result is confusion in the circuits, with unbalanced load conditions, excessive power losses and an undue voltage drop in the overloaded circuits and accompanying reduction in production of the machine tools or other machinery supplied.

Sometimes, there is a tendency to forget that the electric circuit is the vital connecting link between generating machinery and motors or lamps. It thus takes the place of line shafting and belting with their high mechanical losses, and introduces more effective means for power supply and at the same time makes longer extensions possible than could be realized with the older mechanical methods of distribution.

Their very flexibility is one reason why circuits are overlooked so easily and are allowed to become inferior to the well-balanced status which may have existed when the plant was constructed. One large manufacturing establishment is known which has reduced circuits to diagrams or "wiring maps" which form part of the records of the electrical division. Every effort is made to keep them up to date and promote their regular use in wiring work.

The value of suitable standardization for the factory distribution system should not be overlooked, since the addition of equipment must be governed, in part at least, by the adaptability of apparatus on the market to the classes of circuits available in the plant. A leading consideration in the lighting equipment, although it may be relatively unimportant in the motor problem, is that of maintaining rigid separation of power and lighting circuits so that the latter may be protected against voltage variations probable as a result of changing load conditions imposed on the motors.

When advocates of scientific management look upon a 1½ per cent improvement in production efficiency as sufficient to warrant extended efforts to better the manufacturing methods, any part of an electrical system like the supply circuits demands sufficient attention to insure the maintenance of highly effective operating conditions.

TRANSFORMER INSPECTION AN ECONOMIC MEASURE

Thorough inspection of all distribution transformers returned from circuits should be made before they are again issued for service, first to lessen the chance of failure after replacement on the lines, and second to minimize the labor required in making the installation. Chances of failure are decreased if transformers are issued thoroughly clean and dry and with leads and bushings intact. Moreover, it is evident that minor repairs and adjustments can be made better and cheaper in the shop than on the job.

Bushings Need Close Attention. Bushings should always be carefully examined, as they are a frequent cause of failure. A break is not always evident from a casual examination, and each bushing should be shaken to disclose any looseness. A broken or loose bushing, especially a primary bushing, should always be repaired before the transformer is again utilized, since it is almost certain to break down in wet weather and may, under certain conditions, cause a burn-out of the transformer windings. As most bushings are broken in handling transformers after shipping crates have been removed, means should be provided for protecting them. Cylindrical types, whether plain or corrugated, usually become coated with dust whenever there is any oil leakage, and breakdown often results.

In renewing bushings in any line of transformers advantage should be taken of the most recent designs that may be accommodated in the outlet holes. It is important that bushings which are suitable for the service be chosen. Substitutions should not be made unless the new type is superior to the old. A full supply of spare bushings should be carried in stock so that makeshifts will be unnecessary. A blue-print schedule showing the catalog numbers of primary and secondary bushings required for each tank number should be prepared with the assistance of the manufacturers for each line of transformers handled. This will be found of service both in expediting purchases and in selecting repair parts from store-room stock.

When installing new bushings a grade of sealing compound such as is specially recommended by the manufacturers for this purpose should be used. All of the old compound should be removed before the new bushing is placed. If the bushing is of the type set in with babbitt (those inserted from the outside are usually set in with babbitt, paper lock washers or some similar device), this metal also should be completely removed. In chipping out old bushings and compound provision must be made for catching the scraps to prevent their falling into the coils or bottom of the case. Bushings of the curved styles are best made up complete with leads before insertion in the transformers. The more simple styles, which are easily filled with compound, may be filled in place.

Heating Compound to Right Temperature. Care must be taken to heat the compound to the proper temperature before pouring; otherwise cracks will result. The entire corner of the case in which the bushing is placed should be heated so that the compound will not be chilled on striking the metal. To chill the compound will often result in a leak between it and the case. Much of the oil leakage which occurs around leads and bushings is not caused entirely by siphon action along or through the lead, but may be due to cracks between the bushing and the sealing cement or between the latter and the case. This leakage will not occur unless oil is slopped onto the compound, but it is practically impossible to avoid this in handling a filled transformer. To avoid leaks of this character, not only should hot compound be used, but the surface of the compound above the bushings should always slope in toward the center of the case. This can be effected by tilting the transformer while the compound is being poured as well as while it is hardening. Where the compound must be built up a temporary paper dam may be installed, and after the cement has set it can be removed. This scheme also makes it possible to raise the level of the cement above the top of the bushing so that the bushing and recess may be filled in one operation.

Bushings should be kept clean. It is a good plan to incorporate in all directions covering the installation of transformers a note to wipe bushings carefully after the transformer is in place. Most of the oil and dust which, if left on a bushing, are so likely to cause breakdown are accumulated during transportation from the store room to the job. If the bushings are cleaned after the transformer is hung, this cause of trouble is largely avoided. When transformer tanks are being painted care must be taken not to get paint on the bushings, as the rough paint surface will tend to gather dust. Bushings of the larger types should be wrapped with cloth or paper while cases are being painted.

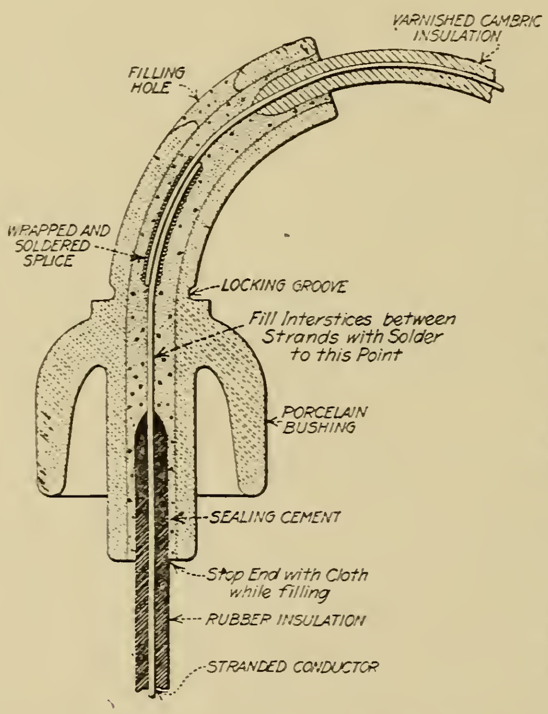
How Trouble with Leads May Be Prevented. Next to bushings, leads require most frequent attention. They are often broken in handling or are cut short when transformers are removed. In addition, they deteriorate because of the siphoning of oil. Secondary leads of the types of transformers under discussion are invariably rubber-covered. Primary leads are usually rubber-covered, although some manufacturers have recently used varnished cambric insulation for voltages of 11 kv. and up. Each material has its advantages. Rubber withstands weather and moisture well, but it is deteriorated rapidly by oil. This weakness is its most serious defect as oil is often siphoned over the leads. Varnished cambric, on the other hand, while benefited by oil, does not withstand weather well when protected only by a braid covering. It is easily dried out by hot weather and is liable to absorb moisture in wet weather. These remarks apply, of course, only to the leads outside of the case: those inside are always insulated with varnished cambric.

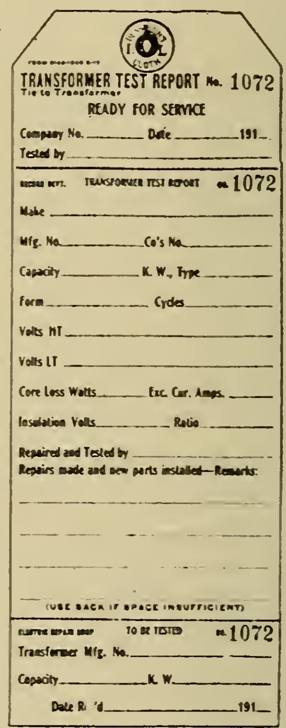
In arranging for shop repairs to transformer leads it is first necessary to prepare a schedule of cables to be used in making renewals, in order to secure uniformity in purchases and repairs. This is preferable to attempting to replace the old lead with one precisely similar in size, insulation and stranding to that installed at the factory, since in the past manufacturers have differed considerably as to these details in transformers having identical ratings. To follow these deviations would require an unnecessarily elaborate stock of cable. A schedule which has proved satisfactory in practice is given on page 55 for 2300-volt transformers. The cables selected, especially those used for primary leads, have not been chosen exclusively on a basis of their usefulness as transformer leads, but also with a view to their use in the wiring of substations and similar work, in order to avoid the carrying of overlapping stocks. All cables are specified as single-braid, rubber-covered. However, if any are to be used extensively in outdoor work, as for instance in wiring between cut-outs and transformers, they may be specified as single-braid and tape. The rubber insulation is that specified by the National Electric Code.

The greatest difficulty in installing leads is to prevent the siphoning of the oil. If this happens, the oil will rapidly deteriorate the rubber of the leads and in addition will gather dirt on leads and bushings and thus increase the danger of breakdown. Where the primary terminal blocks are under oil, as is the case in most recent types of transformers, solid conductors may be inserted between terminal block and bushing to prevent the siphoning which would be caused if stranded leads were used. Where stranded conductors are used the splice between the inside portion of the lead (which is insulated with varnished cambric) and the outside rubber-insulated part, as well as all interstices between strands for a short distance on each side of the splice, should be thoroughly filled with solder.

The splice in primary leads should be placed so as to be completely surrounded by sealing compound, and the short, bare and solder-filled portions on each side of the splice should likewise be covered. A wrapped splice is generally used. Secondary splices and some of the simpler primary splices are placed above the compound. The varnished-cambric insulation of the secondary should be started above the oil level. After filling a bushing with compound, tape should be wrapped around the outgoing lead at the point where it leaves the bushing to prevent the compound from running out before it has set. After the cement has hardened this tape should be removed; otherwise all the oil which may leak between lead and compound will gather at this point and rapidly eat away the insulation.

Instructions should be issued to transformers' installers cautioning them against handling transformers by the leads. Trans-

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Company No. _____ Date _____ 191_
Tested by _____

TRANSFORMER TEST REPORT No. 1072
Make _____
Mfg. No. _____ Co's No. _____
Capacity _____ K. W., Type _____
Form _____ Cycles _____
Volts HT _____
Volts LT _____
Core Loss Watts _____ Exc. Cur. Amps. _____
Insulation Volts _____ Ratio _____
Repaired and Tested by _____
Repairs made and new parts installed—Remarks:
(USE BACK IF SPACE INSUFFICIENT)

TO BE TESTED No. 1072
Transformer Mfg. No. _____
Capacity _____ K. W. _____
Date R. 'd _____ 191_

FIGS. 11 AND 12—BUSHING CONSTRUCTION THAT PREVENTS SIPHONING; THREE-PART TRANSFORMER TEST REPORT

formers are frequently dragged along the ground or truck bed by the leads or are kept from swinging into the pole when being raised by lines attached to the leads. This practice results in many broken leads and bushings.

When new leads are installed they should be made long. In some types of pole installations one additional foot of primary lead will permit direct insertion of the lead into the primary cut-out without a splice.

Some installers make use of the connectors provided on the leads by manufacturers, and use care in handling them; others appear to consider them superfluous and often cut them off. Instructions should be given to use these whenever present, as they are considerable labor savers, especially in the larger sizes, and will give no trouble if properly installed. Any connectors which are not used should be left taped to one of the leads so that they will be available if necessary in some future installation. In removing transformers foremen should be cautioned to cut the leads between the connectors and the line and not the leads between the connectors and the transformers. The connectors may then be saved in the shop. Many leads are cut so short through carelessness that they must be replaced before the transformer can be reissued for service.

Painting of Cases and Care of Oil. Cases should be repainted whenever transformers are brought in from the lines, unless they have been installed only a short time. Sheet-steel cases especially will deteriorate rapidly unless protected by paint and if rusted should be given two coats. Before paint is applied it is necessary to clean the case thoroughly with distillate and a steel-wire brush to remove all dirt and oil. A good quality of turpentine asphaltum paint will be found serviceable for this work. If a system of location numbers is in use, they should be restenciled on transformer cases as soon as they are slightly obliterated. A white-lead and linseed-oil paint should be used for this purpose. Stencils 2½ in. (6.35 cm.) high may be readily deciphered from the ground, still they are small enough so that four or five figures may be placed on the smaller-size cases.

If the transformer has been installed for several years, it is preferable to draw off the oil for testing and treatment as soon as it arrives on the testing platform. On the other hand, if the transformer has been on the lines only a short time and the oil seems clear and without a burned odor, it need not be removed. In the case of the larger sizes of distribution transformers, a sample should be drawn from the bottom of the case with a "sneak" for a moisture test. All transformer oil should be carefully tested, handled and stored in accordance with the recommendations [1] of the apparatus committee of the National Electric Light Association. Men cannot be cautioned too often

[1] *Proceedings N. E. L. A.*, 1917, Technical and Hydroelectric Section, page 281. Also available in booklet form.

against handling oil in the open in damp or foggy weather. Companies utilizing distribution transformers of two voltages will do well to reserve new oil for the higher-voltage equipment and use the second-hand treated and filtered oil in the lower voltage apparatus.

When possible, transformers should be filled with oil before they leave the store room: this, however, is not always possible. If the old oil is not removed when transformers are returned from the lines, an inspection should be made to see that the oil is up to the proper level. Schedules of transformers showing tank symbols and quantity of oil required for each line of transformers in service should be readily available. It should be noted that transformers of the same make and type but of different form may require quite different quantities of oil.

Cleaning of Transformers and Detection of Flaws. The cleaning of the coils of transformers removed from the lines requires careful consideration, especially if they have been installed a considerable time and sludge has been precipitated by the oil. The elimination of oil deposits from the circulating ducts is particularly essential since their effects are cumulative. By impeding the oil circulation they cause the transformer to overheat with a given load, which in turn increases the sediment. An air-transil-oil spray is effective in flushing the ducts. When the oil is drained off it will also clear any moisture which may be present at the bottom of the case.

Many transformers cannot be properly cleaned without removing the coils from the case: this is especially true where the sediment has thickened. Some of the older types of transformers which have no oil ducts between coils should always be removed and cleaned by scraping, as a thick coating is generally to be found on the coils caused by the lack of circulation. Care must be used in scraping to avoid damaging the insulation. An air-distillate spray will be found effective for this kind of cleaning, but should not be used unless the transformer is dried out before being placed in service. A distillate spray should not be used within the test room, owing to the fire risk. A cast-iron grating with removable containers should be provided on the transformer platform for draining coils and cases: otherwise oil will be scattered about. By this means considerable oil or distillate can be saved, as the oil can be filtered for re-use.

Cases should be examined for leaks. A crack in a cover may permit the entrance of sufficient moisture to cause breakdown. Cast-iron cases when cracked may be welded with an oxy-acetylene torch; sheet-steel cases may be repaired by brazing or welding. Drain plugs should also be examined and set in with red lead if leaky. Felt strips should be carried in stock so that when those in service are lost or worn they may be replaced. It is important that these be kept effective.

Hanger irons and lugs should be examined for cracks and flaws. When transformers are returned from the lines it is advisable to arrange some system by which the hangers are kept with them or properly marked so that they cannot be mixed with others.

TABLES I AND II—CABLES TO USE IN RENEWING 2300/460-230-115-VOLT TRANSFORMER LEADS

PRIMARY LEADS

Class	Transformer Size (Kva.)	Size of Lead	Insulation (1/64ths of In.)	No. Strands
2,300-volt	1 to 5	12	8	7
	7½ and 10	10	8	7
	15 and 20	8	8	7
	25 and 30	6	8	7
	37½ and 50	4	8	7
	75	2	8	19
	100	1–0	8	19

SECONDARY LEADS

Class	Transformer Size (Kva.)	Size of Lead	Insulation (1/64ths of In.)	No. Strands
	1 to 3	8	3	7
460-230-115-volt	5	6	4	7
	7½ and 10	4	4	7
	15	2	4	19
	20 and 25	1–0	5	19
	30	2–0	5	37
	37½ and 50	4–0	5	37
	75	400,000 c.m.	6	37
	100	500,000 c.m.	6	61

If a transformer has taps, connecting lugs, nuts and bars should be checked for missing parts. If they are missing, they will usually be found in the bottom of the case, where they were dropped while taps were being changed in the field. Spare connecting links should be taped to leads.

It should be ascertained that coils and core are firmly held in place by the bolts and wedges. To send a transformer out loose in the case will often result in damage to coils and consequent breakdown.

Testing for Burn-Outs. The most difficult of all repairs are those to coils. When a transformer comes in which is suspected of being burned out, unless it is evident from a superficial examination that the coils are completely ruined, tests should be applied with caution. A breakdown insulation test should never be applied until a megger is used. A premature insulation test may injure a transformer beyond repair. If the megger shows the insulation to be in bad condition, the transformer should be dried out by one of the usual methods and the test repeated. Such a dry-out will often correct the difficulty. Often a careful examination of the coils will reveal only a few damaged turns; these may be replaced or reinsulated if carefully handled. If necessary, all coils should be disconnected so that each may be "meggered" to the core separately. The megger test is of course a preliminary step only for the purpose of trouble location. No transformer should be reinstalled which cannot withstand an appropriate insulation test. Ratio, core loss and exciting-current determinations should also be made on each transformer before it is considered ready.

When it has finally been proved that a transformer is burned out it becomes necessary to decide upon its disposal. Several courses are open: It may be scrapped; it may be returned to the manufacturer on some exchange proposition; new coils may be wound in the local shop, or coils may be ordered from the manufacturer. In any case the decision will largely depend on the voltage class of the transformer, its age and type. Antiquated types having operating characteristics inferior to those of modern transformers should seldom be rewound. Transformers of the 2300-volt class can usually be returned to manufacturers for credit on a basis that is more economical than rewinding. On the other hand, it pays to order new factory-made coils for the higher-voltage classes. If a factory repair shop is available within reasonable distance, it may be cheaper to have the factory make complete repairs. When the coils are installed in a local shop, care must be taken to shellac and dry them thoroughly. Some form of drying oven should be available, and the transformer should be placed therein at a temperature of about 85 deg. C. (185 deg. Fahr.) for at least twenty-four hours.

Transformers should be stored in such a manner that they will be easily accessible. If platforms rather than racks are used, ample aisles should be provided between rows to avoid breakage of bushings. Transformers of similar ratings should be grouped together. Burned-out transformers awaiting disposition should not be mixed with the others, and to eliminate any chance of their being taken out by repair men in an emergency they should be given a dash of colored paint or otherwise conspicuously marked.

Some recording system should be adopted in order that transformers returned from the lines shall be assured of proper attention and that no transformer shall be taken out until it is inspected and repaired if necessary. The three-part linen tag shown in Fig. 12 has been successfully used by one company for this purpose. Upon arrival the stock foreman issues a tag for each transformer. The lowest section is torn off and sent to the shop as a notification of work to be done; the remainder is attached to the transformer. When inspection, repairs and test are completed the middle section is torn off and sent to the record department as a notification of work done, and also that the transformer may be again placed on the active list. The upper portion of the tag remains attached to the transformer until it is reinstalled. The condition of each tag shows at all times the status of the transformer to which it is attached, and regardless of the method pursued in ordering out transformers for use, no transformer will be taken which has not received attention.

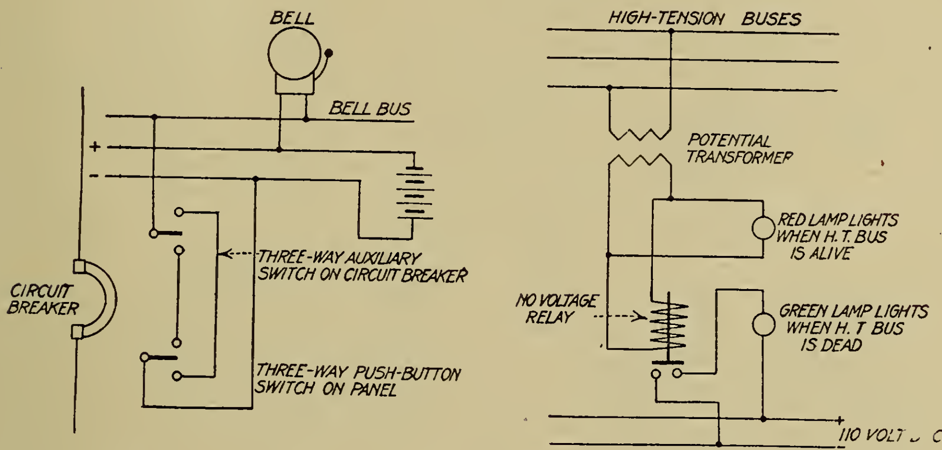
SAFETY FEATURES IN SWITCHING INSTALLATIONS

A great many ingenious and useful safety devices and schemes of connections have been devised within recent years, but the development of large-size and higher-voltage apparatus has been so overwhelmingly rapid that very often old and thoroughly experienced electrical engineers find it difficult to keep in touch with them. Even though the designing engineer is familiar with all of them, he may easily forget to include one or more essential safety features in his design. It is therefore the purpose of this article, by M. M. Samuels and F. N. Bechoff, not so much to exhaust the whole field of safety engineering as to bring out in systematic form some of the well-known safety features and at the same time call attention to some which are less known but which are nevertheless of great importance. It is hoped that other contributors will in the future make additional suggestions so that by and by the designing engineer as well as the operator will have ready references whenever he requires them.

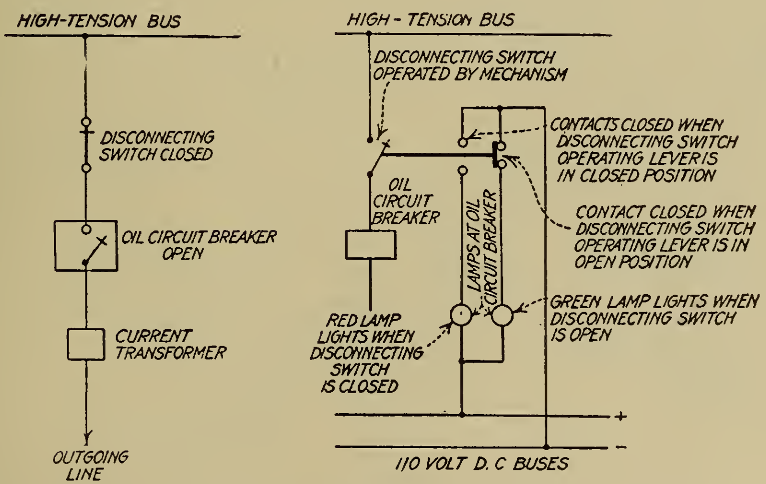
Types of Control Switches Desirable. The design of control switches is one of the first things that demand attention, since switching apparatus used in modern plants is usually installed remote from the switchboard and operated electrically therefrom by means of small control switches. To satisfy the majority of switchboard operators a control switch should be as easy to handle as possible and should be so constructed that the operator cannot perform the wrong operation. These requirements should be obvious, since it is very often necessary to open a circuit hurriedly without having any time for reflection. The switch should always be in working condition and ready to perform safely the next operation. Poor contacts and hidden springs should therefore be eliminated. The usual method of indicating by means of colored lamps whether a circuit is open or closed is not sufficient for modern installations where it is possible not only for a circuit to open automatically but to be opened from other points either inside or outside of the power house. The lamp indicates only that the circuit breaker is open but does not indicate whether the circuit was opened by the operator himself. It is therefore essential that the control switch should be equipped with a reliable, prominent and easily distinguishable mechanical indicator which will indicate the last operation performed by the operator himself. There are some switches now on the market which meet these requirements.

With the great number of indicating lamps on modern switchboards, it is preferable in order to avoid confusion to have the two lamps of a control circuit together with the respective nameplates on a common escutcheon plate with the control switch. It should further be possible to lock the control switch so that it cannot be operated whenever any repairing or inspection is being done on the apparatus controlled by it. Push switches should not be used except in cases where they could not possibly be operated accidentally by the operator's elbow or knee.

To avoid the possibility of closing a main generator circuit breaker without first going through the necessary process of synchronizing, it is customary to interlock the closing circuit of the circuit breaker with the synchronizing receptacle, so that the



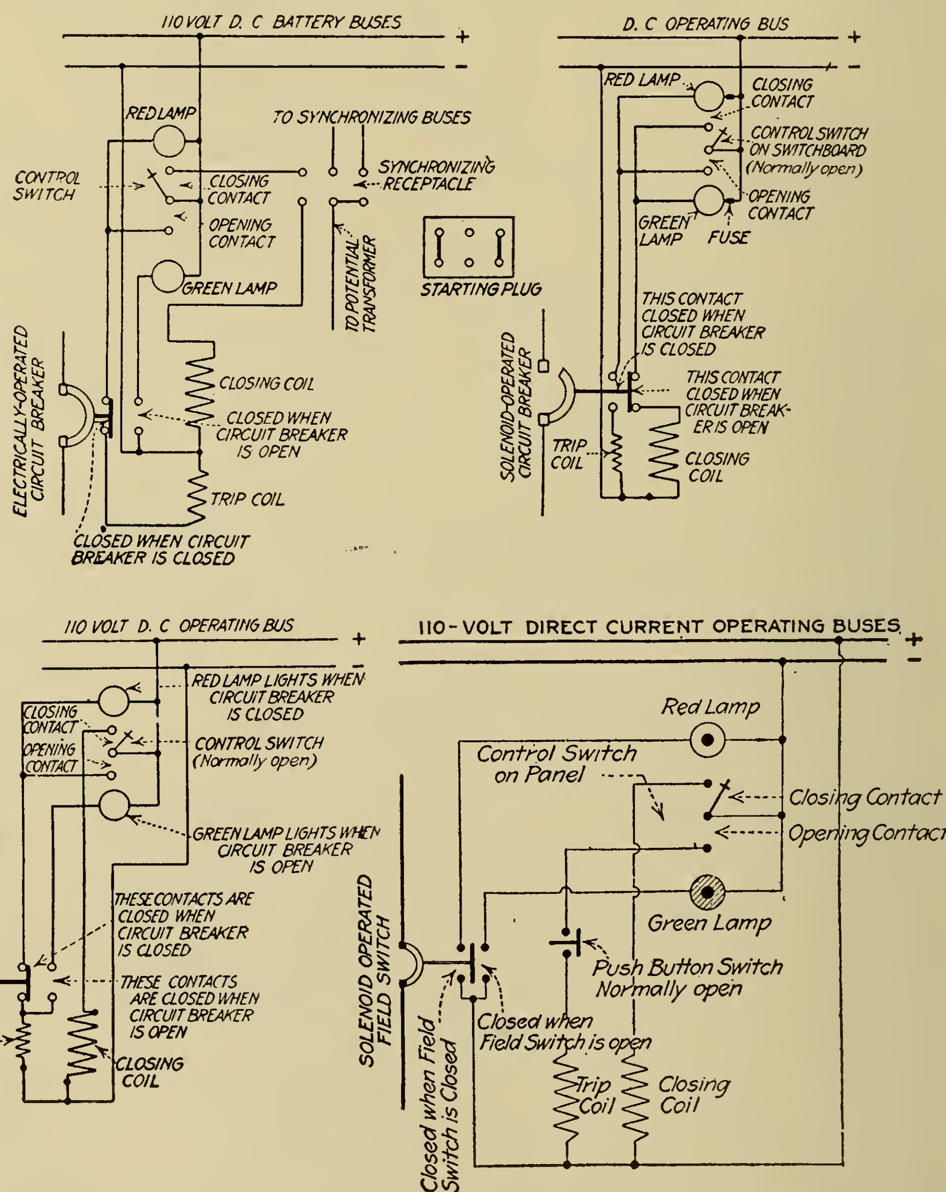
Figs. 13 and 14—Three-way Auxiliary Push-button Interlocked with Three-way Auxiliary Switch for Resetting Bell Alarm; Method of Connecting Danger Signals Along a High-tension Bus



Figs. 15 and 16—Failure to Open Disconnecting Switch May Endanger Person Working Near Oil-switch Terminal; Signals at Oil Switch Indicate Whether Disconnecting Switch is Open or Closed

synchronizing plug must be inserted before the circuit breaker can be closed, as shown in Fig. 17.

A system of control connections like that shown in Fig. 18 is still to be found in a good many installations. This method, although it employs a small number of wires between the switch-board and the circuit breaker, must be condemned from a safety point of view since it may happen, when a circuit breaker is



Figs. 17, 18, 19, and 20—Method of Interlocking Oil-Switch Control Circuit with Synchronizing Circuit; Three-wire and Four-wire Control Circuits (the Three-wire Arrangement has its Disadvantages): Push-button in Field-control Circuit to Avoid Accidental Opening of Field

being repaired, that an accidental short circuit across the green lamp, even with the control switch locked, would energize the closing coil and thus close the breaker and injure the operator. The scheme of connections shown in Fig. 19 is therefore to be recommended as far safer. The fact that with this scheme the red lamp is in series with the trip coil cannot be considered harmful, since a short circuit across the red lamp would only open the breaker. There is an additional advantage with this scheme, which is that any injury to the tripping circuit while the circuit breaker is closed will be called to the operator's attention on the switchboard by the automatic extinguishing of the red lamp. Thus the operator can always be certain that the tripping circuits is in good working order.

Whenever a field circuit breaker of a large unit is electrically operated by means of a control switch care should be taken that the operator does not open the field accidentally or hastily. In order to force the operator to give the matter a second thought before opening the field it is advisable to insert a normally open push-button in series with the opening side of the control switch, so that to open the field both hands must be used. This arrangement is shown diagramatically in Fig. 20.[1]

All bell-alarm relays and other bell-operating devices should be so arranged that the bell continues ringing until stopped by the operator. However, whenever so stopped it should automatically reset itself and be ready for the next operation. A three-way auxiliary switch on the circuit breaker in connection with a three-way snap switch, as shown in Fig. 13, is often used for such purposes. The alarms for the various types of circuit breakers should be made distinguishable by using bells, horns or whistles having different sounds to indicate the automatic opening of different types of apparatus.

The field switch for small units, mounted on the switchboard itself, should not be placed on the front but on the rear of the panel, with an insulated operating handle on the front to avoid accident through flashes. In this connection it may be suggested that it would be a great step toward safety if all lever switches, particularly those on 500-volt circuits, were similarly mounted on the rear of the panels. Carbon-break circuit breakers mounted on the front of the board should be so placed that they cannot strike a person standing near when they open automatically. Double-throw switches, if not mounted horizontally,

[1] By courtesy of C. O. von Dannenberg.

should be equipped with locks or steps to prevent accidental closing.

Fuses of heavy capacity should not be used at all, on account of their unreliability and also on account of the great maintenance expense, says Samuels. Automatic devices should be used instead. If fuses are used they should be of the inclosed type only and should be placed on the rear of the switchboard.

Switchboards and Bus Compartments. Care should be taken to allow for liberal passageways behind all switchboards. A mistake is often made by providing a certain distance from the back of the panels to the wall without regard to the fact that many pieces of apparatus project a considerable distance to the rear of the board, thus materially reducing the size of the passageway. The idea of insulating the switchboard frame must be considered altogether obsolete, and all switchboard framework should be grounded, this being by far the safer method.

Whenever oil switches are mounted directly on the switchboard provision should be made to catch the oil in case of a leak in the tank in order to avoid oily and slippery floors around the switchboards. Buses and connections within reach should be inclosed in grillwork, and in cases where a craneway exists over the switchboard protecting covering should also be installed above the switchboard to protect it from anything which may accidentally fall from the crane.

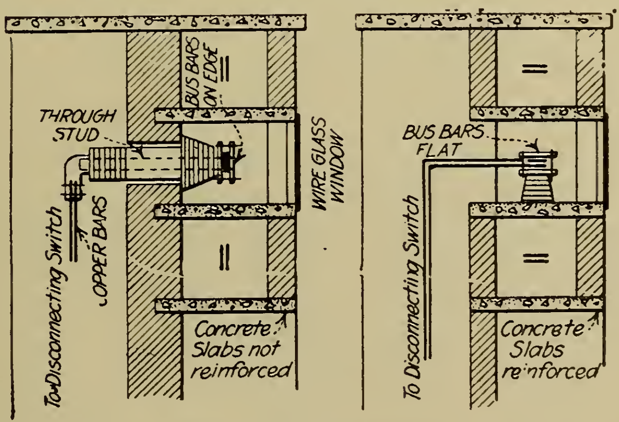
Switchboard illumination is still a much neglected matter. For average switchboard heights 90-in. (228.6-cm.) shades, similar to Benjamin No. 5525, spaced approximately 5 ft. (1.5 m.) in front of board and 1 ft. (0.3 m.) above its top, will be found to give satisfactory results in most cases.

All modern control switchboards should be equipped with mimic bars between all control switches to indicate the interconnections between circuits. Such mimic bus arrangements should be made as simple as possible, and all control switches should be arranged with due regard to a simple layout of the mimic buses.

A great deal of information on the subject of bus and oil circuit-breaker compartments was presented in the *Electrical World* of Jan. 15, 1916. If more attention had been paid to the suggestions made therein, some of the awkward bus arrangements which have recently come to the writer's attention could have been avoided. A few additional remarks on this subject will therefore not be out of place.

All openings in the bus structure opposite bus supports as well as those in front of bus sectionalizing switches should be closed, preferably by wire-glass doors, which will prevent accidental contact with live parts and at the same time allow for frequent inspection. Such doors should preferably be equipped with locks.

The arrangement shown in Fig. 21 is to be preferred to that shown in Fig. 22 because the former allows complete inclosure of the buses without leaving any openings and at the same time



Figs. 21 and 22—Two Methods of Mounting Busbars, the First Being Preferable

gives greater accessibility to the bars. It also makes it easier to arrange the bus laminations in vertical planes, which gives better cooling. In Fig. 22, where the insulator is mounted on the concrete slab, the slab must be reinforced with iron, which is often the cause of heating, while in Fig. 21 no reinforcing is required.

Compartment doors in front of oil circuit breakers or fuses should be so constructed that they can swing out in case of an explosion. On the other hand, doors in front of compartments containing apparatus not subject to explosion should be rigidly fastened. Hinged doors are to be preferred to removable doors, first, because the operator may forget to replace a removable door, thus leaving the compartment open; second, because a removable door is not adapted for locking, and, third, because a removable door if mounted at a considerable height may injure the operator while he is removing it. For compartments containing apparatus of high rating the doors should be provided with openings for ventilation purposes. Hinged doors can be grounded, therefore there is no argument against the use of either all-metal or part-metal doors. In some stations the doors are so interlocked with the circuit-breaker mechanism that they cannot be opened unless the circuit breaker is open. This arrangement, although seemingly offering features of safety, has been found in many cases not to fulfill the requirements for which it was intended, since such interlocks are necessarily complicated and often prevent the door from being opened altogether when it is necessary to open it hurriedly.

Generally it may be stated that the majority of oil circuit-breaker compartments are designed too small and are therefore inaccessible. Oil circuit breakers and mechanisms should be designed so that at least a 4-in. (10.1-cm.) brick wall can be built between phases and still leave ample handling space in the compartments for wiring inspection, repairing and removal of the oil tanks, particularly for cases where a single oil tank is used for multiple circuit breakers. Even in cases where tank lifters are provided there is often hardly room enough for properly attaching the lifter to the tanks.

For very long runs of busbars there should be lamps at certain intervals to indicate whether the bus is "alive" or not, a red lamp indicating danger and a green lamp indicating that the bus is "dead." A simple method for signals of this sort is shown in Fig. 14, where a potential transformer connected across the bus directly operates the red lamp, while the green lamp is supplied from an independent source of energy and is put in circuit by a no-voltage relay on the potential transformer. A green lamp alone would not give sufficient indication that the bus is dead, since an accidental interruption of the potential transformer circuit, either through a short circuit in its winding or other causes, would cause the green lamp to light up even though the bus were alive. When both lamps are used the operator will know that the bus is "dead" only when the red lamp is out and the green lamp is on. In such cases potential transformers should be connected to the buses without fuses, as is done in the case of potential transformers on voltage regulators.

Disconnecting Switches and Instrument Transformers. Where disconnecting switches are operated by switch hooks they should be equipped with locks to prevent their accidental opening. Such locks should be arranged so that the switch hook cannot be removed unless the switch is either entirely open or entirely closed and locked. However, it seems that the time is ripe for the complete elimination of the switch hook, which has ever been a source of danger to operator and apparatus. It is possible to arrange disconnecting switches in such a way that they can be operated safely by means of a mechanism.

Where disconnecting switches are mounted in compartments it should be possible to open the disconnecting switch before open-

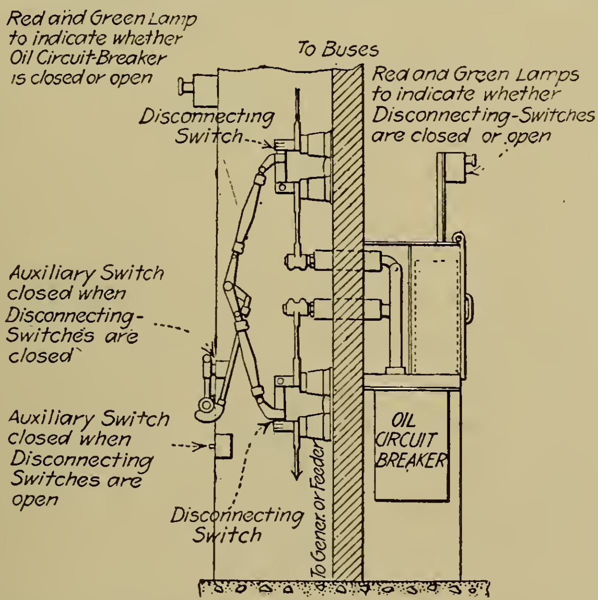


Fig. 23—Proper Location of Red and Green Indicating Lamps on Switch Structure. Indicating Lamps Are Operated by Auxiliary Switches on Oil Circuit Breakers and Mechanically Operated Disconnecting Switches

ing the compartment door for reasons of safety. This, of course, is impossible when the switches are operated by means of a switch hook, but becomes feasible when the operation is performed by a mechanism, since an operating handle can be placed outside of the compartment. Switch hooks are often mislaid or even broken, and even when the switch hook is at hand it takes a considerable length of time to open six disconnecting switches, which must be done in the majority of cases to clear one circuit breaker. With a mechanism like in Fig. 23 [1] all six disconnecting switches can be opened at once.

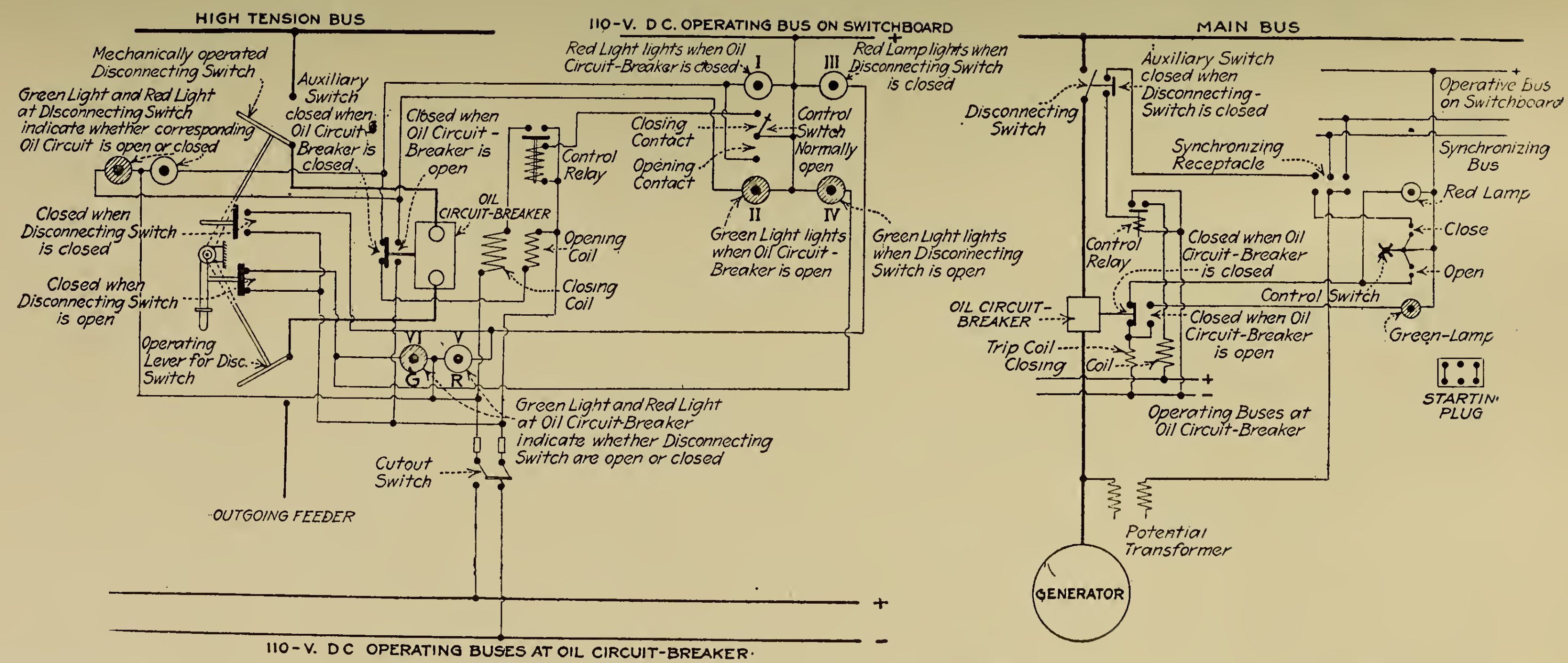
[1] By courtesy of the J. G. White Engineering Corporation.

Where instrument transformers which are connected in series with oil circuit breakers have to be calibrated or repaired the operators sometimes open the oil switch, which of course "kills" the instrument transformer even if the disconnecting switch is closed (see Fig. 15). There are cases on record where an operator, after finishing his work, in attempting to descend from the common foundation of the oil circuit breaker and instrument transformer, accidentally reached over to the live side of the oil circuit breaker and was killed. For this reason it might be advisable to have a warning signal at the oil circuit breaker to tell the operator that the disconnecting switch is closed. Such a signal cannot be provided easily where disconnecting switches are operated by switch hooks. However, where the disconnecting switches are operated by some mechanism it is a very simple matter to install an auxiliary switch which would light a red lamp at the oil circuit breaker when the disconnecting switch is closed and a green lamp when it is open (see Fig. 24). Such auxiliary switches can also operate red and green lamps on the switchboard panels in similar manner.

As an additional precaution, a multi-tumbler lock might be installed on the disconnecting switch handle to lock it in the closed position, so that nobody could accidentally open the disconnecting switch under load. It could also be locked in the open position, so that nobody could close the disconnecting switch when repairing or inspection is being done on the oil circuit breaker. Of course, better results could be obtained with electrically operated disconnecting switches, either by motor or solenoid, and where the extra expense is warranted electrical operation from the switchboard should be used. With this arrangement it is, of course, possible to go a step further and interlock the control circuits of the oil circuit breaker and the disconnecting switches.

Disconnecting switches should be so placed that the blade is dead when the switch is open. This is not always possible when using hook-operated switches but is possible in every case when the disconnecting switches are operated by a mechanism as shown in Fig. 23.

Best Locations for Pilot Lamps. In order to remove as much uncertainty as possible regarding the open or closed condition of oil switches and disconnecting switches when they or their re-



FIGS. 24 AND 25—INDICATING LAMPS ON SWITCHBOARD AND AT OIL CIRCUIT BREAKER AND MECHANICALLY OPERATED DISCONNECTING SWITCH THAT PREVENT FAULTY OPERATION; METHOD OF INTERLOCKING CIRCUIT BREAKER CLOSING CIRCUIT WITH SYNCHRONIZING RECEPTACLE AND AUXILIARY SWITCH

The arrangement shown in Fig. 24 is feasible only with disconnecting switches operated by mechanisms; the connections indicated in Fig. 25 prevent the closing of the oil circuit breaker when the disconnecting switch is open.

spective circuits must be inspected or repaired, indicating lamps can be permanently placed at the points from which they are controlled and at the switch positions too. This is not impracticable if the disconnecting switches are operated by mechanical devices instead of hook switches and are provided with auxiliary switches to control the indicating lamps.

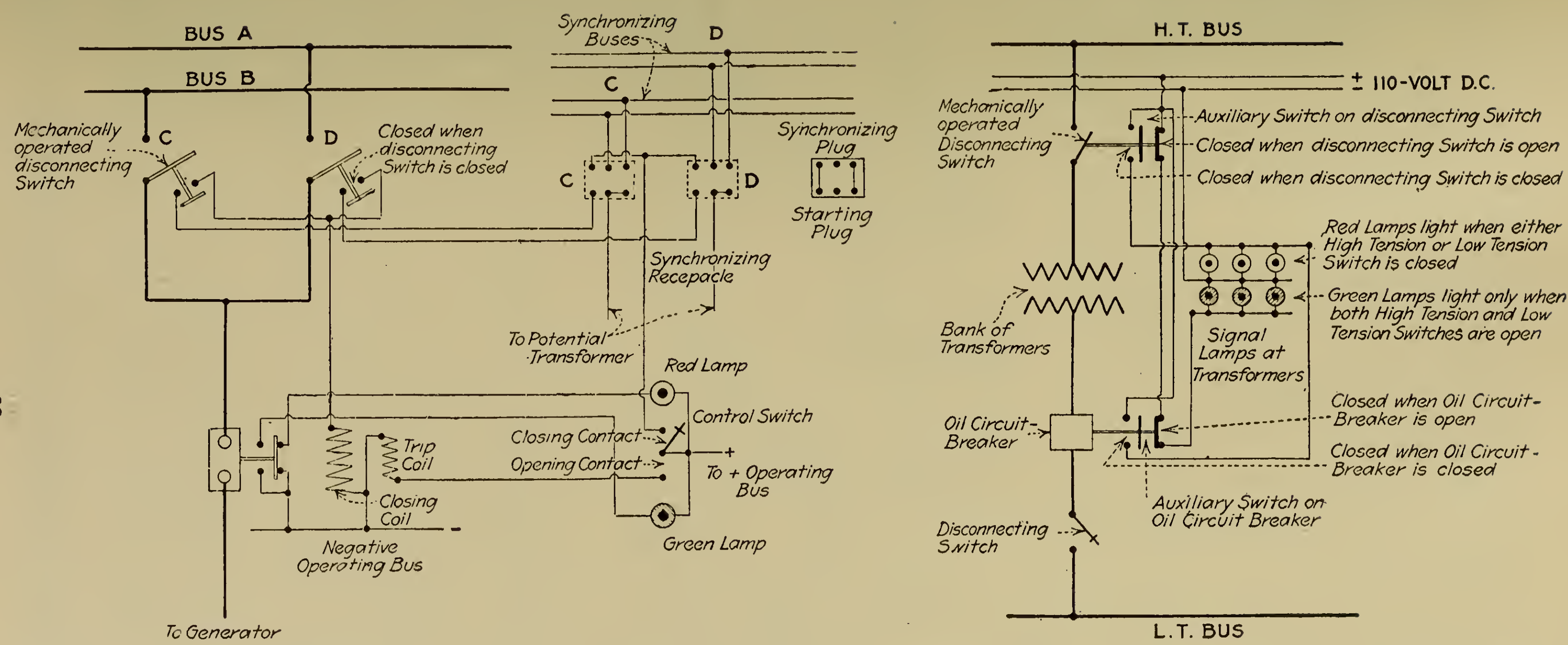
An arrangement which will suggest how this idea can be carried out is shown in Fig. 24, desirable locations for the pilot lamps being indicated in Fig. 23. This scheme can be employed with outdoor open structures as well as with indoor compartment structures.

It is not advisable to use exposed colored bulbs for the pilot lamps, since they are easily damaged and since an operator when renewing lamps might accidentally place a green bulb in a socket intended for a red bulb and vice versa. White bulbs installed in a metal box with red and green lenses in the cover are preferable; the cover should be constructed in such a way that the red and green lenses cannot be interchanged. Details of a box, with lamps and lenses, which fulfills these requirements and allows ample space for the necessary conduit connection and wiring are shown in Figs. 28, 29 and 30. A barrier is provided between the two bulbs so that they can illuminate only their respective lenses. To identify the circuits a name plate can be affixed to the cover.

Possibility and Value of Interlocking Control Apparatus. In addition to providing for the interlocking of oil-circuit-breaker control and synchronizing circuits, it is possible, when using mechanically operated disconnecting switches, so to interlock the control circuit with the mechanism of the disconnecting switch that it is impossible to close the oil circuit breaker unless the disconnecting switch has previously been closed. A method of securing this desirable feature is indicated in Fig. 25.

Even if indicating lamps are used, it may happen that an operator, after having adjusted the speed of a generator to secure synchronism, will close the oil circuit breaker, only to discover that the disconnecting switches are still open. If an operator were sent to close the disconnecting switches and he accidentally did so before the other operator reopened the oil circuit breaker, serious damage might result as a generator would then be connected to a bus with which it was not in synchronism.

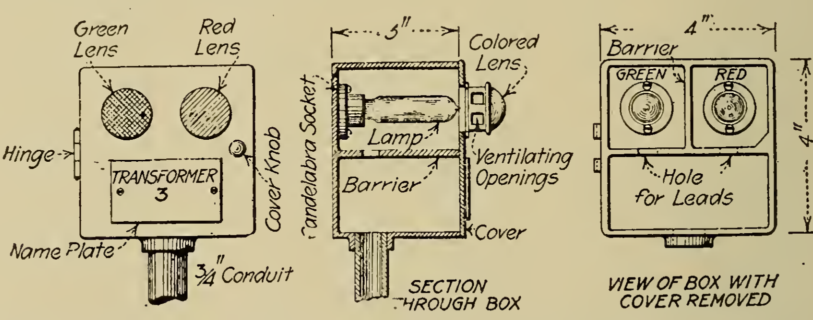
When disconnecting switches are used as bus-selector switches



FIGS. 26 AND 27—SYNCHRONIZING CONNECTIONS SUITABLE WITH TWO SETS OF BUSBARS AND ONE OIL SWITCH; SIGNAL LAMPS AT HIGH-RATED TRANSFORMER TO INDICATE WHETHER TRANSFORMER IS DISCONNECTED ON BOTH SIDES OR NOT

Interlocking of the synchronizing connections with the auxiliary switches and mechanically operated selector disconnecting switches as shown in Fig. 26 prevents throwing of generator on bus with which it is not in synchronism; all auxiliary switches in Fig. 27 operating red lamps are connected in multiple, whereas the auxiliary switches controlling the green lamps are connected in series.

it may happen, when attempting to synchronize two systems, that the wrong disconnecting switch will be closed. If this condition exists and the operator closes the oil switch after apparently synchronizing the two circuits he expects to connect, two buses will be connected which may be entirely out of phase. This would not be liable to happen with mechanically operated disconnecting switches having pilot lamps on the board from which the oil switches are controlled. Absolute safety would be assured if the disconnecting switches, circuit breaker and synchronizing plug were electrically interlocked so that the circuit breaker could not be closed unless the disconnecting switch corresponding to the position in which the synchronizing plug was placed were closed (Fig. 26).



Figs. 28, 29 and 30—Signal Box for Red and Green Indicating Lamps on Switch Structures; Barrier Prevents One Lamp from Illuminating Both Lenses; Unsymmetrical Hinged Cover Prevents Interchangeability of Colors

Some liability insurance companies now require that red and green lamps be placed near each transformer of high rating or high voltage and so connected that the red lamp will indicate when the switch on either the high-tension or the low-tension side of the transformer is closed and that the green lamp will indicate when both the high-tension and low-tension switches are open. This can be accomplished very easily with the connection shown in Fig. 27. The two auxiliary switches controlling the red lamps are connected in multiple, while the two auxiliary switches controlling the green lamps are in series. Where each transformer is installed in a separate compartment it is advisable to provide signal lamps (Fig. 28) ouside of the compartment near the door.

Protecting Main Transformers. All modern high-rated transformers are now equipped with dial thermometers, which indicate the transformer temperature. Some have a contact to ring a bell alarm when the temperature exceeds a given limit. A second contact may be attached to such thermometers in order to trip the transformer oil circuit breaker when the temperature rises above a certain limit. This is particularly advisable when a transformer is placed far enough from the operator to cause danger of the transformer burning out in the interval of time between receiving an alarm and reaching the transformer.

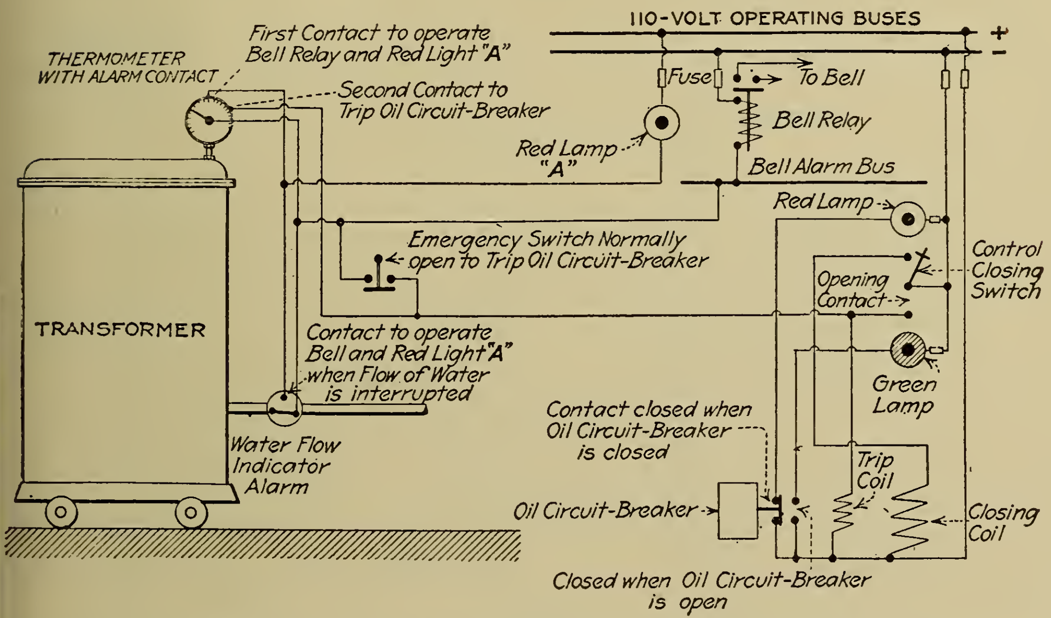


Fig. 31—Temperature and Water-flow Alarm Connections for Transformer

An additional contact is provided on the transformer temperature alarm for tripping the circuit breakers at excessive temperatures; an emergency tripping switch is also provided at the transformer.

Where the transformer is so situated means should also be provided for the operator to trip the circuit breaker from a point near the transformer if an occasion should arise making it necessary. A scheme which will provide such safety features is illustrated in Fig. 31.

Usually water-cooled transformers are equipped with flow indicators which can be electrically connected with the temperature indicator alarm circuit so that interruption of water circulation will automatically give an alarm. When thermometers are used in connection with transformers they should be so installed that it will not be necessary for an operator to climb a ladder in order to read the temperature. Use of contact-making thermometers will eliminate this objection.

Weaknesses of Auxiliary Switches and Relays. Up to the present time, in Samuels' and Bechoff's opinions, there has not been developed an auxiliary switch for oil circuit breakers and other apparatus which is adequate for all purposes. Considering the fact that the operation of nearly all safety devices in power houses and substations depends chiefly on the proper and reliable operation of auxiliary switches, it is obvious that even with modern indicating and automatic safety devices there cannot be

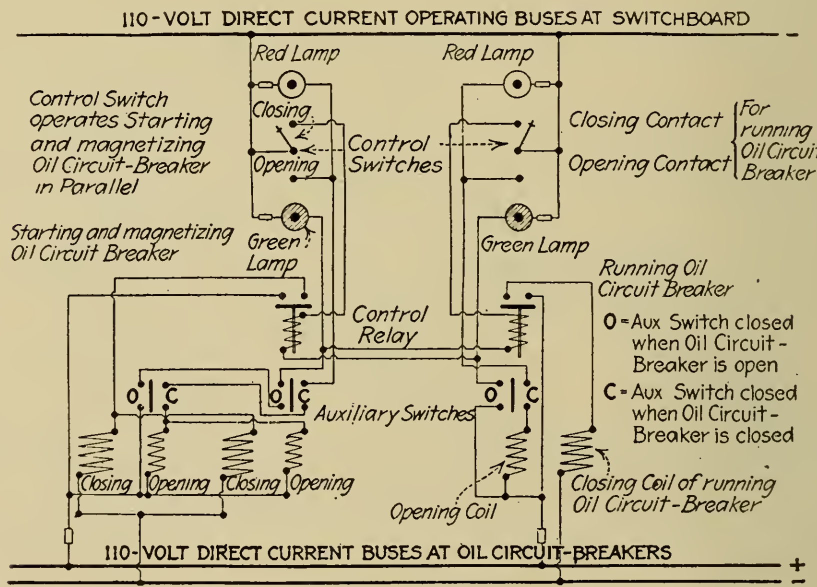


FIG. 32—SYSTEM OF CONNECTIONS FOR INTERLOCKING STARTING, MAGNETIZING AND RUNNING SWITCHES OF LARGE MOTORS; PROPER OPERATION OF INTERLOCKING CONNECTIONS DEPENDS ON RELIABILITY OF AUXILIARY SWITCHES

a high degree of safety unless a standardized, practically infallible auxiliary switch is developed. Auxiliary switches which may have been perfectly satisfactory for apparatus used in the past are not at all adequate for modern circuit breakers because their rupturing capacities and velocities of operation have both been increased. All auxiliary switches should be easily accessible for connection, inspection and repair. Owing to unreliability of auxiliary switches known to the authors, it is sometimes necessary to use multiple contacts, but this precaution does not always prevent auxiliary switch trouble. Usually there is an auxiliary switch in the tripping circuit of each circuit breaker, and if this switch fails the circuit breaker will fail to open when overloaded or short-circuited, thus causing considerable damage to the transformers and other apparatus connected therewith.

The interlocking of circuit breakers to prevent the simultaneous closing of two or more of them where such simultaneous closing would be dangerous is usually accomplished by auxiliary switches. For instance, when large motors are started by means of a compensator a magnetizing switch, a starting switch and a running switch are provided. It is important that the control circuits of these three switches be interlocked so that the running switch cannot be thrown in until the motor is brought to speed by the magnetizing and starting switches. It is of even greater importance not to have the starting and running switches both closed at the same time, since under this condition the compensator would burn out. Interlocking to prevent such trouble may be accomplished with hand-operated switches by mechanical means, but with electrically operated oil circuit breakers it is necessary to interlock the control circuits electrically by means of auxiliary switches unless the control switches are mechanically interlocked. Although interlocking of the control circuits gives a more flexible arrangement, it cannot be considered the safest method unless a thoroughly reliable auxiliary switch is employed. The connections for electrically interlocking oil circuit breakers used in starting either synchronous or induction motors are shown in Fig. 32.

What applies to auxiliary switches is likewise true of relay contacts. Although progress has been made in the design of various types of relays, their contacts should be further improved, since the majority of modern relay contacts are unable to carry the current required to trip large circuit breakers. Often it becomes necessary to resort to auxiliary relays, which are only an additional evil, because the size of nearly all relays is restricted by the secondary ampere rating of the current transformers, which generally does not exceed 5 amp. White 5-amp. secondaries are sufficient on current transformers for use with meters and also for operating automatic devices on circuits of low capacity, they are hardly suitable for oil circuit breakers of high rupturing capacity. Therefore it is suggested that the secondary rating of current transformers for such protective purposes be increased. When this is done it will be possible to develop relays with contacts of adequate size. While the same current transformer is suitable for both the meters and relays in small installations, two separate sets of current transformers are advisable in large installations: One set should be used for the meters and the other for automatic relay protection. With this arrangement it is obvious that an increase in the rating of the secondaries of the relay current transformers would not destroy the accuracy of the meter reading, a consideration of importance.

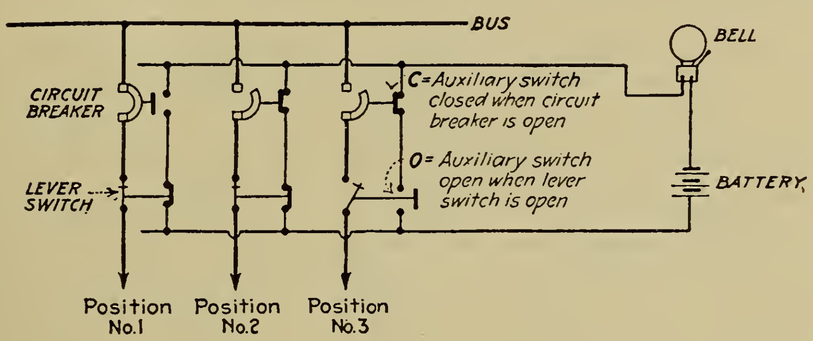
It is still customary to install all relays on the switchboard, this arrangement being necessary because the present relays require constant attention and frequent inspection and adjustment. With current transformers having a higher secondary rating it will be possible to design relays of large sizes and more rugged construction. Such relays would not have to be mounted on the switchboard but could be placed near the oil circuit breakers or other apparatus which they are to protect, thus eliminating unnecessary conduits and wiring and minimizing the switchboard space necessary.

Provisions should be made for disconnecting control devices from the control bus to permit repairing and inspection.

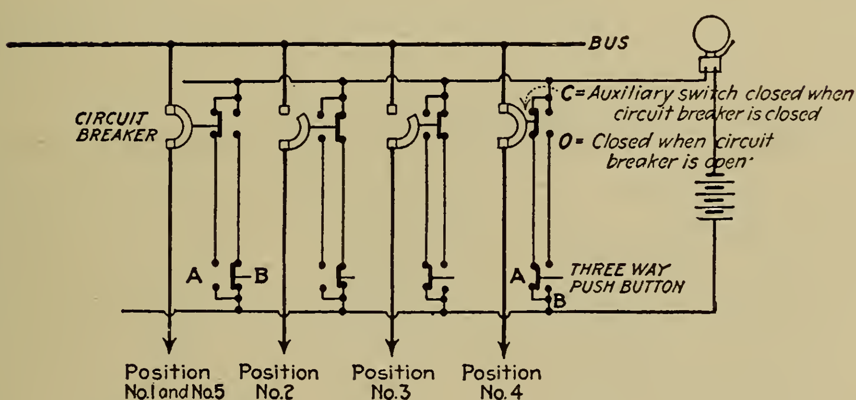
Bell Alarms. Since the major portion of the switching apparatus in large plants is usually installed remote from the switchboard, so that the switchboard operator is not in a position to observe the automatic tripping of circuit breakers or the excessive heating of transformers and other apparatus, it is necessary to provide some form of alarm for this purpose. In spite of the obvious importance of such alarms the subject has hardly ever been discussed in engineering literature, and a great deal of confusion and misconception with reference thereto exists in the minds even of some good designers and operators. It is the authors' intention to give first a brief review of the existing methods of alarm, then discuss their weak points and make suggestions for improvements.

The fundamental requirement of any alarm is that it must be self-resetting. In other words, when the apparatus which caused the alarm is again placed in normal operation the alarm-giving device should automatically be ready to give an alarm if trouble recurs.

Alarms for Hand-Operated Circuit Breakers.—For hand-operated circuit breakers having lever switches in series with them, the connections can be arranged as in Fig. 33. With this method auxiliary contacts are provided on the circuit breaker as well as on the lever switch, both the auxiliary switches being in series with a bell circuit. The auxiliary switch on the circuit breaker



Position No.1 *Circuit in working condition*
Position No.2 *Circuit breaker opened automatically. Bell is ringing*
Position No.3 *Operator opened lever switch which stopped bell*



Position No.1 *Circuit in working condition*
Position No.2 *Circuit opened automatically. Auxiliary switch starts bell*
Position No.3 *Operator brings three way push button from B to A thus stopping the bell*
Position No.4 *Circuit breaker closed again. Bell rings*
Position No.5 *Operator brings three way push button back from A to B thus stopping bell and resetting it for next tripping of circuit breaker*

FIGS. 33 AND 34—CIRCUIT BREAKERS WITH AND WITHOUT LEVER SWITCH IN SERIES

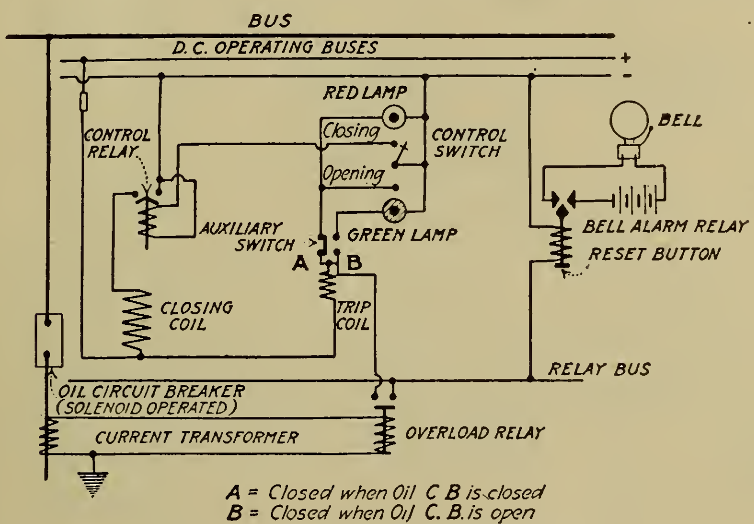
is open when the circuit breaker is closed and is closed when the circuit breaker is open, while the auxiliary switch actuated by the lever switch is closed when the lever switch is closed and is open when the lever is open. Thus when the breaker trips automatically it closes the bell circuit, as shown in position 2 of Fig.

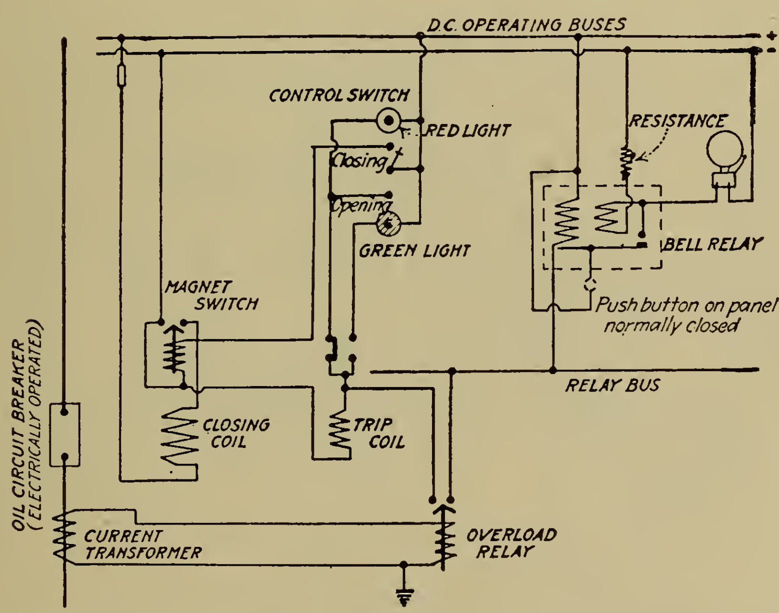
33, thereby ringing the bell. The operator may interrupt the ringing of the bell by opening the lever switch as shown in position 3 of Fig. 33. When the lever switch is closed after reclosing the breaker the bell circuit is made automatically ready to give an alarm if the breaker trips again.

For circuit breakers not having lever switches in series with them the problem becomes a little more difficult. In order to provide automatic resetting of the bell circuit it is necessary to equip the circuit breaker with a double-pole auxiliary switch, one side of which is closed when the circuit breaker is closed and the other side closed when the circuit breaker is open. Such an auxiliary switch is called a "circuit closing and opening auxiliary switch." In addition to this it is necessary to provide on the switchboard a three-way snap or push switch for each circuit breaker, as shown in Fig. 34, the diagram being self-explanatory. With this arrangement the resetting of the bell circuit is not automatic but must be done by the operator. In order to remind the operator to reset the three-way push-button, the circuit breaker rings the bell when it closes and the ringing is only stopped when the operator resets the button.

Alarms for Electrically Operated Circuit Breakers. Of far greater importance is the bell-alarm indication for electrically operated circuit breakers. Such circuit breakers are always placed at a considerable distance from the switchboard. Automatic electrically operated circuit breakers are tripped by means of overload reverse-energy or other types of relays. Such relays are always deënergized the moment the breaker opens, and if the bell alarm were operated directly by the overload relay the bell would only ring for a very short period and might stop ringing before the operator heard it.

To avoid this objection a special type of relay has been developed which is so constructed that the contacts which close the bell circuit stay closed even after the circuit of its coil is interrupted. Thus the bell should continue ringing until stopped by the operator. Such relays are commonly known as "bell-alarm relays." Figs. 35 and 36 show the connections of two of the best-known bell-alarm relays. The type shown in Fig. 35 is so constructed that the core which closes the bell circuit contacts stays up after it is once raised by the coil, even after the coil circuit is broken. In order to interrupt the bell circuit it is necessary for the operator to pull the core down by hand, which can be done by means of a knob at the bottom of the relay. This relay must, of course, be mounted within easy reach of the operator. With the relay shown in Fig. 36 the ringing of the





Figs. 35 and 36—Bell Relay Mechanically and Electrically Reset

bell is maintained by means of an auxiliary coil having common yoke with the main relay coil; interruption of the bell circuit is accomplished by means of a normally closed momentary push-button on the switchboard. It would not be practicable to provide a separate bell and a separate bell relay for every automatic circuit breaker; therefore it is customary to make one bell relay with its bells serve for a great many circuit breakers.

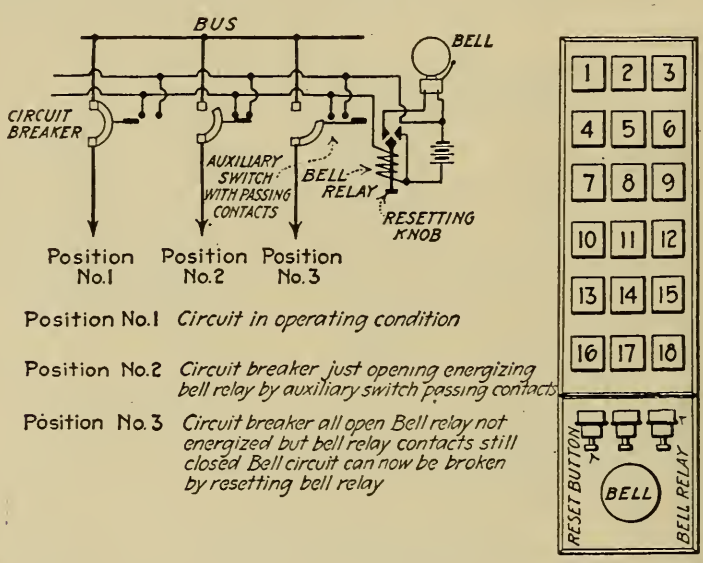


FIG. 37—AUXILIARY SWITCH OPERATES BELL ALARM

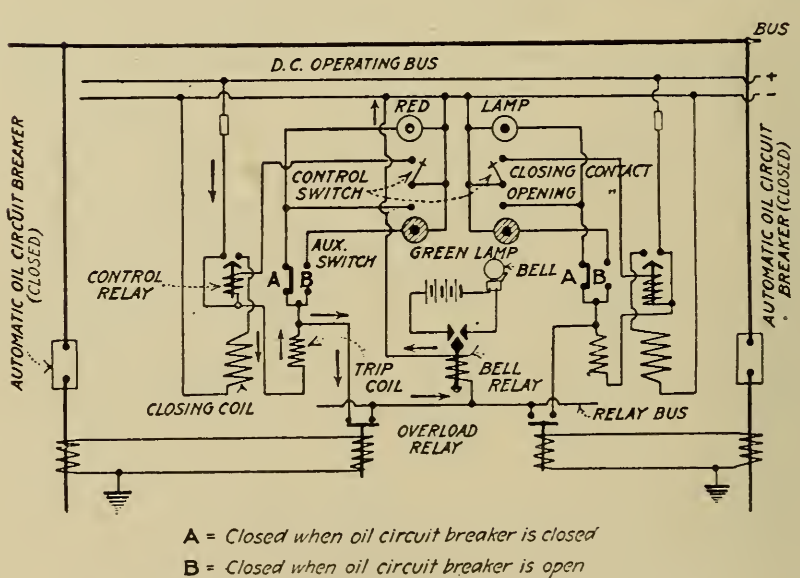


FIG. 38—TRIP COIL IN SERIES WITH BELL ALARM

This is accomplished by means of a bell relay bus, as shown in Fig. 38.

Upon carefully analyzing the connection shown in Fig. 38, which exists in practically every power house or substation using electrically operated circuit breakers, the most startling discovery is made that every trip coil on the system is in series with the one bell-alarm relay coil. This means that if the one bell-alarm relay coil should be out of service it would not be possible for any circuit breaker to open under overload, short circuit or reverse energy, thus subjecting the whole system to disaster.

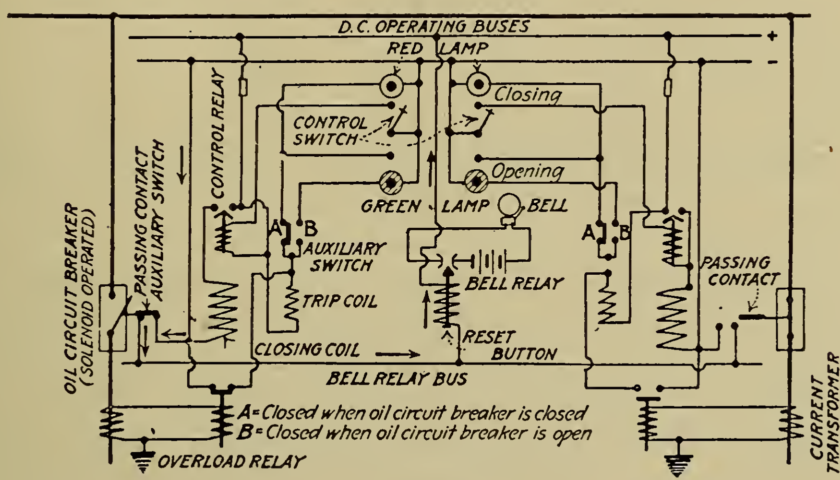


Fig. 39—Tripping Circuit Independent of Bell Alarm

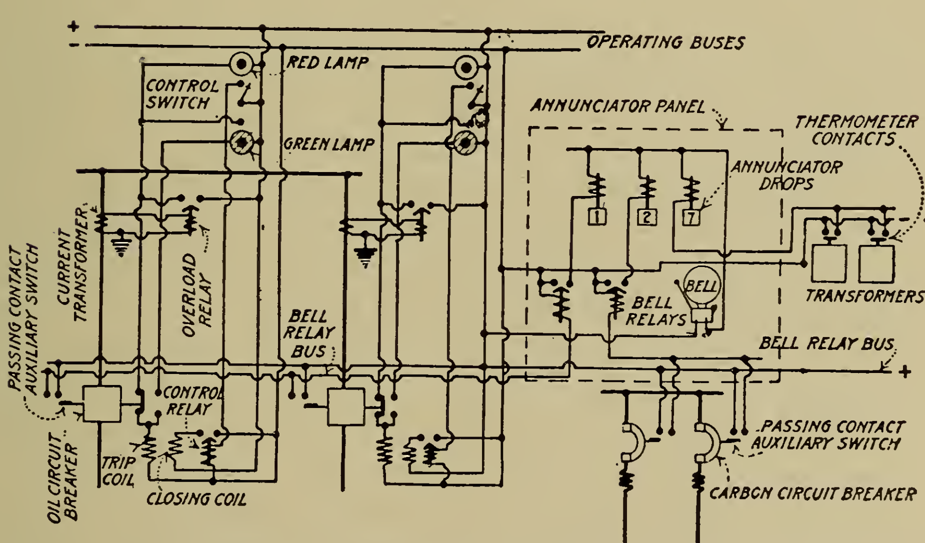


Fig. 40—Connections for Annunciator Making Trip Coils Independent of Alarm

Even though the bell-alarm relay is of very simple construction and not subject to great abuse, the possibility of an interruption is always present. It seems to be due to good fortune only that one does not often hear of station troubles caused by the failure of a bell-relay coil. It is possible that many station disasters in the past, the cause of which could not be traced, were in reality due to an interruption of a bell-relay circuit. A partial remedy can be obtained by the use of two bell relays in multiple, which method is now being employed in some cases. But it must be admitted that such a remedy is only a palliative and does not go to the root of the evil.

Safe Method That Future Will Demand. The only safe method to be employed in the future and to be favored by insurance companies is to make the automatic tripping of the circuit breaker entirely independent of the bell-relay coil. In order to accomplish this it is suggested that there be provided on every electrically operated circuit breaker a ''passing contact auxiliary switch,'' which should be so constructed that it is actuated mechanically by the opening mechanism of the circuit breaker. This auxiliary switch should be so arranged that it closes only momentarily during the opening period of the circuit breaker. This short period would be sufficient to energize a bell relay, the contacts of which would stay closed even after the ''passing contact auxiliary switch'' is open and thus would continue to ring the bell until the operator resets the bell relay. A diagram showing the simplest form of this arrangement is given in Fig. 39, which is self-explanatory. With the scheme shown in Fig. 39 the bell would also ring when the circuit is opened by hand. Instead of being a disadvantage this should be considered an advantage, because the operator who is not in the same room with the circuit breaker, when hearing the bell will know definitely that the circuit breaker actually opened. If so desired, this same auxiliary switch in its simplest form would also ring the bell when the circuit is being closed, which would be a definite indication for the operator that the switch is actually closed, even when the red lamp is burnt out. For remote-control hand mechanisms, which generally have no indicating lamps, the ringing of the bell when the operator closes or opens a circuit breaker would be of still greater importance. If the ringing feature is not desired when closing the circuit breaker it can be easily eliminated by a suitable design of the ''passing constant auxiliary switch.'' By referring to Fig. 39 it will be seen at once that the tripping circuit has no connection whatever with the bell-alarm relay, so that an injury to the bell-relay coil circuit will not endanger the tripping of the circuit breaker under overload.

The "passing constant auxiliary switch" can also be applied to hand-operated circuit breakers, as shown in Fig. 37. This arrangement would eliminate the necessity of installing a three-way push-button for every circuit breaker, as described before in connection with Fig. 34.

ALLOWABLE SIZES OF WIRE FOR INTERMITTENT LOADS

The ultimate temperature rise of a conductor subject to a given intermittent load depends upon the ratio of the "on" and "off" time of the current. Unless the current is off long enough to allow of the dissipation of all of the heat accumulated during the "on" period, the temperature will rise. At low temperatures the dissipation of heat proceeds at a very slow rate, but at the higher temperatures such as 20 deg. or 30 deg. C. it is quite rapid. Therefore the relative time in which a given quantity of heat may be dissipated varies greatly with the temperature rise permitted. These facts are illustrated in Tables III to XVIII inclusive, which are designed to assist in selecting the smallest wire that may be used to carry a given intermittent load. These tables refer only to wire in conduit and are based on extensive tests conducted by H. C. Horstman and Victor Tousley. The data are not presented to discountenance the National Electric Code rulings regarding wire sizes but they do indicate that much smaller conductors can be used with intermittent loads than are now required.

Explanation of the Tables. A separate table is provided for each of the wire sizes considered, and each table has two parts. In the left-hand portion of the tables is given the time in seconds required, for the various currents in amperes given at the top, to raise the temperature of the conductor 2 deg. above the surrounding air within the range of temperature given at the extreme left. Thus, referring to No. 14 wire, 20 amp. will raise the temperature of the conductor from 10 deg. to 12 deg. C. in 120 seconds, but it will require 420 seconds to effect a temperature rise from 20 deg. to 22 deg. In the last columns at the

Time in Seconds Required to Raise or Lower Temperature

TABLE III—THREE NO. 14 D. B. R. C. WIRES IN ½-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 15	20	25	45	Cooling Load (Amp.) 7½	0
10–12	690	120	60	12	330	180
12–14	1,200	130	65	12	350	135
14–16	2,400	180	70	12	180	120
16–18	...	240	75	12	135	105
18–20	...	300	80	12	120	90
20–22	...	420	90	12	105	75
22–24	...	570	100	12	85	60
24–26	...	1,500	110	12	75	60
26–28	...	...	125	12	60	55

TABLE IV—THREE NO. 12 D. B. R. C. WIRES IN ¾-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 20	25	35	60	Cooling Load (Amp.) 10	0
10–12	330	105	48	10	195	160
12–14	480	135	48	10	185	125
14–16	840	165	48	10	135	115
16–18	1,920	225	48	10	115	95
18–20	...	330	48	10	100	90
20–22	...	405	48	10	90	80
22–24	...	560	48	10	80	70
24–26	...	1,860	48	10	70	70
26–28	...	...	..	..	70	70

TABLE V—THREE NO. 10 D. B. R. C. WIRES IN ¾-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 25	35	50	75	Cooling Load (Amp.) 12½	0
10–12	440	120	50	15	390	225
12–14	720	135	50	15	300	210
14–16	1,500	150	50	15	210	180
16–18	...	165	50	15	180	150
18–20	...	180	50	15	150	120
20–22	...	240	50	15	120	100
22–24	...	300	50	15	90	90
24–26	...	400	50	15	80	80
26–28	...	780	50	15	60	60

Time in Seconds Required to Raise or Lower Temperature (Continued)

TABLE VI—THREE NO. 8 D. B. R. C. WIRES IN 1-IN. BLACK-ENAMELED CONDUIT

Temperature	Heating Load, Amp.				Cooling Load (Amp.)	
Range, deg. C.	35	50	70	105	17½	0
10–12	510	120	43	16	540	465
12–14	790	135	43	16	405	370
14–16	1,600	165	43	16	320	240
16–18	...	180	43	16	270	195
18–20	...	210	43	16	215	140
20–22	...	240	43	16	180	125
22–24	...	300	43	16	150	105
24–26	...	350	43	16	100	100
26–28	...	510	43	16	90	90

TABLE VII—THREE NO. 6 D. B. R. C. WIRES IN 1-IN. BLACK-ENAMELED CONDUIT

Temperature	Heating Load, Amp.					Cooling Load (Amp.)	
Range, deg. C.	50	70	80	100	150	25	0
10–12	420	105	75	37	14	750	300
12–14	630	120	80	37	14	510	260
14–16	900	140	80	37	14	390	225
16–18	1,560	150	80	37	14	300	190
18–20	...	160	80	37	14	240	175
20–22	...	180	90	37	14	185	160
22–24	...	200	105	37	14	160	135
24–26	...	210	110	37	14	125	120
26–28	...	240	125	37	14	100	100

TABLE VIII—THREE NO. 4 D. B. R. C. WIRES IN 1¼-IN. BLACK-ENAMELED CONDUIT

Temperature	Heating Load, Amp.						Cooling Load (Amp.)	
Range, deg. C.	70	80	90	100	140	210	35	0
10–12	310	225	135	120	40	17	900	350
12–14	400	250	150	120	40	17	600	250
14–16	500	280	175	120	40	17	420	220
16–18	700	320	200	130	40	17	360	200
18–20	900	390	225	135	40	17	300	180
20–22	1,200	450	240	140	40	17	240	150
22–24	...	540	275	150	40	17	190	120
24–26	...	840	375	180	40	17	160	90
26–28	...	2,100	420	215	40	17	150	75

Time in Seconds Required to Raise or Lower Temperature (Continued)

TABLE IV—THREE NO. 3 D. B. R. C. CABLES IN 1½-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 80	90	100	160	240	Cooling Load (Amp.) 40	0
10–12	420	290	190	47	23	750	450
12–14	490	330	200	47	23	540	300
14–16	700	390	220	47	23	400	260
16–18	1,140	525	240	47	23	300	240
18–20	2,500	660	285	47	23	280	210
20–22	...	760	360	47	23	240	160
22–24	...	1,230	450	47	23	215	140
24–26	...	...	560	47	23	180	125
26–28	...	...	780	47	23	160	115

TABLE X—THREE NO. 2 D. B. R. C. CABLES IN 1¼-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 90	125	180	270	Cooling Load (Amp.) 45	0
10–12	460	150	56	19	780	390
12–14	575	180	56	19	560	330
14–16	720	180	56	19	430	300
16–18	1,250	180	56	19	340	270
18–20	2,400	200	56	19	260	210
20–22	...	270	56	19	210	180
22–24	...	310	56	19	190	150
24–26	...	410	56	19	170	120
26–28	...	520	56	19	150	100

TABLE XI—THREE NO. 1 D. B. R. C. CABLES IN 1½-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 100	125	150	200	300	Cooling Load (Amp.) 50	0
10–12	420	225	115	68	20	810	540
12–14	540	240	122	68	20	600	375
14–16	600	250	130	68	20	450	300
16–18	750	275	135	68	20	405	245
18–20	960	300	150	68	20	315	210
20–22	2,700	375	165	68	20	285	200
22–24	...	480	190	68	20	220	160
24–26	...	580	200	68	20	195	150
26–28	...	730	225	68	20	180	140

Time in Seconds Required to Raise or Lower Temperature (Continued)

TABLE XII—THREE NO. 0 D. B. R. C. CABLES IN 2-IN. BLACK-ENAMELED CONDUIT

Temperature	Heating Load, Amp.				Cooling Load (Amp.)	
Range, deg. C.	125	175	250	375	62½	0
10–12	405	125	64	23	960	480
12–14	495	150	64	23	630	390
14–16	660	160	64	23	510	320
16–18	960	170	64	23	420	270
18–20	400	180	64	23	360	225
20–22	2,400	190	64	23	315	195
22–24	...	215	64	23	280	170
24–26	...	240	64	23	240	150
26–28	...	280	64	23	210	135

TABLE XIII—THREE NO. 00 D. B. R. C. CABLES IN 2-IN. BLACK-ENAMELED CONDUIT

Temperature	Heating Load, Amp.				Cooling Load (Amp.)	
Range, deg. C.	150	225	300	450	75	0
10–12	420	146	51	22	1,080	525
12–14	480	146	51	22	720	375
14–16	580	146	51	22	600	325
16–18	740	146	51	22	500	300
18–20	1,110	146	51	22	420	270
20–22	1,740	146	51	22	345	240
22–24	2,400	146	51	22	285	220
24–26	...	146	51	22	240	200
26–28	...	146	51	22	200	185

TABLE XIV—THREE NO. 000 D. B. R. C. CABLES IN 2-IN. BLACK-ENAMELED CONDUIT

Temperature	Heating Load, Amp.				Cooling Load (Amp.)	
Range, deg. C.	175	262½	350	525	87½	0
10–12	620	130	63	26	1,275	510
12–14	735	150	63	26	840	420
14–16	900	150	63	26	540	380
16–18	1,140	150	63	26	440	360
18–20	1,560	165	63	26	405	345
20–22	3,600	180	63	26	380	300
22–24	...	195	63	26	360	250
24–26	...	210	63	26	325	210
26–28	...	230	63	26	280	185

Time in Seconds Required to Raise or Lower Temperature (Continued)

TABLE XV—THREE NO. 0000 D. B. R. C. CABLES IN 2½-IN. BLACK-ENAMELED CONDUIT

Temperature Range, deg. C.	Heating Load, Amp. 225	281	337	394	450	675	Cooling Load (Amp.) 112½	0
10–12	270	120	100	71	51	21	3,000	630
12–14	320	120	100	71	51	21	1,800	540
14–16	330	135	100	71	51	21	1,320	450
16–18	390	150	100	71	51	21	990	420
18–20	420	165	100	71	51	21	640	330
20–22	465	170	100	71	51	21	480	280
22–24	600	180	100	71	51	21	405	240
24–26	810	195	100	71	51	21	330	210
26–28	1,260	210	100	71	51	21	300	175

TABLE XVI—THREE NO. 300,000-CIRC. MIL. D. B. R. C. CABLES IN 2½-IN. BLACK-ENAMELED CONDUIT [1]

Temperature Range, deg. C.	Heating Load, Amp. 275	343	410	482	550	825	Cooling Load (Amp.) 137	0
10–12	600	250	165	120	77	31	...	930
12–14	670	260	180	120	77	31	2,400	780
14–16	800	280	190	120	77	31	1,650	690
16–18	870	300	195	120	77	31	1,170	630
18–20	960	330	225	120	77	31	900	570
20–22	1,200	360	240	120	77	31	720	470
22–24	1,800	380	255	120	77	31	600	375
24–26	2,000	420	270	120	77	31	550	310
26–28	...	470	285	120	77	31	465	300

TABLE XVII—THREE NO. 400,000-CIR. MIL. D. B. R. C. CABLES IN 3-IN. BLACK-ENAMELED CONDUIT [1]

Temperature Range, deg. C.	Heating Load, Amp. 325	406	487	568	650	975	Cooling Load (Amp.) 162½	0
10–12	600	250	165	120	77	31	...	930
12–14	670	260	180	120	77	31	2,400	780
14–16	800	280	190	120	77	31	1,650	690
16–18	870	300	195	120	77	31	1,170	630
18–20	960	330	225	120	77	31	900	570
20–22	1,200	360	240	120	77	31	720	470
22–24	1,800	380	255	120	77	31	600	375
24–26	2,000	420	270	120	77	31	550	310
26–28	...	470	285	120	77	31	465	300

[1] Figures for this and next size of wire are based on the assumption that N. E. Code carrying capacity would produce the same temperature rise in these conductors as is found in the 500,000-circ. mil. cable. No tests were made on these two sizes.

TIME IN SECONDS REQUIRED TO RAISE OR LOWER TEMPERATURE (Continued)

TABLE XVIII—THREE NO. 500,000-CIRC. MIL. D. B. R. C. CABLES IN 3-IN. BLACK-ENAMELED CONDUIT

Temperature Range	Heating Load, Amp.						Cooling Load (Amp.)	
	400	500	600	700	800	1,200	200	0
10–12	600	250	165	120	77	31	...	930
12–14	670	260	180	120	77	31	2,400	780
14–16	800	280	190	120	77	31	1,650	690
16–18	870	300	195	120	77	31	1,170	630
18–20	960	330	225	120	77	31	900	570
20–22	1,200	360	240	120	77	31	720	470
22–24	1,800	380	255	120	77	31	600	375
24–26	2,000	420	270	120	77	31	550	310
26–28	...	470	285	120	77	31	465	300

right is given the time in seconds required for the conductor to lose 2 deg. within the same ranges of temperature considered for the heating, and provided no current is flowing.

The usefulness of these tables is based on the assumption that no attention need be paid to the heating of a conductor until it approaches the limits imposed by the operating conditions. If intermittent loads continue long enough, there will be a steady rise in the temperature of the conductor until a point is reached at which the cooling is rapid enough to prevent further heating. The higher the temperature attained the less increase there will be with a given current and the more rapid will be the dissipation of heat during the "off" period. Again, taking the table for No. 14 wire as an illustration, it can be seen that 20 amp. will require 120 seconds to cause a rise of 2 deg. from 10 to 12, and that it will require 180 seconds to lose this heat. If the temperature is allowed to rise to 14 deg., however, it will require 130 seconds for the rise from 12 to 14, and the loss of the two degrees will take place in 135 seconds. With 20 amp. "on" and "off" for equal lengths of time there will, therefore, be a continuous rise in temperature until a trifle above 14 deg. has been reached. The same table also shows that if 45 amp. exists for 12 seconds and it is not desired that the temperature rise should go above 16, an off period of 120 seconds would be required. In any case, whenever the "on" and "off" times of the current are in the same ratio as the heating and cooling times given in any horizontal line, the ultimate temperature rise of the conductor will range between the limits given in the left-hand column in the same line. If a current equal to that indicated at the top of the next to the last column is maintained the time required for a reduction of two degrees will be found below opposite the temperature range being considered.

The use of the tables can best be explained by an example: A small electric welder requires a current of 50 amp., and the greatest length of time during which this current is in use is one second, while the shortest off time is two seconds. The present requirements of the National Electrical Code in this case are for a No. 6 conductor; but if the table for No. 10 wire is observed and the column headed "50 amp." traced, it will be seen that in 50 seconds a temperature rise of 2 deg. will take place. Keeping in mind that the cooling time in this case may be twice as long, it can be seen from the column for zero load horizontally to the left of 100 seconds that a temperature of between 20 deg. and 22 deg. will exist. This is the temperature the conductor will attain if it is subject to the operating conditions given for a long time or indefinitely. If this temperature is considered too high for the conditions, the next table for No. 8 may be consulted. In this are no heating and cooling times that balance so nicely, but in the 14–16 deg. line is a heating time of 165 seconds and a cooling time of 240. This signifies that the temperature of the conductor will remain below 16 deg., and since the heating period from 12 to 16 is 300 seconds and the cooling time between 12 and 16 is 610, the temperature rise will be between 12 and 16 deg. In any case it is evident that No. 6 wire is larger than necessary.

On a chart representing a fluctuating load all short-time use of current appears is recorded in the form of triangles. Currents of longer duration usually form approximations to square or oblong bodies, and their effective values may be easily calculated. Now the root-mean-square value of a sufficient number of evenly spaced altitudinal lines in a triangle is about 58 per cent of the extreme altitude. The speed of the paper will affect the appearance of the triangle, but as long as the base is expressed in seconds and the altitude in amperes this will not matter. Hence in all those graphs which approximate a triangular form the root-mean square current may be estimated by striking off the top 42 per cent and widening the triangles at the place where they are cut off to the width of the base. It must be noted that in a calculation of this kind there is no need of any great degree of accuracy since no two duty cycles show the same result. On this account the period showing the heaviest use of current should be selected.

By the use of the tables the proper size of wire to use with any intermittent load may be found in a simple manner. A casual inspection of Fig. 41 shows (neglecting the highest peak load) an average of about 750 amp. "on" and "off" for about equal lengths of time. It is essential to find out what this will bring about in two conductors of 500,000 circ.mil in parallel. For this purpose, as there are two wires in each leg, the current is divided by 2, which gives 375 amp. on one wire "on" and

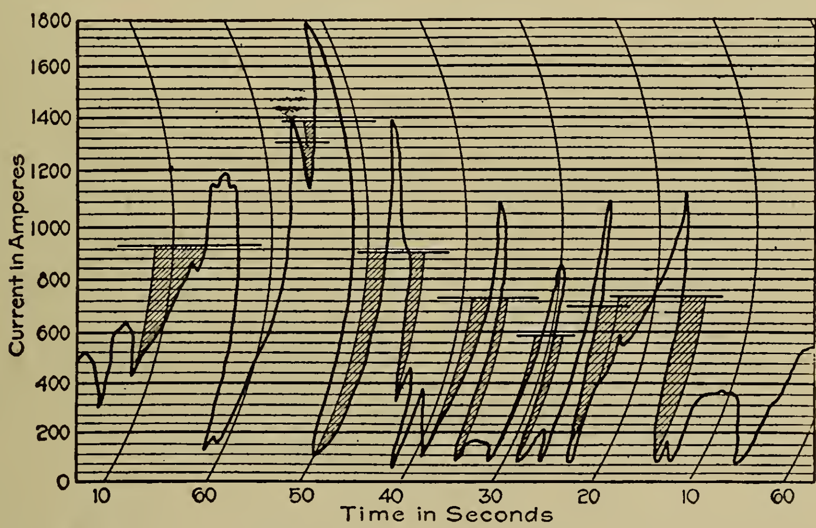


Fig. 41—Method of Approximating Root—Mean—Square Value of Current

"off" for equal lengths of time. Bearing in mind that heating and cooling periods should be about equal and that the current during the "off" period is about 200 amp., the approximate temperature rise may be found from Table XVIII. For 400 amp. heating and cooling times are about equal between 18 deg. and 20 deg. C. But as the cooling time is shorter than the heating time and the current 25 amp. less than that for which the heating time is given, some allowance may be made for this and the final temperature reached after many such cycles assumed to be about 15 deg.

The influence of the peak should now be estimated. It is equivalent to 1400 amp. lasting about seven seconds with an "off" time of about fifty-five seconds as the chart shows. Half of 1400 is 700, and this current, as Table XVIII indicates, will require 120 seconds to raise the temperature of the conductor 2 deg. Considering the cooling period under 200 amp. (the nearest data available) as a criterion, it appears that the cooling time would be 1170 seconds. The ratio of 120 to 1170 seconds is about one to nine. This also points to a temperature rise of about 18 deg. However, since the 375 amp. half-time load produces a higher temperature than a continuous 200-amp. load, the cooling will not be quite so rapid as the figures indicate and the final temperature would run somewhat higher.

PREVAILING TREND IN GROUNDING PRACTICE

The characteristics of different types of ground connections and the field to which each type is fitted for use were discussed by W. C. Wagner, electrical engineer of the Bureau of Standards, in a paper presented before a meeting of the Western Association of Electrical Inspectors. He pointed out that the driven-pipe ground connection is economical and reasonably satisfactory for lightning protection grounds and low-voltage circuits when high-potential and low-potential conductors are not likely to cross and when the resistance is not required to be less than a few ohms. Driven pipes are easily inspected, readily removed and do not require large ground areas.

The latter advantage is important in places where the ground must be installed in restricted space or under pavements. Mr. Wagner said: "A greater depth of penetration than 10 ft. (3 m.) in conducting soil is not, in general, economically advisable. An earth connection to be efficient must be below the frost line, because a variation in resistivity of more than 200 per cent may be expected in reducing the temperature from 20 deg. C to — 20 deg. C. Several driven pipes connected in parallel decrease the resistance of the ground connection when the pipes are separated from 1 ft. to 8 ft. (0.3 m. to 1.8 m.). A pipe ground should not be made near a pole because the pole exerts a shielding effect and shuts off a large part of the current flow. Mechanical considerations will usually govern the choice of size of driven pipe, but it has been found that the best results can be obtained with pipe from 0.75 in. (19.1 mm.) to 2 in. (5.08 cm.) in diameter."

Buried plates are not used to any extent because the driven pipe grounds are more convenient and give the same results in most cases. The area of a single plate in ordinary conducting soil cannot be economically increased beyond 20 sq. ft. (1.8 sq. m.) and should not be buried deeper than 8 ft. (2.4 m.). It is usually better to bury two smaller plates some distance apart and connect them by a wire than to bury a larger plate of the same ground resistance. The surrounding soil greatly affects the use of buried plates, and an increase of conduction can be obtained by surrounding the electrode with salt or a bed of coke. Moisture changes do not affect a coke bed, because the coke bed constitutes virtually an extension of the electrode. Coke has the disadvantage as compared with salt of requiring excavation, as the latter can be carried into the ground by moisture from a pocket at the surface. Coke also exerts a corrosive action where iron is used and is generally considered more detrimental than salt. Copper electrodes should be used where long life and minimum attention is desired. Strips should be used where bedrock is near the surface of the ground and it is impracticable to embed pipes or plates deep enough to provide an effective earth connection. This is especially true in soil of high resistivity because of the electrostatic capacity in the case of a strip is greatest for a given amount of metal. This method is also applicable, therefore, for use in high-resistance soil where driven pipes would be used.

Water pipes give less resistance to ground than any other of the methods discussed. "A water pipe in an average soil," Mr. Wagner said, "has approximately the resistance of from fifty to sixty driven pipes or buried plates in parallel. Pipe systems are easily accessible at the service entrance. Moreover, the areas covered by electric lighting systems are approximately the same as those covered by water mains. This method of grounding is therefore advantageous and in the case of low-voltage alternating-current circuits does not appreciably affect the water-piping systems."

Method of Making Secondary Grounds. On the Memphis (Tenn.) Gas & Electric Company's secondaries, grounds are not made to water systems and the practice of grounding at frequent poles is not used. Instead one ground is placed on each secondary, not more than 200 ft. (61 m.) from the transformer and at the side or back of a house near the service entrance, said C. K.

Chapin, superintendent of distribution, before another meeting of the Western Association of Electrical Inspectors. The ground is made by placing a 12-in. (30.2-cm.) square of sheet zinc 7 ft. (2.1 m.) or 8 ft. (2.4 m.) below the surface of the earth and connecting it to the secondary with No. 6 B. & S. gage weatherproof wire inclosed in a 0.75-in. (19-cm.) pipe. The pipe extends about 9 ft. (2.7m) above the surface of the earth, thus putting the ground wire out of reach of curious persons. The zinc-plate ground used in Memphis will discharge the entire system satisfactorily, and in doing so the maximum voltage between secondary system and the earth reaches 500 volts at a distance of 300 ft. (92 m.) from the ground plate. The ground plate is compelled to dissipate only from 400 watts to 700 watts, thus a very small current has to pass through the ground wire.

The grounds are tested when installed for maximum resistance of 20 ohms at 1 amp. Many tests show that a secondary ground when crossed with the primary will increase its internal resistance three or four times. When two such crosses do not occur on different phases at the same time, the system will continue to discharge through the ground without surging such as would probably occur in the case of ground to water mains. A ground properly installed will probably last from ten to fifteen years, but rigid inspection and maintenance are necessary on all grounds. Failure of the zinc-plate ground can only occur when the trouble is not located and removed promptly. The time to bake out a good ground depends greatly upon the weather conditions, but usually is two to five hours, which gives adequate time for the location and removal of trouble.

DUCT SPLICING SAVES SHORT LENGTHS OF CABLE

The financial loss due to inability to utilize short lengths of cable is a serious one to all companies operating underground systems of distribution. These lengths are constantly accumulating owing to withdrawal of old cable necessitated by changes and replacements of existing circuits. In view of these facts the experience of one of the large lighting companies in the development and use of duct splices as related by J. B. Noe and A. Rabe of the New York Edison Company will be cited.

How Splice Diameter Is Minimized. The underground department of this company made such a splice in November, 1904, joining two sections of three-conductor, 250,000-circ. mil., 6600-volt cable. The diameter of the splice was kept down by staggering the joints in the three conductors, making a joint 24 in. (71 cm.) long, over which was placed a split lead sleeve slightly larger than the original cable, soldered at the seam and wiped to the cable sheath at the ends. This joint was made by drawing in the first section, making the splice in the manhole, and then resuming the pulling, drawing the splice and second section on into the duct. This original duct splice remained in service without failure for several years and when finally withdrawn for some cable changes was opened and found perfect.

In 1911 the proposed addition to the system of about twenty-five high-tension service connections offered a tempting opportunity for the extensive use of duct splices. More than six miles (9.7 km.) of feeder were made, using old cable exclusively. Not one failure has ever occurred in any of these splices or on any of the more than 600 duct splices made on various cables.

In 1915, the accumulation of short lengths again becoming critical, serious attention was turned to the duct splice. Before adopting it as a permanent policy for all types of cable, tests were conducted to determine:

First—Mechanical strength, both of the spliced sleeve and the spliced conductor, as compared with the strain put on them in installing and withdrawing the cable under the severest duct conditions.

Second—Dielectric strength of the duct splice after it had been subjected to the strain of installation.

Third—Heating in the duct splice due to heavy loads.

All of these tests showed the duct splice as made up to be superior to the body of the cable.

A decided improvement was made at this time by "burning" on the lead sleeve instead of using solder. This made the joint as flexible as the rest of the cable, and as the spliced lengths could be put upon reels without fear of cracking, it became the practice to make the joints in the cable yard instead of in the manhole, effecting a very great saving in cost. At odd times and on rainy days the short pieces were spliced up to make sections of such lengths as could be easily matched.

Among the various types of cable on which the duct splice has been used, two deserving of special mention are triplex 350,000-circ. mil, 25,000-volt armored submarine cable and single-conductor 2,500,000-circ. mil low-tension cable with pressure wires. During 1916 a duct splice was developed for two-conductor, 1,000,000-circ. mil low-tension concentric cable with three pressure wires.

Some idea of the amount of cable transformed from scrap or very slow-moving stock to actual service may be gained from the fact that the company has to date a total of 211,569 ft. (approximately 64,460 m.) of duct-spliced cable of various types, representing a value of approximately $380,000. Practically all of this material is now installed.

ADVANTAGES OF WOOD DUCT FOR UNDERGROUND SYSTEMS

Although the dielectric qualities of wood duct are not so good as those of fiber duct, extensive testing by R. A. Paine, Jr., general foreman of details and records, Edison Electric Illuminating Company of Brooklyn, has shown that they are sufficient for the requirements of low-voltage 115–230 volt distribution mains and services. Low installation and maintenance costs are obtained by the use of wood duct. The cost per unit length is only slightly greater than that of fiber and tile, and it requires no concrete envelope.

In the following tabulations of tests, creosoted wood duct, which is used by telephone companies, was adopted. Its inside diameter is 3⅛ in. (7.9 cm.), and it is 4½ in. (11.4 cm.) square on the outside.

Breakdown Tests. An alternating-current breakdown voltage test was made on four pieces of wood duct and four pieces of fiber duct in order to show the comparative insulating value of wood and fiber duct. Pieces No. 1 were sealed at one end, filled with water and allowed to stand forty-eight hours. Pieces No. 2 were sealed at one end, placed in a barrel of water, keeping the inside duct dry, and allowed to stand forty-eight hours. Pieces No. 3 were placed in a barrel of water, allowing inside and outside of duct to be in contact with water for forty-eight hours. Pieces No. 4 were taken from stock.

Three test sections were taken from each piece, using tinfoil electrodes and increasing the voltage by steps of 500 volts after each minute, and the following average breakdown values were obtained:

	Piece No. 1	Piece No. 2	Piece No. 3	Piece No. 4
Fiber duct	9,300	8,700	4,300	[1]
Wood duct	1,000	1,000	800	2,200

Resistance to Short Circuit. The resistance of wood duct to arcs as compared with fiber was determined by the following tests: To determine what the results would be if a short circuit occurred on distributing mains in the duct, three legs of 150,000-circ.mil R. & L. cable were placed in fiber duct and punctured so that they would short-circuit. A slow-burning short resulted, when they were connected to the source of energy, which burned three holes in the bottom of the duct, the fiber bursting into flame. This flame would probably have consumed the whole piece of duct, but it burned so fiercely that it had to be extinguished.

For the same experiments with wood three lengths of the duct that had been soaked in water for five days and two stock lengths were tested. Three legs of 150,000-circ.mil R. & L. cable were placed in the ducts and punctured so that they would short-circuit. A very high temperature was generated in the ducts when they were connected to the mains, and this was allowed to increase until the cables burned in half and cleared themselves. This operation was repeated four times, twice over the joint and twice in the middle of the length on both the water-soaked and the dry duct. From the water-soaked duct a relatively small amount of thick black smoke or gas was generated at each short. This smoke or gas did not seem to be combustible, and the duct was in very nearly perfect condition after the test. A very large amount of greenish white smoke was liberated at each short in the dry duct. One short burned for five minutes, destroyed two cables and filled up the bottom of the duct with molten copper and lead. After this short the duct smoldered near the joint, liberating a large amount of smoke.

It was shown that the wooden duct was better than fiber in case of a short circuit occurring in the conduit, because the latter may easily be entirely destroyed. The durability of wooden duct

[1] Piece No. 4 of the fiber duct withstood 11,500 volts for five minutes.

is apparent from the extensive use and experience which telephone companies have had with it.

THE ECONOMICAL LOADING OF TRANSFORMER BANKS

Where several transformer banks of similar characteristics are available to carry a variable load it is of interest to determine the economical point for switching an additional unit into service. Ordinarily this is done when the load has reached the ca-

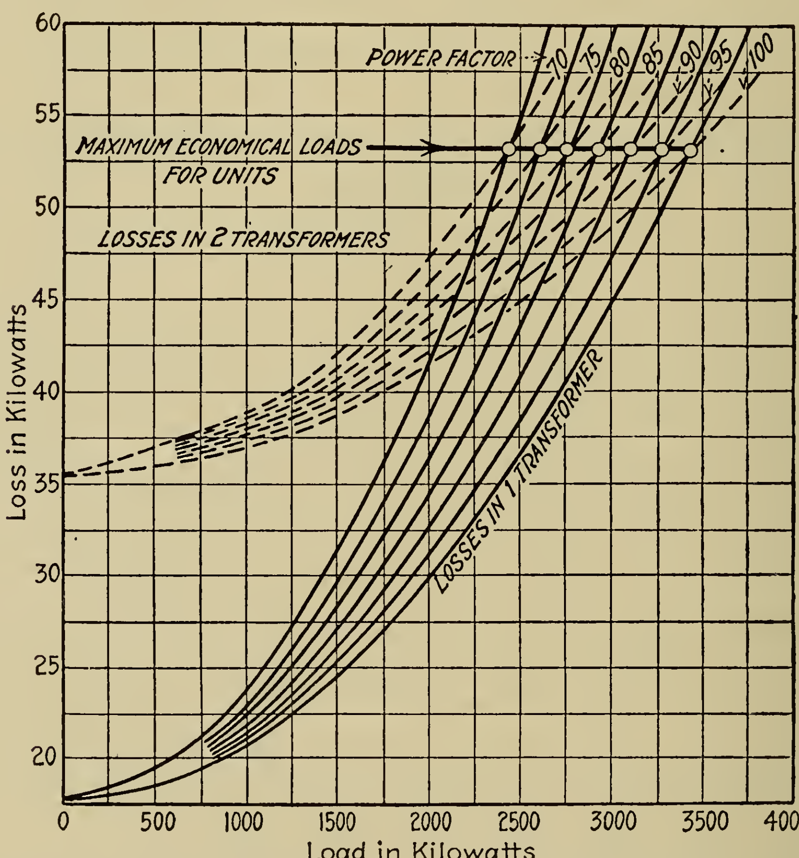


FIG. 42—LOSSES IN THREE-PHASE, 3000-KVA. TRANSFORMERS UNDER VARIABLE LOADS

Gives comparison between losses in one unit carrying total load and two units each carrying one-half of total.

pacity of the working units, but this may not always be the most economical practice. Obviously, switching in an idle unit will increase the total core losses which are constant for each unit, but the corresponding decrease in the variable or copper losses may more than counterbalance this increase. As the ratio between these losses differs widely in different classes of transformers, it is necessary to investigate each case individually.

Fig. 42 is a sample set of curves indicating the losses in a 3000-kva. three-phase transformer for varying loads and power factors. From this the loss in kilowatts may be read directly for any load at any power factor. The curves are plotted in kilowatt load rather than kilovolt-amperes, as the load may be read directly in kilowatts on the station meters and will thus permit the operator to pick the economical switching point more readily than if expressed in kilovolt-amperes. The curves are based on test results or data furnished by the transformer manufacturer. On the same sheet is plotted a second set of curves showing the total losses in two transformers, each carrying half the load. These curves may be calculated from the first set.

For instance, at unity power factor and 1500-kw. load, the loss in one transformer is seen to be 24.5 kw. Therefore, for a total load of 3000 kw., if two transformers are used the total loss will be 49 kw., which gives one point on the unity power-factor curve of the second set. Each loss curve for two units intersects the corresponding loss curve of one unit, beyond which point of intersection it will be more economical to operate two units than one. It will be noted that in the particular example given the economical point on the unity power-factor curve is at 3430 kw. (or kva.), or slightly more than full load. On the 70 per cent curve the intersection is at 2440 kw., or 3486 kva. Thus it will be seen that the economical point of change is at a practically constant kva. load regardless of power factor. It will also be noted that the economical switching point is at a constant value of loss regardless of power factor, and that this point is that at which the total loss in one transformer is three times the core loss in one transformer.

Similarly, with the two units in service it will be most economical to switch in a third when the core loss per transformer equals one-sixth the total copper losses or when the core loss in one of the pair equals two-thirds the copper loss in one of the pair. In a general way, when n units are running switch to $n+1$ units, when the losses per transformer are $W_e = nW_{cn}/(n+1)$.

These results are plotted in Fig. 43 for a number of combinations. Knowing the load per unit, the operator can tell at once when it will be economical to switch a unit on or off. If the load is known in kva., the division points on the unity power-factor line should be used.

While the above equation holds true only for groups of iden-

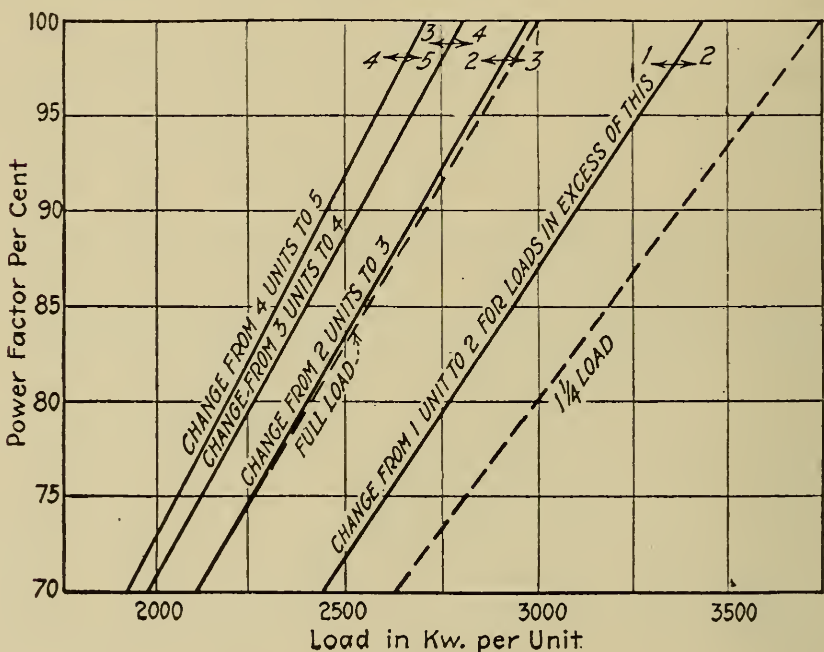


Fig. 43—Economical Switching Loads

Thus if the load reaches 3000 kw. at 87 per cent power factor, it becomes economical to switch in a second transformer.

tical transformers or other apparatus having losses partly constant and partly varying with the square of the load, the graphical investigation may be suitably modified to apply to generators, dissimilar transformers or other apparatus.

TRANSFORMER CONNECTIONS FOR EMERGENCY MOTOR STARTING

Where transformers arranged for three-wire secondaries are connected in delta for service to three-phase motors the neutral points may be connected to one side of a double-throw switch to provide half voltage for starting. This scheme is one which has been much used in the past and should never be overlooked in emergency cases.

A modification of this system may be readily applied where transformers having 2300/460-volt secondaries are in use to furnish low voltage for starting 2300-volt motors. In such transformers only two secondary leads are available, and it is necessary to run an extra lead out of the case. If connections are made as shown in the upper part of the accompanying illustration, 53 per cent of full voltage can be procured for starting. This will ordinarily afford good starting torque without an excessive rush of current.

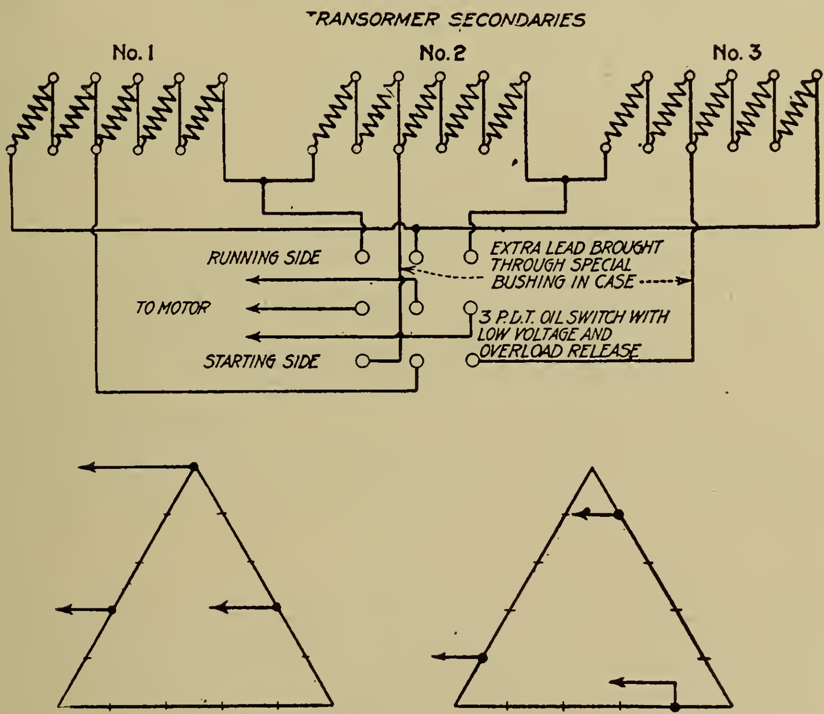


Fig. 44—Connections for Obtaining Different Starting Voltages with Vector Relations

This connection was recently used successfully in operating a 350-hp. motor from three 100-kva. transformers after the autostarter had burned out. The double-throw oil switch was equipped with low-voltage and overload release. If this voltage is insufficient, 60 per cent or 72 per cent normal voltage may be obtained by tapping, as shown by the vector diagrams at the bottom of the illustration.

FROM TWO- TO THREE-PHASE WITH STANDARD TRANSFORMERS

Where two-phase service is supplied and three-phase energy is desired, but only standard transformers are available, the following plan can be followed: Assume that the primary voltage is 2200 and that 2200/220-110-volt transformers are available. Connecting the primary windings of two transformers across the two phases and joining the secondary of one transformer with the mid-point of the other transformer's secondary will not give

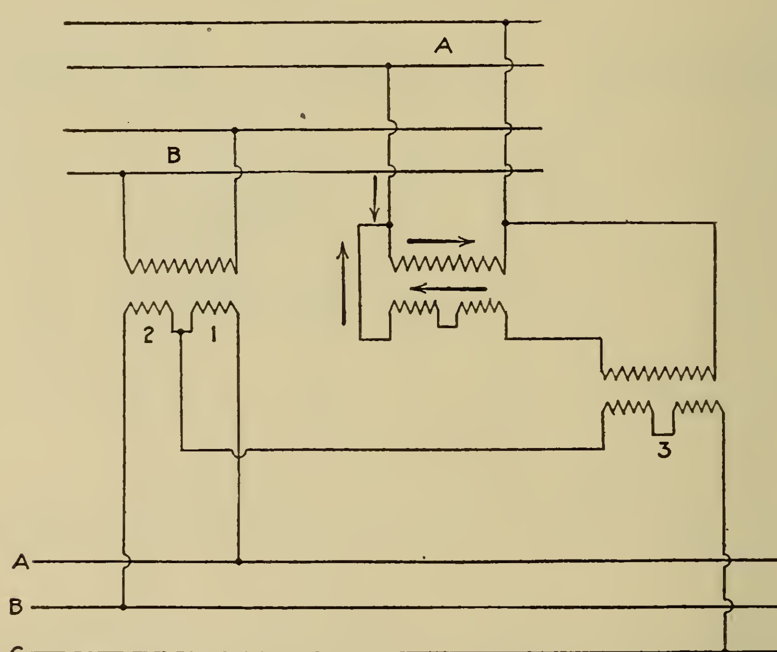


Fig. 45—Method of Connecting Three Standard Transformers to Convert from Two-phase to Three-phase

balanced three-phase voltages, since the secondary windings do not have the proper number of turns, relatively, for T-operation. In fact, operating the transformers mentioned above in T the phase voltages[1] would be 228, 261 and 261.

By connecting a third transformer across phase A to "buck" the primary voltage of transformer 3 by 220 volts, however, the voltages across phases are made nearly equal, as shown by the

[1] Based on actual measurements for a specific installation—voltages across windings 1 and 2 were both 114, while voltage across winding 3 was 235.

following calculations: Voltages across both windings 1 and 2 were 110 volts and the pressure across winding 3 was 198 volts. Thus the voltage across windings 1 and 2 would be 220 volts, while both the other delta voltages would be

$$\sqrt{110^2 + 198^2} = 227 \text{ volts.}$$

This scheme was proposed by E. Charles Seares.

TRANSFORMER RECORD CARD

Reproduced below is a transformer record card that has been used for several years with success by a Western company. The two sides of the card are shown, one side giving a complete rec-

TRANSFORMER RECORD

MAKE	TYPE	MAKER'S No.	COMPANY'S No.
G. E.	H, Form G	137l416	2563

VOLTS — PRIM 11000 10500 - 10000; SEC. 2300 - 460 — CAPACITY K. W 50 — DATE REC'D 4-7-15

STATION No	INSTALLED Mo. Day Yr.	REMOVED Mo. Day Yr.	REMARKS
7146	5 1 15	10 7 15	
9011	11 2 15	1 3 16	Primary Bushing Broken
61700	2 2 16		

TEST RECORD

DATE	WATTS CORE LOSS	AMPERES EXC. CUR.	INSULATION VOLTS	RATIO	REMARKS
4·9·15	248	.043	22000	OK	
10·10·15	245	.040	22000	OK	
1·8·16	245	.041	22000	OK	Repaired Primary Bushing

OIL RECORD

DATE CHANGED	REMARKS
10 - 10 - 15	
1 - 8 - 16	Flushed Coils

Fig. 46—Form of Transformer Record and Test Sheet Used by Western Company

ord of the life of the transformer and the other side test information and condition of oil. It will be noted that the form records exclusively information with reference to the transformer. Information concerning the load connected to a transformer after it is installed is put on a second card file, which contains transformer station numbers, arranged numerically, whereas in the transformer card file the transformers are arranged numerically by location number. A cross reference between these two files is in the one case the transformer number and in the second case the location number. Location numbers are arranged in such a way that the number tells at a glance the district and feeder to which the transformer is connected. The location number appears on the cover and side of each transformer in white letters 2½ in. (6.4 cm.) high, easily legible and not likely to be obliterated.

SCHEME FOR INSPECTING TRANSFORMER INTERIORS

Often it becomes necessary to inspect the windings or interior connections of oil-immersed transformers. To overcome the difficulties of using a lamp and trying to see through the oil, one Southern central-station company is employing a telescoping tube the lower end of which is sealed with a glass disk to prevent oil filling the tube and obstructing vision. A lamp is attached to the outside of the tube near the lower end so that the glare of the filament will not reach the user's eye. When the proper voltage is not available for operating an incandescent lamp, a flashlamp may be attached to the tube. The tube is made of five sections, each about 2 ft. (61 cm.) long. This device enables the men to inspect the interiors of oil-immersed transformers without getting into the oil as is sometimes necessary.

CARRYING OVERLOADS BY INCREASING PRIMARY VOLTAGE

It is often possible to carry increased load without adding copper to the distribution system by raising the primary voltage, provided, of course, that the secondary voltage is held at its normal value. Too great an increase in primary voltage, however, would seriously increase iron losses of transformers on the lines. Voltages may usually be raised economically as much as 10 per cent. Curves of iron loss and exciting current as affected by the impressed voltage are shown in the accompanying illustration, from which it is seen that the power losses in transformers increase very rapidly with primary voltage.

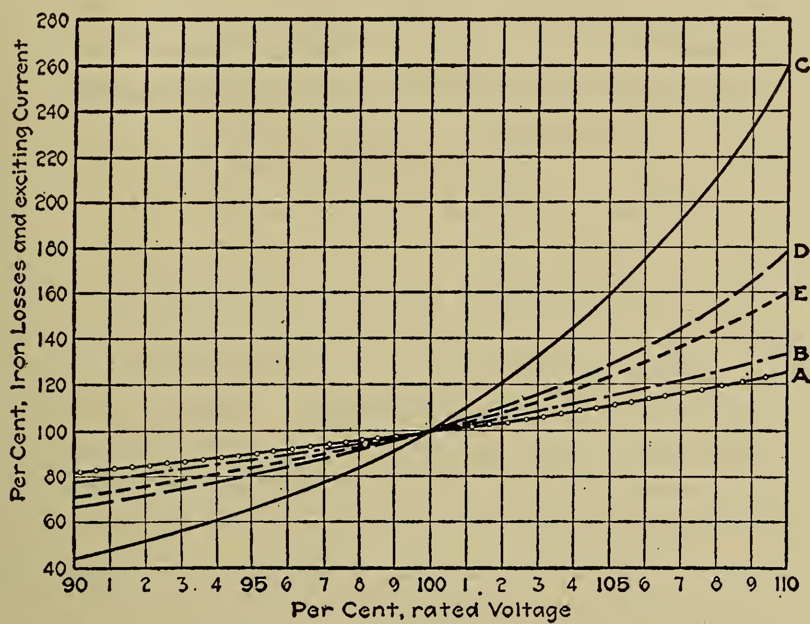


FIG. 47—VARIATION OF IRON LOSS AND EXCITING CURRENT WITH VOLTAGE

Curves B and C show iron loss and exciting current respectively for large units. Curves A and D give corresponding values for small units. Curve E gives iron-loss variation from a number of tests.

This suggestion, as well as the curves reproduced here, were contributed by W. B. Stelzner.

REDUCING THE COST OF INDUSTRIAL SWITCHBOARDS

A new development in switchboards for industrial plants, conceived by Louis F. Leurey of San Francisco, is being adopted by many concerns doing industrial plant wiring on the Pacific Coast. By eliminating the use of copper busbars and marble panels and substituting instead insulated wire leads properly housed and iron pipe or angle-iron framework carrying inclosed switches, these companies are building boards at low cost. It is reported, moreover, that the boards thus built are operating just as satisfactorily as any of the older types. If it is desired to make the job appear more complete, steel-boxed panels made of ordinary sheet steel can be used, but these boards are still inexpensive.

Eliminating the necessity for busbars effects a still further reduction in cost. The mains are brought to the switchboard in conduit or can be run either across the front or the back of the board in galvanized-steel troughs made by any tinsmith. This box has flanged sides to which a removable cover is screwed. Taps to each switch are made through ordinary types of connectors. This construction is said to be not only less expensive in first cost but also to permit extensions and changes at costs less than those incident to changes on boards with which bar copper is employed.

One particular advantage of these boards is that they may be made up on short notice because all of the necessary material can easily be secured locally and very little machine work is necessary. On marble and slate panels made to specifications in the factory delays are likely to occur. Another advantage is that these boards need to be made to conform only to the requirements of space available and equipment to be mounted. Panel-boards, on the other hand, must be laid out according to certain prescribed standard panel dimensions. This advantage of flexibility is considered especially important where electrical apparatus is to be installed in a structure already built. It is expected that these boards will grow in favor as the necessity of conserving copper and eliminating unnecessary transportation of such heavy products as slate becomes more urgent.

Actual Installation Cost of Inexpensive Switchboard. Cost data have been compiled to show the inexpensiveness of one type. They measure 18-in. (45.7 cm.) by 84 in. (203 cm.), and the average group consists of two or three panels. On the panels are mounted three triple-pole, single-throw, fused, 100-amp., 500-volt switches manufactured by the Square D Company, Detroit, Mich.

Each switch controls an average of 50 hp. in motors, and the total cost of erection with labor at $7 per day was $140 per panel. Therefore the average cost per horsepower of motors controlled would be $140 divided by 150 hp., or 90 cents. This cost includes the panel-board completely erected with all pipe connections made and wire installed. It does not include, however, the necessary sheet steel, condulets and angle iron used in the panel. These items are not estimated because they vary considerably in the different parts of the country and they represent only a minor part of the total expense.

REBUILDING A FEEDER BOARD WITHOUT STOPPING SERVICE

Reconstruction of a three-wire feeder board to provide for double the number of circuits formerly handled was undertaken by the Pacific Gas & Electric Company in an interesting manner at Station C. Since the circuits controlled could not be de-energized for the entire period required for reconstruction, the work was done without interrupting service at all, this being accomplished by the use of a temporary panel.

The original board consisted of twenty-one 3-ft. by 7½-ft. (91.4-cm. by 228-cm.) marble panels, each one consisting of two sections—28 in. (73 cm.) and 62 in. (157 cm.) high respectively. All of the switches (two double-throw single-pole knife switches to each positive and negative circuit) and the ammeters (one for the positive and one for the negative circuit) were on the upper or larger panel, the lower one being blank and serving only to give a finished appearance to the board. The positive meters were along the top of the board and the negative meters just below. As two sets of negative and positive busbars arranged in one horizontal plane were in use, and all of the switches were in one horizontal row, considerable copper had to be used for jumpers between the busbars and switch lugs.

To provide for the new circuit it was decided to install the new switches on the lower blank panel and regroup the meters on the upper panels to allow for those required for the new circuits. The latter operation was accomplished without disfiguring the panels by inverting the upper panel, plugging the old holes with plaster of paris and drilling new holes as required. The ammeters covered most of the plugged holes. To avoid the use of excessive amounts of copper, all of the switches on the upper panel were used as positive switches and those on the lower panel as negative switches. This required a rearrangement of the busbars. Instead of using four busbars in one horizontal plane as before, one busbar was supported back of each row of switch lugs, thus requiring only short jumpers and making the back of the board more accessible. This arrangement utilized the entire space of the panels giving four feeders to a 3-ft. (91.4-cm.) panel, which before accommodated only two circuits. Furthermore, a more orderly arrangement of switches was secured.

To accomplish reconstruction without cutting out a single feeder, a temporary two-feeder panel was installed and the two feeders from the first panel of the board were connected with it by jumpers. This arrangement cleared one complete panel so that it could be taken down, redrilled and put back in place according to the rearranged plan. Since the capacity of each panel was doubled by the arrangement, the temporary panel was required only while the first unit was being rebuilt. Thereafter the additional capacity gained by the revised connections took care of each additional unit as it in turn was reconstructed.

The necessity of making the change without interfering with the service made the work consume much more time than would have been ordinarily required. However, the complete reconstruction of the connections was effected in about ten months by one journeyman and a helper. The satisfaction attendant upon the use of the rearranged board is such that the company has adopted this panel arrangement as standard.

SELECTION OF FUSES FOR INDUCTION MOTORS

Although fuses are quite commonly employed in motor-circuits their use is liable to be attended with uncertain results when starting and operating induction motors, the starting current of which may greatly exceed the full-load current, unless they are properly applied. The accompanying table brings out a few of the difficulties which may be experienced in the attempt to select a fuse with a rating adapted both to starting conditions and to ordinary running conditions.

STARTING CURRENT OF THREE-PHASE, 60-CYCLE SQUIRREL-CAGE INDUCTION MOTORS

	Starting with Light Load		Starting with Full Load	
Manufacturer's Indication	Per Cent of Full-Load Current	Time Involved	Per Cent of Full-Load Current	Time Involved, Sec.
1	600	Instantaneous	600	5
2	500 to 600	Instantaneous	500 to 600	5 to 8
3	600	Instantaneous	600	6
4	450 to 500	Instantaneous	450 to 500	4 to 5
5	600	One-half second	600	30
6	500 to 600	Instantaneous	500 to 600	5
7	600	Instantaneous	600	6
8	500	Instantaneous	500 to 606	6 to 8

From this table it is apparent that in many cases of starting induction motors a fuse selected to protect from overload is very likely to blow at starting and a fuse capable of carrying the starting current will not protect for ordinary conditions of operation. Hence in those cases where the motor is started and operated through the same fuses it is necessary to take into account the starting current, the time interval over which the high starting current flows and the time lag of the fuse itself. Such tests show that these factors vary over quite wide limits for different fuse types and to some extent for the same fuse at different periods.

CONVENIENT ARRANGEMENT OF FUSES ON FEEDER PANELS

Considerable waste of space and an unsightly installation have usually been found to result from the design of feeder panels in which bus connections and fuses are a part. On several occasions H. Burt Foote has found it necessary to design feeder panels for three-phase, 440-volt and 500-volt alternating-current circuits. As a result of some thought and consideration of the requirements the construction shown herewith has been worked out.

Switches with 600-volt spacing in ratings of 30 amp. and 60 amp. combined with 600-volt fuses usually make an awkward arrangement. So the 100-amp. size with 250-volt spacing, as this is also permissible for 600 volts alternating current and adaptable to circuits up to 50 hp. Selection of this type gave uniformity and besides, this switch possesses enough mechanical strength to adapt it to general use, which is not true of the 30-amp. and 60-amp. size with 600-volt spacing. Placing fuses on the front of a panel increases its size, making additional expense and a waste of space. As ordinarily placed on the back of a panel, they cover a portion of the studs and bus connections, making it difficult to tighten up a loose joint and inconvenient to get access to the outgoing feeders. These difficulties have been overcome, and the fuses are so placed that they bear a direct relation to the switches and that the connection from switch to fuse is reduced to a minimum.

The distribution boxes on which the fuses are mounted are made of sheet metal fastened as shown to the panel supports and forming a side inclosure for the back of the panel. The conduit enters them in a neat manner at top or bottom, and the wires are led direct to the fuse blocks through a bushed hole. Where more than one panel is used the adjacent boxes may be combined

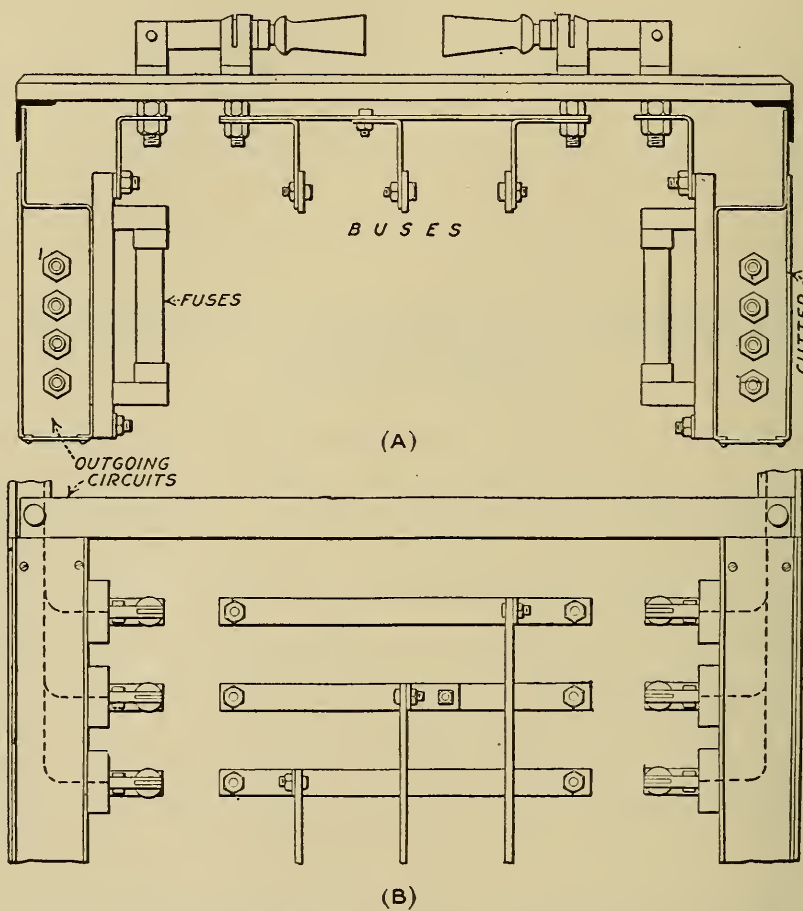


FIG. 48—ARRANGEMENT OF FUSES AND DISTRIBUTION BOXES

in one. The front-connection fuse blocks make them interchangeable for any size of circuit. The busbar construction will be found to be very simple and accessible.

PREVENTING INSTALLATION OF WRONG-SIZED FUSES

Safety stickers of the style shown herewith may be pasted on fuse cabinets to serve a twofold purpose. They are a precaution against the use of wrong-sized fuses, and they emphasize the fact that it is dangerous to let the body become the connecting link between live wires and a good ground. When the fuse sticker is pasted in the cabinet box and an inspector later discovers the wrong fuse in use he has tangible evidence that previous warn-

FIG 49—SAMPLES OF STICKERS PASTED ON FUSE CABINET BOXES TO GIVE EVIDENCE OF PREVIOUS INSPECTION

ing had been given and can act accordingly. H. J. Clark of the Oklahoma Inspection Bureau reports that the stickers are very effective.

PANEL FOR TESTING DIFFERENT-SIZE FUSES

Shown in the illustration on page 110 is an easily made panel which may be used in industrial plants for testing various types of fuses. As will be noted, both sides of the fuse blocks are connected in multiple. One side is connected directly to the supply line, while the other side is connected to the line through a 10-watt lamp. The placing of a good fuse in any fuse block will light the lamp.

SPECIAL USES FOR POTHEADS

Two interesting and economical uses of disconnecting potheads have been worked out by N. L. Allen, electrical engineer for the American Zinc Company of Tennessee. Sometimes, in connection with the operation of its concentrator, it is necessary to reverse certain motors when the belts are thrown off for repairs. Since it is not necessary to do this very often, three G. & W. disconnecting potheads have been installed at each motor in the three-phase leads to permit reversing the leads quickly and to avoid the necessity of reversing controllers. Of course, where the reversing of motors is more frequently necessary reversing controllers are provided. Another use of potheads is in the leads

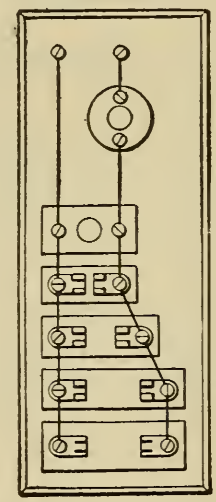


Fig. 50—Fuse-testing Panel for Different Sizes

from the surface feeder to the feeder bus in the mine. The feeders on the surface, which operate at 2300 volts, three-phase, 60 cycles, are connected by means of disconnecting potheads at the pole to steel-armored, lead-covered, paper-insulated cable containing three No. 4 copper wires. These cables go down into the mine a distance of about 500 ft. (152.4 m.) to the feeder bus. A spare cable is provided for emergencies. Both of these cables are "phased out" and marked so that the potheads at both ends can be quickly and properly changed in case of damage to the operating cable.

WALL ENTRANCE FOR USE WITH FLAT BUSBARS

To prevent birds and cold air entering its transformer room in the winter and yet give proper ventilation and insulation for outgoing busbars the arrangement shown in Fig. 51 was used by a large cotton mill in New England. Two 10-in. (25.4-cm.) by

0.25-in. (0.64-cm.) bars per leg are used in the secondary circuit where it runs through the wall, the spacing between phases being 6 3/16 in. (15.7 cm.). Ebony asbestos wood is used around each

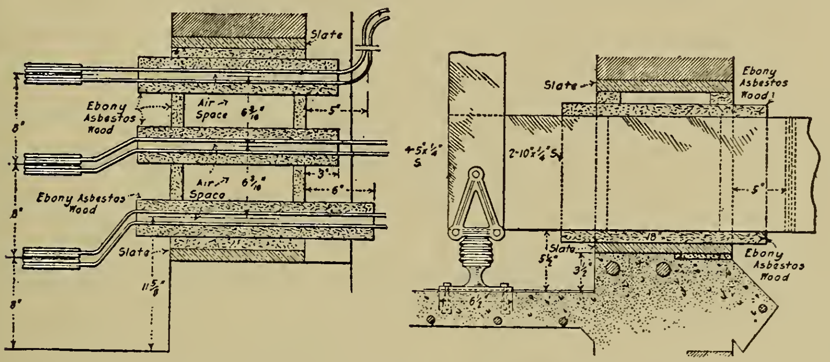


FIG. 51—DETAILS OF BUS ENTRANCE TO TRANSFORMER ROOM

pair of bars with slate between the asbestos wood and the building walls. To secure the spacing mentioned asbestos slabs are inserted as shown. The pressure on the buses is 6600 volts.

TWO METHODS OF BENDING CONDUIT

Elaborate apparatus does not have to be employed for bending conduit if an outfit like the one illustrated herewith is constructed. The principal part of the outfit consists of two 6-in. by 6-in. (15.2-cm. by 15.2-cm.) timbers 12 ft. (3.6 m.) long with a 3½-ft. (1.14-m.) timber of similar size bolted across the end as

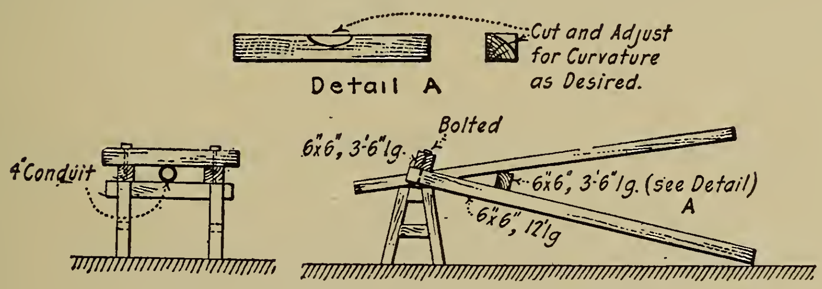


FIG. 52—DETAILS OF CONDUIT BENDER

shown. This end of the frame is laid on a sawhorse or pile of bricks or stone, one end of the conduit to be bent being placed beneath the cross timber, and another cross timber, modified as shown in detail A, placed across the frame beneath the portion of the conduit which is to be bent. Downward pressure may then be applied to the free end of the conduit, causing it to bend over the unfixed cross timber.

Another simple but effective method has been developed by E. A. Phipps of the Rockingham County Light & Power Company, Portsmouth, N. H., that has saved considerable time and labor in the reconstruction of this company's power plant. The outfit consists of a frame upon which a jack can be placed to press against a shoe conforming to the general shape of the conduit. Other shoes are provided at the upper corners of the frame, where they are pivoted so that they will adjust themselves to the curvature of the conduit. The effectiveness of the equipment depends chiefly upon the drawing effect of the shoes.

The outfit will bend any iron-conduit pipe from 1.25 in. to 4 in. (3.2 cm. to 10 cm.) or larger in diameter, using any make of jack on the market. The device is light, portable, easily operated by one man, and can be used in straightening as well as in bending conduit. It will make a 90-deg. bend without flattening the pipe considerably because the recess in the shoe immediately over the jack is relatively deep. Only one piece—the central block—has to be changed in adapting the bender to different-size pipe. The frame occupies a space of only about 3 ft. (0.9 m.) high by 3 ft. (0.9 m.) long by 18 in. (45 cm.) wide. A bender of this type has been used at Portsmouth, where more than 20,000 ft. (6096 m.) of conduit, requiring every variety of bend, was necessary, without destroying a single piece of stock. Furthermore, a great saving was effected by not using the usual heating method. It is estimated that the machine easily paid for itself in making the first fifty bends.

TAPPING A 13,200-VOLT THREE-CONDUCTOR CABLE

When it is necessary to make branch and Y joints on three-conductor, 13,200-volt cables the method described below, which has been found satisfactory by E. B. Meyer, assistant to chief engineer Public Service Electric Company, Newark, N. J., may be used.

The ordinary specifications for making a straight joint are followed, except that a 6-in. by 28-in. (15.2-cm. by 71.1-cm.) sleeve is used instead of a 4-in. by 20-in. (10-cm. by 50.8-cm.) sleeve. A copper connector of a sufficient size to accommodate two conductors laid side by side is employed. The ends of the through cable are cleaned in the same manner as usual. After the end of the tap is cleaned in a similar way it is bent slightly and laid parallel to one of the through cables, which have been butted together. A connector somewhat larger than the conductors is spread over them and all are sweated together. Then each leg is insulated in the usual manner, and in addition the tape is threaded through the Y-shaped branch formed by the tap and conductors. In belling the end of the lead sleeve at the double end it will be found necessary to cut away a portion of the lead to conform to the shape of the two cables leading into the splice. A small piece of sheet lead may be required to form a backing for the lead between the cables. Filling of the joint is done in the usual manner.

CHAPTER III

MOTORS, CONTROL, SPECIFIC APPLICATIONS, TROUBLES AND REMEDIES

INDUSTRIAL APPLICATIONS OF ELECTRIC POWER

There can be no doubt as to the vast influence which manufactured power has had in the industrial development of the country during the last few years. In fact, it is problematical whether this remarkable progress in manufacture would have been realized without the corresponding development in ways and means of applying power which have characterized many steps of industrial efficiency.

These applications of power have been greatly affected by the electric motor because of its high efficiency in both large and small sizes, and moreover by the increased flexibility in transmission and distribution permitted with electricity as a substitute for the older methods of line shafting and belt drives.

The peculiar character of the work calls for the specially trained engineer who has ability to analyze not only the electrical problems connected with the motor and its operation, but who can, moreover, analyze with equal skill the mechanical features of the machinery to be driven and thus combine in his solution the most efficient types of motor and control to operate the machinery at lowest first cost and the least possible operating expense.

That this is particularly difficult engineering is evidenced by the fact that more than ordinary trouble has been experienced in finding men capable of handling successfully the problems concerned with motor applications, including, as such problems do, a large proportion of mechanical as well as electrical engineering details, and often presenting perplexing and indefinite features. In other words, the special province of the application engineer is to take a given problem with many factors and indefinite relations and reduce them to a definite basis by careful study and analysis.

One of the most striking points is the fundamental importance of the motor in the conservation of labor expense, a feature set forth clearly by contrasting the great differences between various typical industries on the basis of the value added to the product by manufacture.

In the study of factory power, and more particularly of the electric motor, the outstanding items of power economy and increased production may be looked upon sometimes as dependent merely on the relative electrical and mechanical efficiencies of the various motors, on the one hand, and the actual increase in output brought about through a motor-driven machine, on the other. While these two items do constitute the starting point in most of the problems, the expert is confronted with a large number of factors, any one or all of which may make up the net advantages included by these two primary items.

Any given example may thus be resolved into a study of the type of motor and control available for the particular requirements, corresponding study into the mechanical requirements themselves, and a summary of the operating conditions which may be expected to follow application of the motor. These considerations are rendered more valuable by proper emphasis upon the economies afforded by the adoption of such a system of drive in comparison with older methods.

FOR AND AGAINST SYNCHRONOUS MOTORS

The synchronous motor has always been supposed to have certain drawbacks which limited its application for industrial drive. First among them was low starting torque. Second, since a synchronous motor runs at a fixed speed (the direct-current field of the rotor is locked to the alternating-current field of the stator) no slip is allowed; therefore the flywheel effect was supposed to be limited. Complication due to the separate exciter has also been cited. A fourth objection is sometimes made, viz., that synchronous motors require more careful attention and more skilled operators than other kinds. In order to determine the advisability of installing synchronous motors these four objections must be considered in turn and the question answered in view of the facts. This is the purpose of this article by Will Brown.

The Starting Torque. It is necessary to make a distinction between a synchronous motor's operation during the starting period up to the point of pull-in and its operation after synchronism has been attained. The critical point in starting a synchronous motor is the pull-in. Like a squirrel-cage motor, it starts and increases speed up to a certain point, known as its rated slip speed. This slip-speed rating varies according to the load. At this point of maximum speed as an induction motor a synchronizing torque must be exerted to pull the rotor field up into step with the rotating field of the stator. This operation may be compared to paralleling an alternator on the line. All operators have observed the large synchronizing power which is exerted as the incoming alternator approaches the frequency of the line. It is the same thing with the synchronous motor. The line current might be considered as gripping the field of the rotor and yanking it up into step.

It can be readily understood that the more slip there is in the rotor speed at the pull-in point the greater must be the torque exerted to pull the rotor up to full speed. It is possible to increase the initial starting torque by increasing the resistance in the damper bar windings, but this results in a larger slip or lower speed at the pull-in point. Therefore the limit of load which can be "pulled in" at a specified kva. input determines the starting torque. The future will doubtless see a considerable improvement in this pull-in characteristic of synchronous motors. By proper design it may be possible to change the pull-in peak current so that the same work can be done by lower current input over a longer space of time. Synchronous motors can now be designed to start and pull into step a load amounting to from 30 to 50 per cent of full load with a kva, input not to exceed 250 per cent of normal rating. It is probable that the time will come when the synchronous motor can be made to start and pull in its full rated load with a kva. input which will not exceed safe operating limits.

Use of Clutches. When the starting duty is so severe that a synchronous motor cannot handle it—on heavy line shafts, for instance—the solution may be found by the proper use of clutches. There are two types of clutches used, viz., mechanical and magnetic. The cost of a magnetic clutch is higher, but it has a number of points of superiority for certain types of duty, such as automatic safety control, etc. The variation of the grip on the clutch faces allowed by magnetic control can often be used to good advantage.

Among certain industrial plant operators of the old school there has been a widespread prejudice against the use of clutches. Their favorite remark was: "Oh, I wouldn't bother with a clutch. I get a slip-ring motor big enough to start the load and that's all I care about."

It is true that they could do this very thing in the past, but it is equally true that they are not going to be able to continue doing so. Central stations supplying power to these kinds of motors on this kind of drive have learned a lesson. They are going to demand high power factor, and the use of large synchronous motors for driving line shafts is one solution. Proper clutch installations will take care of severe starting duty.

The Northern States Power Company, at Minneapolis, has a number of flour-mill loads, many of them driven by slip-ring motors. There have also been quite a few installations of synchronous motors belted or directly coupled to the line shafts. According to their experience, the synchronous motors are superior to the induction motor for this service. They have proved more satisfactory to the power used in point of efficiency and to the power company in point of power factor. The above company has recently ruled that it will allow nothing but synchronous motors on loads of this kind about 100 hp.

The clutch problem, after all, is not the bugbear that many operators think it is. Trouble in the past has often been due to the fact that too small a clutch was installed. It was not always the buyer's fault either. Many clutches were overrated by the manufacturers. The buyer would select a clutch too small and then his troubles would begin—clutch linings would burn out and necessitate shut-downs. The result was that the plant owner would condemn all clutches. With the selection of a clutch of proper size to allow sufficient margin for all conditions of starting and running there should be no trouble. Most assuredly it will pay engineers to investigate this subject of clutches from an impartial standpoint. At the present time clutch manufacturers are very willing to make the necessary engineering investigations and recommend the proper size amply to take care of the load.

Those who have studied the present performance of synchronous motors must admit that while low starting torque has been one of the chief objections in the past, motors as now designed are able to carry a wide variety of loads without trouble. A still greater improvement in starting characteristics is likely to further widen the application of such motors for industrial drive.

The subject of flywheel effect required for synchronous motor drive is too technical to discuss in an article of this kind. Synchronous motors as now designed with normal excitation can stand instantaneous overloads of several hundred per cent. In fact, the pull-out point of a synchronous motor can be made so high that it is far beyond the heating limits of the machine. It is true that the synchronous motor does not allow the flywheel to act over a definite slip period as does the induction motor. There is, however, a certain amount of "give" between the direct current field and the alternating-current field on the synchronous motor as the load increases instantaneously. That is, the motor can slide back a portion of a pole face, and during this brief interval the flywheel is allowed to act. This helps considerably in taking care of the sudden jolts of the load such as those at the end of the stroke on compressors and other reciprocating machines.

On certain heavy, fluctuating loads it is possible to use a magnetic clutch with the magnetic pull on the clutch lining set to allow slippage at a certain maximum load. When the load exceeds this there will be a slip between the two halves of clutch, and the flywheel can carry part of the load. An interesting example of such an installation may be seen at the Trap Rock plant, Dresser Junction, Wis. A single line shaft is driven by a 600-hp., 200-r.p.m. synchronous motor. From this line shaft several crushers and other machinery are driven by ropes or belts. There is one large jaw crusher capable of receiving a full carload of rock in the hopper. Two large flywheels, approximately 16 ft. (4.8 m.) in diameter, weighing from 15 tons to 20 tons each, are set on each side of the crusher. When the heavy peak comes on the crusher the magnetic clutch slips, allowing the flywheels to help carry the load.

The third objection, previously mentioned, namely, the complications due to a separate exciter, is not a very serious one and is much more than offset by the advantage that synchronous motors can supply the necessary magnetizing kva. for induction motors to counteract the lagging power factor they produce. Very little trouble or inconvenience arises from the separate excitation since it involves no more complication than there is in the exciter circuit of any direct-current machine.

Unity-Power-Factor Operation. Motors which are to drive mechanical loads at the highest efficiency should be operated as nearly as possible at unity power factor. Motors operated in this manner constitute a non-inductive load, and while they do not operate at leading power factor, except at infrequent intervals, they do help improve the power factor of a line to a limited extent.

The design and construction of synchronous motors for unity-power-factor operations differs from synchronous condensers in the following respects:

First—The field winding need not carry so large a current for unity-power-factor operations, therefore field copper is somewhat reduced. Also the rating of the exciter is reduced to about half the size of exciter used for a condenser. Since the field current is thus limited, it is impossible for the motor to operate at a low leading power factor anywhere near its kva. rating at unity power factor. At very low leading power factor such a motor could carry less than one half its normal kva.

When a motor is operating at leading power factor the field is overmagnetized from an exterior source of magnetization, in this case the direct-current exciter. When the motor is running at lagging power factor the field is magnetized from the alternating-current side. Since this magnetizing current is in quadrature with the voltage, it has zero power factor and produces no heating effect in the field. This explains why the field heating in a synchronous motor is high at leading power factor and low at lagging power factor.

Second—Among the differences between a synchronous motor designed for unity-power-factor operation and one designed for power-factor correction is that no rheostat is necessary for controlling the field of the synchronous motor of the first type. This eliminates rheostat losses and helps efficiency to a slight extent.

Third—It has often been said that a synchronous motor is merely an alternator supplied with damper windings on the pole faces. This is not quite correct. In any alternator the shape of the pole tip as well as the extent of the pole span is limited by the field leakage which the poles must withstand when operating at low lagging power factor. Since it is not necessary to provide for such a condition with a synchronous motor operating at unity or slightly leading power factor, it is possible to design the pole faces and pole tips so as to get much better distribution of the slots for the squirrel-cage winding, and thus succeed in reducing the actual electrical air gap. (This is different from the mechanical air gap.) This makes it possible to reduce the amount of excitation necessary to produce a certain specified pull-out torque. It can be seen that such a design of pole construction will reduce the field losses and increase the efficiency of the unit as compared with the alternator (shorter pole span) type of design. Manufacturers who use the same design for their synchronous motor poles that they use for the alternator poles cannot take full advantage of the above-mentioned opportunities.

A synchronous motor designed to operate at full-load unity power factor will be from 10 to 25 per cent lower in price than a synchronous motor designed to operate at low leading power factors. This comparison is based on prices including exciter in both cases.

Attention Required. The fourth objection, that synchronous motors required more careful attention and more skilled operators than induction motors, is less important to-day than it was a few years ago. Most operators who are capable of handling induction motors of larger sizes can easily learn to start and operate synchronous machines. In the past the manual operation of starting a synchronous motor was often done in rather a crude and unscientific manner. Starting has now been simplified to such an extent that any careful operator can start a synchronous motor without mistake. It seems quite likely that automatic starting devices will ultimately be installed for synchronous motors which will guarantee at all times the most efficient starting, regardless of the skill of the operator.

After the motor is running at synchronous speed there is very little likelihood of "hunting" any more. Whenever such action arises it is generally due to faulty engineering in the installation. Commutator trouble in the exciter is not nearly so likely to arise with a synchronous motor operating at unity power factor as would be the case with an alternator where the power factor of the line is varying. Besides, exciters, as now designed, give comparatively very little trouble.

After facing all the practical objections which can be made to synchronous motors we must admit that the advantages more than offset the handicaps—on heavy loads of constant speed. With ordinary intelligent handling they operate satisfactorily with very low maintenance cost.

WHAT SYNCHRONOUS MOTORS CAN AND CANNOT DO

In many discussions of synchronous motors the subject of power-factor correction and condenser capacity is mixed up with and allowed to overshadow the characteristics of motor performance. A motor should be judged, however, by its ability to perform a certain duty and should stand or fall upon this performance alone. If it is able to improve the power factor of the system, this characteristic may then be considered as an additional point in its favor.

Service That Synchronous Motors Cannot Give. Will Brown of the Electric Machinery Company points out that while synchronous motors as now designed are quite different from the modified alternators of older days, and can develop 30 to 50 per cent full-load torque at starting, there are certain duties they cannot perform. So as to clear up any misunderstandings that may exist concerning synchronous motors in regard to either their limitations or advantages, some of the purposes to which they cannot be adapted will be outlined first.

(1) They cannot be used profitably on small loads. This generally means anything under 100 hp. An exception should be made in the case of small synchronous motor-generator sets, however.

(2) They cannot be used on intermittent loads involving frequent starting and stopping, such as crane motors, reversible hoist motors, etc.

(3) They cannot be used where variable speed or adjustable speed is demanded unless some mechanical means of regulating the speed change is provided.

(4) They cannot be used where it is necessary to start up the

full load from rest unless a clutch or some other mechanical method of easing the starting condition is supplied.

Uses to Which Synchronous Motors Are Adapted. In answer to the question which now probably arises in the reader's mind, "Where are synchronous motors now in use?" Fig. 53 is presented. It does not by any means cover the full field of

TYPES OF PLANTS USING SYNCHRONOUS MOTORS AND THE MACHINES WHICH ARE DRIVEN	AIR COMPRESSORS	AMMONIA COMPRESSORS	CENTRIFUGAL PUMPS	CONVEYORS	CRUSHERS	FANS	FREQUENCY CHANGERS	GRINDERS	JORDANS	LINE SHAFTS	MIXERS	MOTOR GENERATOR SETS	PULP GRINDERS	RECIPROCATING PUMPS	ROLLS	SCREW PUMPS
AUTOMOBILE PLANTS	■						■			■		■				
BRICK AND CLAY PLANTS			■	■		■										
DRAINAGE PLANTS			■				■									■
ELECTRIC LIGHT AND POWER PLANTS							■					■		■		
FLOUR MILLS										■						
FOUNDRIES	■											■				
ICE AND REFRIGERATING PLANTS		■										■				
IRON WORKS	■						■					■				
IRRIGATION PROJECTS			■													
MINES	■		■			■						■				
MARBLE AND STONE CUTTING PLANTS								■		■						
METAL WORKING PLANTS	■									■					■	
OIL REFINING PLANTS			■									■				
PAPER MILLS									■			■	■			
QUARRIES	■				■											
RUBBER MILLS										■		■			■	
RAILROAD SHOPS	■									■						
SHIPYARDS	■											■				
STEEL PLANTS	■											■				
SUCTION DREDGES			■													
SEWAGE DISPOSAL PLANTS			■									■				■
STONE CRUSHING PLANTS				■						■						
TEXTILE MILLS										■		■				
WATER WORKS			■											■		
MISCELLANEOUS	■	■	■			■	■			■		■		■		

Fig. 53—Applications to Which Synchronous Motors Are Adapted

possible applications, but it does indicate the already wide range of these motors and the promise of a much greater use in the future.

Where a heavy and fairly continuous load can be driven at a constant speed, there is generally an opportunity to install a synchronous motor. High efficiency and reliability of service are the two great essentials in such work. It is safe to say that a synchronous motor is always higher in efficiency than an induction motor of corresponding rating. At low speeds the advantage in favor of the synchronous motor is even greater than at high speeds.

There are many heavy-duty machines which must be run at low speeds. Formerly, if these machines were to be driven by motors it was necessary to install some form of belt or gear drive. They can now be directly connected to synchronous motors and operate efficiently at speeds as low as 72 r.p.m.

Starting Ability.—The old handicap of synchronous motors was their inability to start up from rest while carrying a mechanical load. This handicap has been overcome to a greater extent than most engineers realize. There are practical examples of large synchronous motors developing a starting torque as high as 50 per cent of full-load torque obtained without a prohibitively large kva. input. The future will probably bring even more remarkable results.

It is a fundamental fact that a low-speed synchronous motor cannot develop as high an initial starting torque with the same starting voltage as the high-speed motor, it being understood that horsepower ratings of the two motors are the same. For example, a certain motor with a synchronous speed of 200 r.p.m. can develop a starting torque of 35 per cent of full-load torque on the 40 per cent voltage tap with an input of 130 per cent of full-load kva., whereas a 600-r.p.m. motor can develop a starting torque of 40 per cent of full-load torque on the 40 per cent voltage tap with an input of 115 per cent of full-load kva.

Variable Loads.—Many types of heavy-duty machines requiring variable output are now designed so that they can be started and driven by synchronous motors. For instance, in a certain reciprocating pump installation a variable stroke is automatically obtained by means of bell cranks and by shifting the cylinder. This permits varying the delivery from zero up to 4200 gal. (15,900 l.) per minute.

Mechanical methods for changing the inlet or outlet passages for fans and blowers permit the use of constant-speed motors where formerly only adjustable-speed motors could be used. There are already a number of such installations—for instance, large exhaust fans such as are used on mine shafts, etc.—and it seems quite likely there will be many more in the future.

Line-Shaft Drive.—In cases where manufacturing processes are so correlated that a line-shaft drive is preferable to individual motor drive, the synchronous motor is finding wide applications. The motors may be either direct-coupled or belted. For this service it is nearly always necessary to use a clutch, either mechanical or magnetic, to permit starting and bringing the motor up to speed before the load is thrown on. The writer knows of a number of installations of this type in flour mills, also in rubber mills, all of them operating very satisfactorily and handling heavy loads, in which there are at times considerable fluctuations.

Efficiency and Ruggedness.—The high efficiency which can be secured with a synchronous motor is well illustrated in the following installations: One marble-working concern has been operating a 150-hp. synchronous motor driving a line shaft for nearly four years. The choice originally lay between an induction motor and a synchronous motor. The higher efficiency obtained by the synchronous motor brought a saving in the first two years of operation which more than made up for the higher original cost of the synchronous motor.

There is a rather interesting installation in a paper mill where a 1150-hp. synchronous motor is driving two direct-coupled pulp grinders. No difficulty has been experienced either in starting or running. An induction motor of similar horsepower driving a similar load has caused more or less trouble, which is generally traced to the very small air gap. The slightest wear in the bearings alters the air gap sufficiently so that a very heavy magnetic pull is set up on one side of the rotor and quickly wears the bearings down still more until the time arrives when the motor must be stopped and the bearing repaired. Very frequently the windings of the armature are damaged also. The synchronous motor, owing to its comparatively large air gap, is much more rugged and dependable for operation on low-speed, direct-connected loads.

Air-Compressor Drive.—Air compressors, especially those of sufficiently large capacity to require 100 brake horsepower or more, can be economically and efficiently driven by a synchronous motor. The old idea that it was necessary to change the piston speed with change in air demand has been abandoned. Mechanical methods of regulation on the compressors now permit the driving motor to operate at a uniform speed.

In practice synchronous motors are used both belted and direct connected to the compressor. On direct-connected units the speeds required are generally within the range of 260 r.p.m. down to 120 r.p.m. Probably the greatest number of direct-connected synchronous-motor-driven compressors operate at a speed in the neighborhood of 200 r.p.m. This speed is very much higher than was ever thought advisable by compressor builders a few years ago. The increased speed has been made possible by the adoption of a light plate valve with a low lift. The time required to open and close such a valve is so small that it permits operating the piston at much higher speeds.

In starting an air compressor the pressure can be relieved by a by-pass so that the motor has only the friction load and inertia to overcome in breaking the compressor from rest. This is very easily taken care of without drawing excessive kva. from the line, and the motor can pull into synchronism without causing objectionable fluctuation of the line voltage.

Since the load factor of a compressor is generally high, and since the power factor of a synchronous motor can be maintained at unity, a favorable rate can usually be secured when energy is purchased from a central station. The fact that these motors operate at unity power factor or lightly leading (at part loads) should appeal with even greater force to plants generating their own energy. The power factor and efficiency obtained with a typical direct-connected synchronous-motor-driven air compressor are shown in Table XIX.

TABLE XIX—EFFICIENCY AND POWER-FACTOR TESTS OF 560-HP., 225-R.P.M. SYNCHRONOUS MOTOR DIRECT-CONNECTED TO AIR COMPRESSOR

Exciting current remaining constant at all loads

	Quarter Load	Half Load	Three-Quarters Load	Full Load	One-and-a-Quarter Load
Efficiency	92.6 per cent	95.6 per cent	96 per cent	96 per cent	95.4 per cent
Power factor	73 per cent Leading	93 per cent Leading	98 per cent Leading	100 per cent	98 per cent Lagging

Recently there has been an enormous demand for large synchronous-motor-driven air compressors among the shipyards of the country. They range in size from 150 hp. to 1200 hp. Among other lines of industries using synchronous-motor-driven air compressors might be mentioned mines, foundries, automobile factories, structural steel works; in fact, any industry where a large quantity of compressed air is used. In driving tunnels the air pressure can be maintained in the headings by means of a battery of low-pressure compressors driven by synchronous motors.

Ammonia-Compressor Drive.—The large ammonia compressors used in ice plants (50-ton or over) are driven in exactly the same way as air compressors, by either belted or direct-connected synchronous motors. The starting duty required is somewhat more severe than in the case of air compressors, however. In order to obtain the required starting torque it is sometimes necessary to use a higher voltage tap on the starting compensator than would be necessary with the corresponding air-compressor installation. The large flywheel combined with the inertia and friction of other moving parts requires that the motor be specially designed to produce maximum starting torque.

The preference for direct-connected synchronous-motor-driven ammonia compressors is very markedly shown in the ice and refrigerating plants recently constructed or now in course of construction. It may be said safely that the energy cost with direct-connected synchronous-motor-driven machines is less per ton of ice manufactured than is the case with any other type of motor drive.

Once it was considered essential, in order to meet the varying demands for ice, that the speed of the ammonia compressors should be adjustable. This is no longer necessary. In place of one large unit running at variable speeds, ice plants can have two or more smaller units which run at constant speed. By running different combinations of the compressors in parallel, fluctuation in demand can be easily cared for without any provision for speed adjustment. When the demand drops to a minimum the smallest compressor only may be used, so the losses may be kept at the minimum It can be seen that the overall efficiency of such a plant will be very much higher than in the old-fashioned variable-speed plant.

Another method of varying the output of the compressor at constant speed is by means of an adjustable clearance pocket, or cylinder, at each end of the compression cylinder. By means of these the clearance can be increased and the capacity lowered to any desired point between full load and one-quarter load or even lower. Thus the flexibility of the compressor is fully equal to that of the old adjustable-speed compressors driven by low-speed Corliss engines.

The efficiency curve of the synchronous motors is quite flat throughout a wide range of load, so that there is very little loss in efficiency on the part of the motor when run at part loads. As far as the compressor is concerned, the efficiency at part loads seems to be practically as good as at full load. This is due to the general conditions under which ice-manufacturing plants operate. The efficiency and power factor for a typical synchronous-motor direct-connected to an ammonia compressor are indicated in Table XX.

TABLE XX—EFFICIENCY AND POWER-FACTOR TESTS OF 450-HP., 200-R.P.M. SYNCHRONOUS MOTOR DIRECT-CONNECTED TO AMMONIA COMPRESSOR

Exciting current remaining constant at all loads

	Quarter Load	Half Load	Three-Quarters Load	Full Load	One-and-a-Quarter Load
Efficiency	87.7 per cent	92.6 per cent	93.7 per cent	94 per cent	93.8 per cent
Power factor	70 per cent Leading	94 per cent Leading	99 per cent Leading	100 per cent	99 per cent Lagging

Direct-Connected Centrifugal Pumps.—Quite a number of installations of synchronous-motor-driven centrifugal pumps have been made recently. In most cases the motor is directly coupled (through flexible coupling) to the pump shaft. Starting requirements of a centrifugal pump can be met by a properly designed synchronous motor. Before starting, the pump is primed. The discharge valve is closed when the motor starts, so the impeller merely churns the water. The load increases rapidly, running up to 30 per cent, or even 50 per cent, of full load as the motor approaches synchronous speed. When full voltage is applied and the motor is pulled into step, there is a momentary rush of current, which, however, should not be excessive and should fall almost immediately as the motor settles down to synchronous operation. The maximum peak at pull-in should rarely exceed 150 per cent of the full-load kva.

As long as the discharge valve is closed the impeller is churning the water, and this energy is transformed into heat. If this operation is continued too long, steam might be generated. A small by-pass for liberating air relieves any possibility of steam pressure. Of course the proper thing to do is to open the discharge valve as soon as the motor is running at synchronous speed and allow the pump to begin discharging at its normal head.

There are numerous cases where centrifugal pumps driven by synchronous motors are used for suction dredging. As the pipe lines which carry the discharge are extended from point to point as the dredge continues its work, a large change in the friction head occurs which necessitates two-speed drive for the pump. This requirement can be met by using a two-speed helical gear.[1]

Each installation of centrifugal pumps is a special problem, and both motor and pump must be designed as such if best results are to be secured. Generally speaking, centrifugal pumps are designed to operate at constant speed. Synchronous motors with speeds as low as 72 r.p.m. are used directly coupled to low-head pumps. High-head pumps with speeds as high as 1200 r.p.m., or even 1800 r.p.m., are also directly coupled.

Unity Power Factor Operation.—A synchronous motor designed for so-called unity power factor operation has a fixed exciting current which cannot be exceeded, so that absolutely unity power factor cannot be maintained if the load fluctuates. As the load drops off the power factor will change to leading, but the change in power factor from full load to quarter load is surprisingly small. From one-and-a-quarter load to one-half load the change in power factor is less than 10 per cent. At one-half load the power factor is slightly leading and at one-and-a-quarter load slightly lagging. If the load should be removed entirely from the motor, it would operate at approximately zero power factor up to about one-half of its rated kva. capacity. (The fric-

[1] In one plant using this drive which the writer inspected the energy cost was only five-sixths of the amount that fuel cost when steam was used for the same purpose. Furthermore, the motor-driven suction dredge was handling considerably more material. If the present price of coal was taken into consideration, the energy cost would be only about five-twelfths of the full expense.

tion losses in the motor would constitute a load, so that in practice the power factor could never reach zero.) The limitation to the exciting current prevents the motor from carrying its full kva. rating. Of course, variations of design will change the characteristics of motors, so the preceding statements are only general and must be modified under certain conditions. The extent to which a power user can afford to go in installing synchronous machines depends largely on the annual cost of power. The advantage to be gained may run anywhere from 10 per cent to 30 per cent of this amount.

Correcting Power Factor.—In the case of an isolated plant generating its own alternating current, the use of an over-excited synchronous motor at a leading power factor is often very desirable. Such a motor if properly designed may operate at a power factor, say, 80 per cent leading, while at the same time carrying three-quarters of its rated mechanical load in horsepower. Under this condition the motor may exert nearly the maximum corrective effect on the system's power factor. The magnitude of the system load and the power factor must be taken into consideration, however.

This problem of power-factor improvement cannot be met in the future, as it has been in the past, simply by the central station installing large synchronous condensers. It will become more and more desirable to have a connected load of many fair-sized synchronous motors scattered over the system. This is much better from the standpoint of voltage regulation, transmission efficiency, etc., than the old method of combining all the power-factor correction for the circuit in one or more synchronous condensers.

The result will be that central stations will encourage the use of synchronous motors more and more on their lines. This tendency is already apparent in many sections of the country, especially where large individual users of power are scattered over the system.

INTERPOLE MILL MOTORS VERSUS NON-INTERPOLE

By far the larger proportion of direct-current motors in steel mills require rapid braking, either by "plugging"—that is, reversing at full speed—or by dynamic braking, says W. R.

Runner of the Westinghouse Electric & Manufacturing Company. The former operation is the more severe of the two, as it will be seen that if a series or heavily compounded motor is reversed when running at high speed the armature emf. adds to the line emf. The effect of this is cumulative, the increasing current causing an increasing armature voltage, the maximum value of the latter depending on the speed and the saturation of the magnetic circuits of the motor. While the peaks are of very short duration, the armature emf. sometimes goes to nearly double normal value and the current to three or more times the full-load value. As these peaks tend to produce flashing at the brushes, tests have been made to determine the effectiveness of the interpole in eliminating the flashing. That the interpole motor is better adapted to this service than the older type of motor was very clearly shown by the results obtained.

The motors tested were all of the totally inclosed mill type, series-wound, and represent standard designs of interpole and non-interpole machines. That the motors of a given rating were very similar in speed, voltage and weight is shown in the following table. Likewise, their performance curves are very similar so that the comparison is made on an equitable basis:

	One-Hour Rating, Hp.	Speed R.p.m.	Voltage	Weight, Lb.
Interpole	80	480	230	4,550
Non-interpole	75	500	220	4.360
Interpole	40	525	230	2,900
Non-interpole	37½	535	220	3,070

The two motors of a size were coupled together, and the one not being tested was used as a generator for load. This had the additional advantage of operating both motors with the same inertia load, an important point in tests of this type. The usual type of magnetic control was used, so that the interval the current was off between ''run'' and ''reverse'' was essentially the same as in actual practice.

Referring to Fig. 54, it will be seen that the interpole motor commutated a peak load of 320 per cent normal load at 80 per cent of the full-load speed, and that increasing the speed to 200 per cent of normal decreased the maximum peak only to 270 per cent full-load current. On the other hand, while the non-interpole motor commutated 270 per cent full-load current at

80 per cent speed, it commutated only full-load current at 200 per cent speed.

In addition to the foregoing tests a cycle test was run to determine the effect of plugging on the two types of motors. The same general scheme of connections was used, except that all operations were controlled by a motor-operated master drum. The cycle of operation was start, run under load, and plug, this being carried out on each motor alternately. This cycle was repeated approximately 7500 times on each test, each cycle

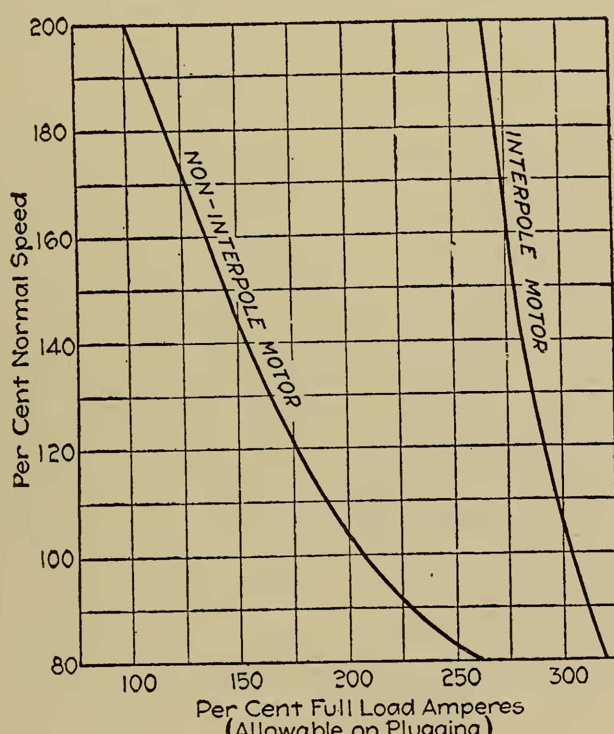


Fig. 54—Relative Effects of Interpole and Non-interpole Motors

requiring about thirty seconds. At the end of this time it was found that the commutator of the interpole motor had acquired a good polish and showed no bad effects from being plugged at 150 per cent speed with a peak of approximately 275 per cent full load. The non-commutating-pole motor, however, did not show up so well as indicated by the curve in Fig. 54, as the commutator began to show signs of pitting, due to plugging peaks of slightly more than full load, the speed and number of cycles being the same as for the other motor. This test was conducted on several different sizes, the results being very much the same in each case, showing that the interpole is extremely desirable in motors which are to withstand severe plugging service.

USE OF LIGHT-WEIGHT MOTORS A MEANS OF ECONOMIZING

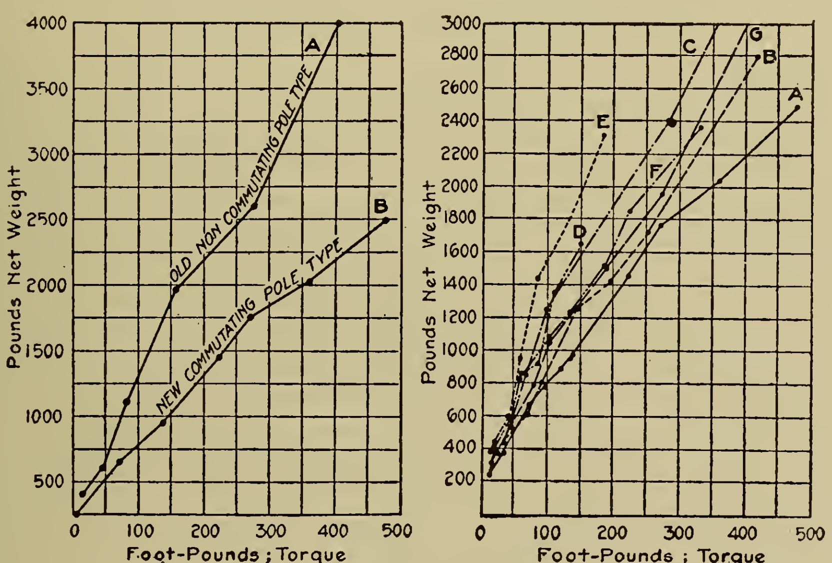
Economy with all the resources of the country is of the greatest importance under the present conditions, it being just as important to economize with copper and steel as it is to economize with food and coal. In order to pay off the immense war debts it will be imperative for this country to make the best possible use of its resources. Of these copper and iron ore form very prominent parts. Economy in these metals must be made at every point, and no part of a machine should contain metal not necessary for its proper operation. By giving preference to lighter motors of equal rating users will encourage manufacturers to seek out means of economizing metals and thus release a very substantial amount for other uses.

Records submitted by A. Brunt of the Westinghouse Electric & Manufacturing Company indicate that the average-size direct-current general utility motor sold has a torque of 65 ft.-lb. (8.97-kg.-m.), corresponding to 15 hp. at 1200 r.p.m. This size of motor can be bought with a weight varying between 605 lb. and 1080 lb. (274.4 kg. and 489.8 kg.) (Fig. 56). Assuming the average weight of motors of 65 ft.-lb. (8.97-kg.-m.) torque to be 845 lb. (383.3 kg.), and further assuming a total production in this country of 30,000 motors per year, the waste of material by using the average motor instead of the lightest motor will be (845 — 605) $\times$ 30,000, or 7,200,000 lb. (3,265,865 kg.) per year. This figure is appalling, especially under the conditions which exist at the present time.

Improvements in the design of direct-current motors — chiefly the adoption of the commutating pole, a more thorough knowledge of allowable operating temperatures and more effective means of ventilation — have made it possible for progressive manufacturers to reduce the weight of their machines very substantially (Fig. 55).

Since all manufacturers sell in the same market, their prices for motors of the same rating must necessarily be nearly the same. The purchaser of a motor naturally will ask, "Should I buy the light or the heavy motor?" The motors will all be designed to have the same temperature guarantees, and, assuming that the speed characteristics will be satisfactory and the efficiencies equally good, it may be asked, What are the advantages of the one over the other?

Naturally many purchasers of direct-current motors will think that by buying the heavy motor they are getting more for their money. A careful comparison of the two motors, however, will show that this is not so. If the heavy motor should have more excess capacity, this should also show itself in dimensions of shaft and bearings. However, an examination of the pulley-end



Figs. 55 and 56—Relation Between Weight and Torque for Commutating-pole and Non-commutating Pole Motors; Also for Seven Various Makes of Motors

bearing diameter for two competitive lines of motors manufactured by prominent concerns shows that there is very little difference between shaft diameters of competitive motors.

The lighter motor necessarily must be the better ventilated one, which means that the motor is so constructed that the cooling air comes in thorough contact with those internal parts in which the heat is generated. Thus it follows that the excess of actual external temperature over the temperature measured by applying a thermometer to outside surfaces must be smaller in the light, well-ventilated motor than in the heavy motor, with consequent smaller danger to the insulation. In this respect the light, well-ventilated motor is much to be preferred over the heavier one.

Light motors further can be handled more easily and also have a lower freight rate, which is an advantage to the purchaser in case the motor is to be shipped outside of a free-delivery zone. That great weight is not necessarily an equivalent of superior qualities is well illustrated by the weight curves of Fig. 55. Efficiency and especially commutation of the commutating-pole motor are decidedly superior to the same qualities of the very much heavier non-commutating-pole motor.

INDUSTRIAL MOTOR CONTROL

In certain respects motor-controlling devices have been simplified greatly since the early days of the art. In the beginning the electric motor was a peculiarly tender piece of apparatus both electrically and mechanically. The control of sparking was very imperfect, the insulation was none of the best, the slotted armature was unknown, and above all the motors in small sizes were commonly installed on lighting circuits of meager capacity so that their effect was unpleasantly conspicuous. Under such circumstances motors had to be installed where the brushes could receive constant attention, a precaution doubly necessary if any attempt were made to introduce variable speed. The starting rheostat had to be provided with many steps, and it behaved rather badly at that. Remote control, current-limiting devices other than open fuses, sometimes replaced by wire nails, and low-voltage automatic stops were quite unknown.

The complicated starting rheostat can now be brought to a most elementary form, even down to a single step of resistance variation, and it is indeed not very unusual to omit the external starting resistance entirely. It is well to look a bit into the cause of this now justifiable change in practice. In the first place, direct-current motors are much better designed with respect to sparking than they were in the old times. A first-class modern motor will stand all kinds of speed changes and changes of load with never a blink at the brushes, so that rheostatic control to avert commutator trouble at starting or in changing speeds is rather unnecessary. Second, the individual small motor is so trivial an element on the average electric system that it can be switched on or suddenly loaded without any perceptible effect on the system. A 10-hp. motor across the outside of a three-wire system is no longer a cause of worry to the station operator or to its own operation. This is one of the beneficial results of sheer magnitude in the scale of operations—that it takes 100 hp. or so to bear the same relation to the system operation as 5 hp. or 10 hp. a quarter century ago. Again, those who buy and use motors are much less fussy about some of their characteristics than in the early days.

Starting Induction Motors. Control of induction motors is a subject of very direct practical importance on account of the almost universal use of the induction motor for a very large variety of work. It is only in cases involving for the most part delicate speed control that the direct-current motor has intrinsically any special reason for being, although, of course, it is in many localities the only form of motor for which power can be obtained and is now, as it always will be, extremely useful. In starting induction motors practice has been very widely modified since the early days of the art. In the beginning the induction motor had to make its way against the most violent, not to say abusive, kind of competition, during which period all kinds of absurd things were required of it, things which no man contemporaneously dreamed of asking of a direct-current machine in regular service. The average central station twenty-five years ago was small in output and had meager copper in its distributing system. A high call for current at starting, particularly current very badly out of phase, was so serious a matter that early designers of induction motors were put to it to deal with the starting load in such manner as not to offend the delicate sensibility of the central-station men, stirred up to hypercritical caution by salesmen of direct-current apparatus. All that has, of course, now gone by with the overwhelmingly great use of alternating current, and the huge increase in station capacities makes a starting load of well-designed motors a relatively trivial matter.

So it has come about that simple and effective automatic starting apparatus has come into use for induction motors of a kind which could not have obtained a hearing, much less commercial acceptance during the unnecessarily fussy period referred to. Small motors, unless they have to develop exceptionally large starting torques, are almost universally slammed on the lines with no more ceremony than one would exercise in turning on a bank of lamps. For larger motors some reasonable precautions are still in order. The larger squirrel-cage motors are customarily started at reduced transformer voltage by the use either of dead resistance or of the ''autotransformer'' or ''compensator'' device. The resistance type of starter, very simple and cheap, is commonly employed with resistance in two only of the three leads. In good old times the very suggestion of this would have shocked the manufacturer and produced long and violent discussion in the columns of electrical papers. However, it works admirably with small loss of efficiency and great convenience. When the starting current is dropped below a predetermined point the automatic starter cuts the motor squarely over on to the supply mains, and that is the end of the matter. Starting at reduced voltage from some variety of auto-transformer is the method very commonly applied to the larger squirrel-cage machines. In its original form the motor was started on the low voltage and thrown over at somewhere near the proper point by a manual double-throw switch. This left rather too much to the discretion of the operator, and automatic controllers have in considerable measure come into use.

It has been found desirable to introduce certain devices to protect the insulation by disconnecting the low-voltage connection entirely after the motor is up to speed and by keeping the motor in circuit during the passage from low to high voltage by the use of a protective inductance or resistance to save the transformer. Very excellent automatic starters of such type are in use and have been evolved for convenient push-button control in which the operator can start the train of operations from one or several points distant from the motor. The slip-ring motor with round rotor is the form widely used in cases where the starting torque is great and the motor of considerable size. Here, too, unbalanced secondaries are not infrequently used except in extreme cases of demand for torque, inasmuch as the apparatus is thereby simplified, and the operation appears to be entirely satisfactory. A well-designed controller, operating automatically on the secondary resistance, brings the motor up to speed with ample torque and great smoothness, although for certain special cases manual control still holds an important place. Altogether, the problem of easy and convenient starting for induction motors has been admirably solved, so that in point of fact nobody thinks seriously about it at all, but simply installs the type of starter which seems most convenient for the case in hand.

Speeding Shopwork with Automatic-Control, Adjustable-Speed Motors. Time and labor as measures of production cost have become so important in the Union plant of the Bethlehem Shipbuilding Corporation at San Francisco that extensive changes in equipment have been made to speed up the rate of doing work and decrease the labor required. Many of the older machine tools have recently been provided with automatic control or equipped with new adjustable-speed motors outright. Experience with these improvements has been such that the new machine shop has been equipped throughout with adjustable-speed direct-current motors with dynamic brakes and entirely automatic control.

Although all the equipment has not yet been installed, there are now about 100 motor-driven machine tools in service in the shop. The motors are all sizes ranging up to 35 hp., the total installed capacity being about 500 hp. The shop schedule is such that no equipment is allowed to stand idle except when repairs are necessary. As soon as new tools are received they are put in service immediately.

The direct-current equipment and the automatic features are working out very satisfactorily. With about thirty speeds extending over a ratio of four to one and controlled by conveniently placed push-buttons, operators work much more effectively than where only four speeds could be attained, and that with some effort in shifting pulleys. Moreover, the dynamic brake brings the work to a stop so quickly that time is saved in the inspection and the operator is inclined to examine it more frequently. Foremen regard this is a most important factor in speeding up the work, and the workmen themselves prefer it because of its "convenience." The automatic control gives a fixed rate of acceleration.

MACHINE-TOOL DRIVE

The use of motors has steadily increased with the improvement of their applications and the general availability of electric power until today the majority of new equipment of the heavier sort is fitted for motor drive. Its fundamental advantages of convenience, efficiency, flexibility and exact speed control are well known. The objections on the score of high first cost, the price of power and the conservatism that clings to old methods have been steadily fading from view. From now on, as new shops are equipped, the motor is surely coming into its own. Heretofore there have been the inconvenience of changing over machines for individual drive and the natural objection to scrapping equipment in good condition. Moreover, in an old shop fully organized for belt drive many of the characteristic advantages of motors cannot be fully realized. In starting afresh the whole layout of the shop can be planned for maximum efficiency without having to consider the necessities of arrangement from the viewpoint of the transmission of power by belts and shafts.

Group Versus Individual Drive. Speaking broadly, a machine in which the item of power consumption is a considerable one in the cost of product should be individually motor-driven merely on account of the increased efficiency. If, as very commonly happens, exact speed control exercises an important influence on its rate of output—that is, on the working efficiency of the operative—individual drive with its complete power of speed control is doubly necessary. Only with light machines steadily worked in groups at fairly uniform output can group driving be really advantageous. It is the working unit, whether of one or half a dozen machines, that must be considered. At the present moment the amount and character of overtime work is a peculiarly important item. With individual drive certain combinations of machine tools necessary to production can be made at will without reduction of efficiency from the power standpoint, while with belt and shaft drive as generally found full efficiency can be obtained only when the plant is in full operation. Most important of all, however, is the influence of individual motor drive on shop layout and working organization. When every machine has its own separate motor, not only can the plant be kept more clearly and better lighted, but it can be arranged for the highest efficiency of production irrespective of all considerations of power supply. Machines can be grouped and placed so as to insure the minimum of back-lash in that steady movement of materials, processes and finished work that is so necessary to high output at a minimum cost.

Mere saving of time due to speed and ease of control and to the placing of machines so as to call for the least human effort in handling the work is no small practical item of gain. Likewise, the abolition of shafting, belting and all overhead gear leaves the space clear for the cranes and travelers needed for the easy transference of heavy products without interference with the floor space and often with the workers as well. In fact, it is these operative advantages, quite aside from the saving of power, that constitute the strongest reason for going to individual motor drive in all new installations.

Thus, the advantages of individual drive are in lessened constant losses in the power supply, in extremely facile control and in the independence which may be secured in the placing of various machines. The contrary factors are enhanced first cost of individual motor drive, particularly in machines requiring motors of small output, and the consequent gain from dispensing with separate motors altogether in the cases where a number of machines are operated simultaneously like a unit and practically at full load. There are also collateral advantages from belt drive including a number of machines in cases where each individual machine is subject to extreme changes of load which in case of a separate motor would require such high overload capacity as to increase the cost and decrease the efficiency. The friction losses due to shafting in an ordinary machine shop are rather large—at least 25 per cent on the whole, and often 30 per cent. This therefore gives a reasonable opportunity for actual saving of power by the use of individual motors.

In the somewhat exceptional cases where the power cost of an operation is a very material factor this saving might of itself be enough to justify the individual drive, but there is very much to be said for the separately driven machine merely from the standpoint of that flexibility which means increased output. Anything which can cut down the relative importance of the element of human labor should in these days be sought earnestly, and if by the use of carefully regulated electric drive the speed of operations can be increased and the finished product delivered with less time spent with the laborer, there is a very definite gain irrespective of whether the work is piece work or day work. In the one case there is, of course, a direct saving in cost of labor, in the other an indirect saving by that increased production which raises the efficiency of the whole shop.

The balance of the argument therefore stands in a large per-

TABLE XXI—DATA ON MACHINE GROUPING AND POWER REQUIREMENTS IN A LARGE SHOP

Motor		Machines				
Group No.	Hp.	No.	Kind	Size	Hp.	Remarks
1	15	31	Shaper	24 in. x 14 in.	2	
		30	Shaper	24 in. x 11 in.	2	
		32	Drill press	½in.-3 in.	1	
		42	Planer	12 ft. x 4 ft.	15	
		65	Planer	12 ft. x 3 ft. 10 in.	15	
		7	Borer	8 in.	1	
		43	Drill press	½ in.-3 in.	1	
2	5	28	Planer	6 ft. x 1 ft.	3	Cylinders
		40	Shaper	15 in. x 10 ft.	2	
		33	Drill press	½ in.-3 in.	2	
		18	Lathe	12 in. x 7 ft.	1	Shaft
3	5	8	Lathe	10 in. x 4 ft.	½	Turret
		37	Emery wheel	8 in.	1	
		71	Surface grinder		1	
		38	Drill press	½ in.-2¼ in.	1	
		68	Sandstone		1	
		13	Lathe	9 in. x 4 ft.	½	Prentiss tool
4	3	10	Lathe	12 in. x 4 ft.	1	Shaft
		69	Grinder (cutter)		1	Garvin
		70	Grinder (cutter)	¼ in.-1 in.	1	
		46	Drill press		½	
		45	Drill press	¼ in.-1 in.	½	
5	10	39	Drill press	in-1 in.	½	
		57	Auto screw cutter		5	
		58	Auto screw cutter		5	Jones & Lamson
		72	Saw	14 in.	1	Bars and shafts
6	5	73	Saw	14 in.	1	Bars and shafts
		74	Saw	14 in.	1	Bars and shafts
		47	Pipe cutter	3 in.	3	Threads
		48	Pipe cutter	4½ in.	3½	Threads
		66	Punch press		1	

Motor Group No.	Motor Hp.	Machines No.	Kind	Size	Hp.	Remarks
7	5	7	Gear cutter		5	
8	10	2	Lathe	33 in. x 9 ft. 3 in.	7½	Drum boring
		12	Lathe	18 in. x 1 ft.	5	Upright turret
9	10	1	Lathe	36 in. x 14 ft.	10	Large
		4	Lathe	24 in. x 9 ft.	5	Drum turning
10	7½	35	Drill press	¼ in.-1¼ in.	½	
		25	Lathe	8 in. x 1 ft.	½	Screw
		24	Lathe	10 in. x 2 ft.	1	Turret
		14	Lathe	12 in. x 2 ft.	1	Turret
		44	Emery wheel		1	
11	10	3	Lathe	24 in. x 11 ft.	5	Crankshaft
		6	Lathe	18 in. x 6 ft.	2	Winch turning
		5	Lathe	22 in. x 1 ft. 8 in.	3	Gear turret
		67	Wet emery wheel		1	
		29	Slotter	10 in.	5	
		56	Drill press	½ in.-2 in.	½	
		55	Miller	4 ft. x 1 ft.	10	
		9	Lathe	11 in. x 13 ft.	1	Shaft
		15	Lathe	10 in. x 5 ft.	½	Shaft
		16	Lathe	8 in. x 4 in.	½	Shaft
		20	Lathe	12 in. x 18 in.	½	Shaft
		17	Lathe	13 in. x 7 ft. 6 in.	1	Shaft
		19	Lathe	11 in. x 8 ft.	½	Shaft
12	15	11	Lathe	10 in. x 8 in.	½	Shaft
		36	Miller	4 ft. x 1 ft.	10	Shaft
		41	Crank Press	8 in. 100 tons	1	Shaft
		49	Miller	4 ft. x 1 ft.	10	
		50	Miller	4 ft. x 1 ft.	10	
		51	Drill press	¼ in.-1¼ in.	½	
		52	Grinder	5 in.	1	Emery
		53	Slotter	10 in.	5	
		54	Grinder	5 in.	1	Emery
13	10	21	Lathe	9 in. x 5 ft.	1	Shaft
		22	Lathe		1	Shaft
		23	Lathe	8 in. x 4 ft. 6 in.	1	Shaft
		26	Lathe	8 in. x 3 ft.	1	Shaft
		27	Lathe	8 in. x 4 ft. 6 in.	1	Shaft
		59	Saw	24 in.	5	Circular blocks
		75	Drill press	¼ in. to ½ in.	½	Circular blocks
14	7½	50	Saw	24 in.	5	Circular blocks
		61	Lathe	42 in.	2	Pattern turning
15	7½	62	Saw	12 in.	1	Pattern
		63	Planer	15 ft. x 1 ft. 6 in.	3	Patterns
		64	Saw	3 ft.	3	Band

centage of cases in favor of the individual drive, save in the operation of small and homogeneous groups of machines under nearly constant load and a few exceptional cases of extremely variable load.

Power Requirements of Machines in Large Shops. In the table on pages 140 and 141 are given the power requirements and best grouping of machines in a large machine shop that was recently laid out. The shop is divided into fifteen groups, the table giving a description of the driven machines as well as the horsepower of the motor required to drive the apparatus. This table should prove of value to engineers grouping machines for motor drive. The machines have been so arranged that for most jobs raw materials will enter the rear of the shop and pass from group to group, leaving the last group as a finished product.

Motor-Driven Planers. The planer is one of the most important of machine tools and in some respects the least efficient from the standpoint of output, since at best only half of its motion is taken up in cutting, as opposed to the works of lathes and milling machines. The first requirement, therefore, of a scientific drive is that it should operate on the cutting stroke at the speed of maximum efficiency for the particular metal and the cut in hand, and that it should get back for another stroke in the minimum possible time with as little fuss and strain on the equipment as is practicable.

The actual work required in making the cut is a comparatively small part of the cost of the whole planing operation, so that power economy itself is a less important item here than in many other machines. To meet the requirements of the particular cycle of operation necessary two general schemes are in use. The first of these provides an independent motor drive of the planer, using the ordinary belt equipment and eliminating the line shafting. In this case the motor runs at constant speed and the ordinary belt-shifting device takes care of the varying speed required in the cutting stroke and of the swift return necessary. It is not unusual to accelerate the return by automatic change in the field resistance. The obvious difficulty with the arrangement is the heavy demand for power and the severe strains imposed during the mechanical reversal.

Of late planer manufacturers have been looking with more and more favor on the purely electric drive with reversing motor, using dynamic braking to take up the shock of the necessary reversals. A complete electric drive, of course, gives all manner of opportunity for proper speed variation, at the cost of somewhat more complicated and costly motor equipment. The chief advantage gained is a greater degree of flexibility and the practical abolition of the very severe strains arising from inertia of rotating parts. The inertia of the moving platen is small and that of the rotating parts is relatively very high, causing a corresponding violent effort in reversal. With the dynamic braking possible in the directly driven equipment this difficulty is greatly reduced, and when properly adjusted the direct-driven planer ought to be able to do the work with less wear and tear than if belting were employed with a continuously running motor. The balance of cost in the two cases is not altogether easy to figure out, but experience with other electrical drives would indicate that the increased smoothness and flexibility of control with the reversing-motor equipment is well worth the while in standardized operations where workmen can be taught to use habitually the most efficient speeds. And in this, as in many other similar cases, it is output which counts as the largest item in successful manufacturing, especially when costs of material and labor are running to exaggerated figures.

Minimizing Load with Group Grinder Drive. If the work cycles of grinding machine are arranged so they overlap and they are started in succession to take advantage of their flywheel effects the motor driving a group of them can be rated much lower than would otherwise be necessary. Starting the grinders is particularly beneficial because they have considerable inertia which would demand a very large starting current if all were started together. An investigation along this line, made by Sydney Fisher, is given in what follows:

The drive consisted of twelve Hemming grinders, each machine having a cup-shaped emery wheel 16 in. (40.6 cm.) in diameter with a radial thickness of 1.25 in. (3.2 cm.) and operating at a speed of 625 r.p.m. The work feed is 1 ft. (30.5 cm.) per minute. Originally a 35-hp. motor was installed to drive six machines, but this motor was finally used to drive all twelve machines.

The machines are arranged in groups of six, each of which is operated by one man. The method of operation and the rate of feed is such that the power demand gradually increases to a maximum when all six machines are grinding simultaneously, and then gradually decreases to a minimum when the machines have finished grinding.

The two portions of the accompanying curve marked A and B indicate the variation in power demands under two different conditions of operation. During the period marked A the relative operation of the two groups is such as to cause their work cycles to be exactly in phase, while during period B they overlap. As shown by the curves, there is a marked difference in the power demand for the two conditions.

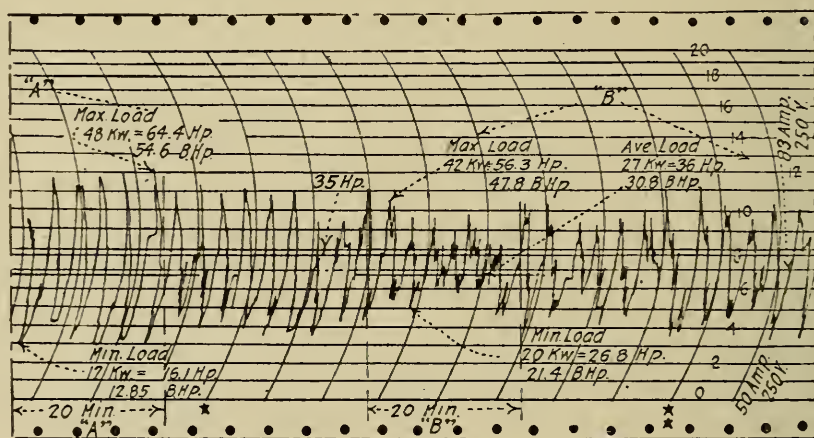


FIG. 57—LOAD CURVE WITH GRINDERS OPERATING UNDER DIFFERENT CONDITIONS

With loading A the average power is 30.8 hp., which is less than the rated output of the motor. The peak load is 54.6 hp., which is well within the maximum overload capacity of the motor. The minimum load is 12.85 hp. Evidently there is quite a variation in power demand.

The average power with B operation is 30.8 hp., the same as that for A, the work done in each case being practically the same and the periods equal (twenty minutes). The variation in power demand is considerably less and approaches the ideal condition of a uniform load of 30.8 hp.

With intelligent operation as exemplified in B excessive current variation is obviated and higher operating efficiency is obtained. Most important of all is the lessened possibility of interruption of service due to tripping of the overload relays with excessive overload.

Automatic Guard for Drill Presses. An automatic guard for drill presses was recently built for use in the plant of the Commonwealth Steel Company of Granite City, Ill., after one of the operators had been killed. This guard extends horizontally just above the drill table so that when struck or touched the main-line switch to the drill motor is opened, thereby causing a dynamic brake to stop the drill in one-quarter of a turn. This is practically instantaneous as the speed of the drill is 150 r.p.m.

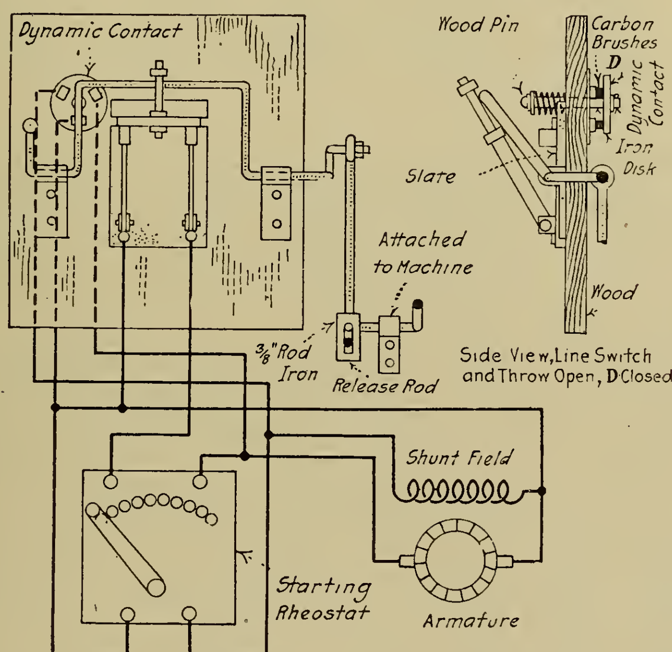


FIG. 58—ARRANGEMENT FOR STOPPING DRILL QUICKLY

All of the machine operators are instructed in shutting down the machines to do so by applying the dynamic brake by touching the guard instead of walking to the switch box and opening the circuit manually. In this way they become so accustomed to using the dynamic brake that in case they were pulled into the drill at any time it would be almost second nature to them to strike the guard in some way. By examining the diagram, Fig. 58, it may be observed that the release rod merely opens the main switch and short-circuits all the motor leads. The device was perfected by William Schnieder and H. E. Howey.

PLATE-SHOP DRIVES

Factors governing the selection of motor drives, the rating required and some of the characteristics which were desired for driving the plate-shop equipment of the Staten Island Shipbuilding Company are discussed in what follows by David Elwell, electrical engineer for Lockwood, Greene & Co.

Since it was necessary to put this shop in service as soon as the building was up, and as the question of electric power supply for the whole plant had not been worked out at that time, the 220-volt direct-current energy then available was used. The machine tools listed in Table XXII were installed and equipped with individual motors, in most cases belted directly to the machines.

Conditions Influencing Drive. Every consideration involved in connection with the plate-shop machines led to individual drives. Neither the type of building, the arrangement of machines nor the operating conditions surrounding the use of them made group drives desirable.

The building is a high-studded steel-frame building with peak roof and two longitudinal bays, with a traveling crane in one of them. Under these circumstances the shafting necessary for group drives would be cumbersome and expensive. Furthermore, in order to secure sufficient space around the machines for handling the large plates and angles that are being fabricated considerable clearance had to be left between machines. This would further add to the expense of providing group drive.

The other controlling factor is the fact that while the final product of the yard may be standardized (*i. e.*, a number of identical vessels) on a given contract, each machine tool is used for several operations. The work on any given machine is, therefore, very much of a ''jobbing'' proposition, and the use of any machine is required for long or short periods at indefinite intervals. To give the greatest flexibility of service, maximum utility and the lowest power cost for the output involved individual motor drive was therefore chosen without question.

The arrangement of tools in the plate shop and routing of materials to and from other buildings is shown in the diagram of Fig. 59. The demand for immediate operation was so pressing that no opportunity was offered for any testing, and

TABLE XXII—DATA ON PLATE-SHOP ELECTRIFICATION (STATEN ISLAND SHIPBULDING COMPANY)

Machine No.	Machine	Original Direct-Current Motor			Work During Test	Maximum Expected Work	Hp. Input to Motor While			Note [1]	Expected Maximum Load, Hp.
		Hp.	R.P.M.	Pulley Diam. In.			Starting	Running Light	Working		
1	Grindstone and emery wheel	3.5	1800	4	....	....	3.2	0.9	2.3	..	2
2	Niles Tool Works 25-ft. plate planer......	15	1000	7.5	3/8-in. plate	5/8-in. plate	20	2.3	4.4	..	9
3	Hilles & Jones 30-ft. plate planer........	20	950	14	3/8-in. plate	5/8-in. plate	22	3.5	6.2	..	12
4	Niles Tool Works 18-ft. bending rolls for 3/4-in. plate, main roll 21 in. diameter..	30	600	15	1/2-in. plate	3/4-in. plate	26	4.4	2.3	..	30
5	Hilles & Jones angle punch............	7.5	475	7.5	3/8-in. angle	3/4-in. angle	11.7	1.5	2	F	4
6	Hilles & Jones angle shears	7.5	825	6	5/16-in. angle	3/4-in. angle	7.3	1.5	2.3	F	5
7	Drill press, 2 1/2 in.....................	10	730	12	1/4-in. hole	1 1/2-in. hole	8.8	1.8	2	..	5
8	Blower for forge	10	730	20	....	....	11	2.6	2.6	..	5
9	Hilles & Jones No. 4 plate punch........	7.5	825	6.5	7/8-in. hole	1-in. hole	11.5	2	2.6	F	5
					5/8-in. plate	1 1/8-in. plate	..	..	..	..	..
10	Long & Allstatter No. 2 plate shear.....	5	550	6	9/16 in. plate	5/8-in. plate	8.8	1.5	4.1	F	5
11	Long & Allstatter No. 2 plate punch.....	5	550	6	7/8-in. hole	1-in. hole	8.8	1	2.6	F	5
					1/2-in. plate	1 1/8-in. plate	..	..	..	..	..
12	Detrick & Harvey radial countersink....	6	1465	5.5	....	....	7.3	2.9	4.7	..	4
13	Cleveland Punch & Shear Company's plate punch	7.5	475	7	13/16-in. hole	1-in. hole	11.7	1.2	3.8	F	5
					7/16-in. plate	1 1/8-in. plate	..	..	..	..	..
14	Detrick & Harvey radial countersink.....	3.5	625	10							
15	Fitchburg Machine Works radial countersink				....	....	6.8	1	2.6	..	3
		3.5	625	10			6.8	1	2.6	..	3
16	Long & Allstatter No. 1 plate shear......	7.5	475	7	1/2-in. plate	5/8-in. plate	11.7	1.8	3.2	F	5
17	Angle punch	7.5	825	8	5/16 in. angle	3/4-in. angle	11.7	1.5	2.3	F	3

[1] F—These machines provided with fly-wheels.

the motor sizes were chosen with the idea of not having them too small even if they were too large.

Soon after the building had been successfully put into service the question of permanent electric power supply for the plant was taken up, the old direct-current plant being entirely inadequate for the requirements of the new yard and occupying a site needed for other buildings. A careful analysis of all power requirements led to a contract for alternating-current service

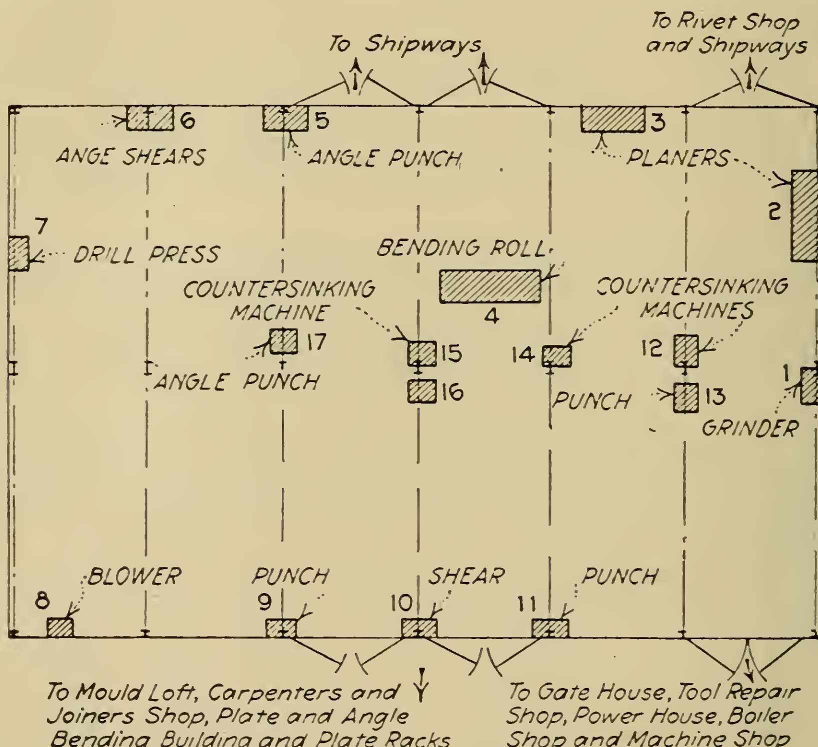


Fig. 59—Layout of Machines in Plate Shop

being entered into with the Richmond Light & Railroad Company.

The necessity of changing the motor drives from direct current to alternating current for operation on the purchased-power lines therefore afforded the opportunity for determining the actual duty cycle of work on the machines and the proper alternating-current motor to install. Ammeter and voltmeter readings were taken on the individual direct-current motors on each of the drives, with the results which are given in Table XXIII.

Determination of Proper Rating. Considering the test data on the direct-current motors, item 1 is the conventional grindstone and emery wheel used for sharpening the shop tools. The motor drives a small counter-shaft from which both grinding wheels are belted. This group was found to be considerably over-motored, a 2-hp. motor proving sufficient for the load.

TABLE XXIII—ALTERNATING-CURRENT EQUIPMENT INSTALLED IN PLATE SHOP (STATEN ISLAND SHIPBUILDING COMPANY)

		A. C. Motors Installed				
Mach. No.	Machine	Hp.	Type [1]	Full Load R.P.M.	Pulley Diameter, In.	Starting Device [2]
1	Grinders	2	S	1720	4.5	A
2	Plate planer....	10	S	1150	6.5	B
3	Plate planer....	15	S	1740	7.5	E
4	Bending rolls...	25	S	1160	8.0	E
5	Angle punch....	5	SH	680	5.5	C
6	Angle shears....	5	SH	850	6.0	C
7	Drill press.....	3	S	1730	5.0	D
8	Blower	5	S	1735	8.5	C
9	Punch	5	SH	850	6.5	C
10	Shear	5	SH	680	5.0	C
11	Punch	5	SH	680	5.0	C
12	Countersink ...	5	S	1730	4.5	C
13	Punch	5	SH	680	5.0	C
14	Countersink ...	3	S	1730	4.0	D
15	Countersink ...	3	S	1730	4.0	D
16	Shears	5	SH	680	5.0	C
17	Angle punch ...	5	SH	850	8.0	C

[1] S = squirrel-cage motor, standard design; SH = squirrel-cage motor with high-resistance end rings.

[2] A = three-pole, 250-volt, 30-amp., inclosed switch fused for 20 amp.; B = three-pole, 250-volt, 100-amp. inclosed switch fused for 90 amp.; C = three-pole, 250-volt, 60-amp., inclosed switch fused for 50 amp.; D = three-pole, 250-volt, 30 amp., inclosed switch fused for 30 amp.; E = starting compensator arranged for conduit wiring with inverse-time-element overload and no-voltage-release coils.

The plate planers (items 2 and 3) have long beds, on which the plates whose edges are to be planed are placed, the plate being held firmly by adjustable jack screws on the upper frame of the machine. The cutting tool is held on a carriage which travels parallel to the edge of the plate on a long screw. The tests showed that both the plate planers were considerably over-motored as then equipped and that 10-hp. and 15-hp. motors for items 2 and 3 respectively would be found to be ample.

The bending rolls (item 4) are for bending plate cold into circular shape, the relative location of the rolls being adjusted manually to increase the curvature as the plate is passed back and forth through the rolls. The motor is belt-connected with a counter-shaft from which open and crossed belts operated by a shifter drive the rolls in either direction. While the rolls were equipped with a 30-hp. motor, the tests indicated that a 25-hp. motor was proper for this drive.

Instead of a 10-hp. motor on the drill press and blower (items 7 and 8), 3-hp. and 5-hp. motors respectively were found of ample size. On the countersinks (items 12, 14 and 15) a 5-hp. motor for No. 12 and 3 hp. each for the other two were found to be suitable.

No unusual starting conditions existed in connection with the foregoing drives. On some of them the motor is started light and the load applied by shifting the belt, and on others the tool starts directly with the motor; but as there is little inertia to overcome on account of the absence of flywheels, etc., standard squirrel-cage motors were used.

The most interesting motor applications are the punch and shear illustrations (items 5, 6, 9, 10, 11, 13, 16 and 17). They are low-speed machines and ones in which the working interval is very short, being simply the stroke during which the tool is punching or shearing. At that moment, however, the instantaneous power requirement is very heavy. Rather than use a motor big enough to carry the tool through its working stroke, the machine-tool designers adopted the wise expedient of using a heavy flywheel, which stores up energy when the machine is running light and delivers it as the machine slows down on the cutting stroke.

The presence of the flywheel permits a much smaller motor than would otherwise be required, but proper acceleration of the machine presents quite a problem. The severe starting conditions which resulted are indicated by the accompanying test data.

Some Factors that Affect Selection. Three important points which have to be recognized in the selection of a motor are the power required to start the machines, that required to run them, and the maximum horsepower necessary which the motor can develop at starting without throwing off the motor belt.

The tests indicated that 9 hp. to 12 hp. was necessary to start the punching and shearing machines. Since a standard squirrel-cage motor of about the sizes required would only develop a starting torque equivalent to one to one and a half times full-load torque, it is evident that a motor of proper size to handle running conditions would stand no chance of starting these machines under the conditions shown to exist. If the driving belt happened to be too loose, the motor pulley might slip and throw it off, but it could not develop sufficient torque to meet the starting requirements indicated by the test. If a starting compensator were used, it would lower the starting torque still further by reducing the applied voltage. For these reasons it was impossible to use a standard squirrel-cage motor either with or without starting compensator.

The proper drive for punching or shearing machines is therefore one which gives a powerful yet gradual starting characteristic. This may be secured from an alternating-current motor with slip rings and external starting device or from a squirrel-cage motor with high-resistance and rings. From the standpoint of simplicity, price and quick delivery, the high-resistance end-ring type was considered preferable, as a number of manufacturers carry a stock for elevator service.

When this type of motor is thrown directly on the line the high resistance in the rotor end rings causes considerable slip at starting, allowing the motor to accelerate powerfully and yet gradually. Another advantage of the high-resistance type is its falling speed characteristic with increasing load, which results in an increasing torque and helps the flywheel over the peak of the load. The speed-torque characteristics of this motor are very similar to that of the series direct-current motor used for traction purposes, and they fit it admirably for this work. The greater complexity of the slip-ring motor and its susceptibility to trouble from dirt and grit in machine shops were other factors which affected the selection of high-resistance end-ring squirrel-cage motors for the punching and shearing machines.

The only compensators in the shop are used on items 3 and 4. These were necessary, as the motors are rated in excess of 10 hp., the compensator being used to limit the inrush of current at starting.

On the other motors, because of their small size, no compensators are necessary to limit the starting current, while on the high-resistance end-ring motors no compensation is permissible, as full line-voltage is necessary on these motors to give the proper starting torque.

A motor voltage of 220 was chosen for the plant to secure maximum safety for the operatives. With this low voltage it was not necessary to use oil circuit breakers for starting the motors, so safety inclosed fused knife switches were chosen. The switch is opened or closed by a handle outside and offers complete safety for the operative.

To take the large starting current of the squirrel-cage motors it was necessary to fuse their switches so heavily that no protection is afforded to the motor at moderate overload. In case of grounds or dead short circuit in the motor, however, the fuses would cut it off. With individual motors on machines which are always under the eye of the operative there is little chance for overload on the motor which the operative will not know about. The plant was designed and equipped under the supervision of Lockwood, Green & Company, Boston and New York.

WOOD WORKING

Woodworking is one industry in which the advantages of motor drive over shaft and belt drive are very marked. Electric drive is especially desirable because the machines can be located for the most convenient handling of the products and because long shafts will be required with group drive if the machines are scattered to permit the piling of stock and finished products. Furthermore, much of the machinery is used intermittently for comparatively short periods, resulting in considerable transmission loss if shaft and belt drive is used.

For driving wood-working machinery the induction motor possesses such characteristic advantages that practically nothing else would be considered on its merits even were there a choice of direct-current and alternating-current service. The immunity of induction motors from the ill effects of dust and dirt, and freedom from danger of fire through the misbehavior of a dirty commutator, form sufficient reasons for abandoning any machine that has a commutator. Only in very rare instances, where extreme variation of speed is required for special operation, has the direct-current motor any claim to consideration. Most wood-working machines are conveniently driven by motors of the squirrel-cage type. If the squirrel-cage rotor has low slip it drives ahead with remarkably good speed regulation and so holds up the output. If only a small amount of flywheel effect is desired the same type of motor designed for larger slip meets the requirement, but wherever great flywheel effect is necessary it is generally thought desirable to install a slip-ring motor with an external resistance, preferably adjustable, to meet the requirements of flywheel working, although a fixed resistance is frequently all that is necessary. The latter arrangement is a common practice in operating the large bandsaws for timber sawing. These saws may run at speeds up to 10,000 ft. (3048 m.) per minute and the band wheels themselves may weigh several tons. In such instances the flywheel effects are very powerful, and there must be heavy starting effort and reliance on stored energy to drive through peaks of load.

With certain other classes of wood-working machinery, such as planing mills, cases also occur where the slip-ring type of motor with wound rotor is advisable on account of the necessary heavy starting torque. Push-button control, often from more than one point, is found to be a very important feature in the operation of certain machines, saving much time and electrical energy as well.

Where Group Drive Was Advisable. The Riddle-Rehbein Manufacturing Company of St. Louis has laid out its drives with such care that practically all objectionable features of the ordinary wood-working plant have been eliminated and energy bills are less than for similar plants of smaller output, says W. A. Black, engineer with Fairbanks, Morse & Co. In most cases individual drives are used, as with this method the motors remain idle except at such times as the machines are in use.

In planning the drive it was found that there were certain places where individual drive would not be economical. For instance, a battery of nailing machines were arranged for group drive because a careful study showed that the load is intermittent and that seldom more than one machine is required to do actual work at any one instant. If individual drive had been used, a 2-hp. motor would have been required for each machine and the motor would have been loaded only intermittently, giving a very low load factor with its resultant low power factor and efficiency. With the arrangement adopted a 5-hp. motor drives a battery of five nailers, running with approximately steady load at approximately full load and giving a higher power factor and efficiency than the small machines even had they been operating at full load.

Another factor influencing the choice of group drive was that in this work the machines are never operated as individual units, but each machine performs its part of a progressive operation. The machines are used for making boxes, two end machines being used for framing the boxes, the next two machines for nailing sides, and the center machines for nailing the bottom of boxes coming from each side. The boxes finished by center machine are loaded on a truck placed within reach of the operator.

Value of Substantial Foundations. The 30-in. (76-cm.) double surfacer was direct connected to a 50-hp., 1200-r.p.m. induction motor. The planer and motor are mounted on I-beams embedded in a concrete foundation which extends through the basement into solid ground. Six hundred and fifty cubic feet (18.2 cu. m.) of concrete was used in the foundation, but the expense of making it is well offset by the freedom from vibration and the perfect alignment maintained thereby. The advantage of a firm foundation cannot be overestimated, especially for direct-connected machines. The foundations should be large enough to accommodate both the machine and the driving motor, as failures have occurred where a machine and the driving motor were mounted on separate foundations, owing to foundations moving with reference to each other and thus throwing the machines out of line.

The advantages of a solid foundation for maintaining perfect alignment are well illustrated by the performance of a 54-in. (137-cm.) resaw, which was mounted on a substantial foundation and directly connected to a 35-hp., 600-r.p.m., motor. After being in service over four years, the machine, with a tension of 2000 lb. (907 kg.) on a saw, would run for two minutes and thirty seconds after the power was shut off. With a less substantial foundation the heavy machine would have vibrated out of line and the strain on the bearings would have caused excessive repair expenses.

Ball Bearings Reduce Maintenance. Direct-connected ball-bearing motors reduce the maintenance expense cost to a minimum. There are no belts to slip, break or be taken care of. The ball bearings are contained in dust-proof inclosures requiring only infrequent attention compared with other types. With such motors and bearings the greasy dust so prominent in most woodworking plants can be avoided. Furthermore, the absence of oil and grease on motor frame and windings makes it possible to clean the machines by blowing off the dry dust. For the purpose of cleaning machines the woodworking company has a small motor-driven air compressor which is in use only when the cleaning is necessary.

While machines which are belted to motors mounted on the ceiling have all of the advantages of individual drive, they have the disadvantage that the belts obstruct the light. In addition, since the belts are long, they require more attention and are harder to cover with protective guards. To overcome these objections many of the motors in this plant were mounted on the ceiling under the driven machine and a belt was run through an opening in the floor. This arrangement had all the advantages of ceiling mounting and at the same time permitted the use of short belts that could be easily protected by guards. No changes were necessary in the bearing construction as ball bearings were used and only occasional attention is required. With this type of drive it was necessary to guard against the use of excessively short belts and against the location of motors directly under driven pulleys, as these conditions would reduce the area of contact of belt on pulleys.

Vertical Shaft Motors for Shapers. A very practical drive was obtained for the two-spindle shapers used in this plant by belting them to two 3-hp., 1800-r.p.m., vertical motors. The starting switches are mounted on side of machine opposite the motor within reach of the operator. Either or both spindles can be readily started or stopped as required. The use of vertical motors eliminates the need of crossed belts, and the ease with which spindles can be started or stopped reduces the tendency for the operator to leave spindles in operation when not in use.

On a small jig-saw used for cutting out ornamental work the lines of which have to be followed very closely a unique arrangement is used to keep the work free from sawdust. A small ball-bearing motor is belted to a blower, which in turn is connected by flexible tubing to a nozzle placed close to the work. The air from the blower is forced through the nozzle, which blows all sawdust from the work and leaves the lines visible. With ball-bearing motors it is practicable to cover the motors as it is not necessary to remove the covers frequently for oiling.

Dovetail Glue Jointer. A drive which required careful consideration before it was successfully worked out was that of a Linderman automatic dovetail glue jointer driven by a 15-hp., 1200-r.p.m. motor. In cold weather the high torque necessary to start required either a larger-size squirrel-cage motor or a motor of the wound-rotor type. With the larger squirrel-cage motor the starting current would have been objectionable and the power required would have only lightly loaded the motor after the machine had attained full speed. The wound-rotor type of motor with a secondary starter would have overcome the difficulty of operation but would have imposed the necessity of more care owing to slip rings, brushes and starter contacts.

The drive was very successfully taken care of with an internal starter motor. With this motor it was possible to obtain a high starting torque with a low starting current in a reasonably short starting period. The starting switch was simply a single-throw switch, and slip rings and brushes were eliminated. The installation has been in operation for over three years and has given perfect satisfaction.

Value of Flywheels in Woodworking. Owing to the fluctuations in load obtained with certain kinds of woodworking machinery, it has frequently been the practice to over-motor the machine in order to carry the peak loads. As a result the load factor, the power factor and the over-all motor efficiency have been detrimentally affected and more than the necessary outlay of money has had to be invested.

In several instances David R. Shearer has found that the average load on a given woodworking machine is only 50 per cent of the installed motor capacity and that some load peaks run as high as 100 per cent above the motor rating. In other words, some peaks occur which are four times the average load.

If the first cost of the motors were the only factor to be considered, much larger motors than are demanded by the machines might not be so objectionable; but the fact that any motor operating much below its rating will not operate at its maximum efficiency throws a different light on the subject. In the case of induction motors the power factor decreases with the load so that the system may be seriously disturbed if the motors are underloaded, especially if fed by a small local or isolated plant. The highest efficiency is usually obtained from an induction motor at full-load rating and the highest power factor at slight overloads. With one standard motor of the induction type the efficiency dropped 2 per cent from full load to half load, and the power factor dropped 12 per cent with the same decrease in load. Below half load the results are still more serious.

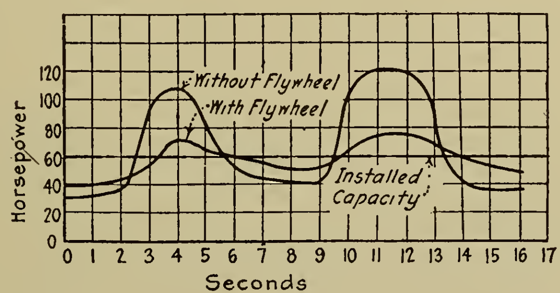


FIG. 60—LOAD CURVE OF A GANG-EDGER OPERATING ON GREEN LUMBER WITH AND WITHOUT A 1500-LB. (680-KG.) FLYWHEEL

The motor driving this machine is rated at 60 hp. and is directly connected to operate at a speed of 1800 r.p.m. on 440-volt, three-phase energy supplied by an isolated plant. The operating conditions were practically the same in both tests so that the value of the flywheel can be readily observed. Without the flywheel the demand increased above the maximum capacity of the motor for an instant. It caused excessive heating and sometimes stalled the machine. After the flywheel was attached the motor was operated at a lower temperature and never stalled during periods of heavier cutting.

On account of the trouble experienced with some motor-driven woodworking machines in the past, some apprehension has arisen regarding the advantages of individual drive which should be dispelled, inasmuch as the trouble has generally been caused by improper application of the motor. So strong has been this objection that in some instances the individual drive has been taken out and group drive substituted so that the machine peaks could be carried by the overload capacity of a larger motor. This method of drive may be the correct thing in some cases, but is less desirable than the individual drive on account of the necessary shafting and belting with the attendant losses in efficiency. Furthermore, the group-drive motor may be subjected to concurrent peaks (Fig. 61) which may pull it out of step, thus shutting down the whole installation and causing serious delay.

The simplest and cheapest way to obviate pronounced peaks is to install individual flywheels on the motor shafts of each machine and retain the advantages of the individual drive. With this arrangement the loads can be carried by motors considerably lower in rating than would be required if flywheels were not used, and in addition the motors will operate more nearly at normal load. Of course, the flywheel must be especially designed for each machine as the operating characteristics vary considerably.

The duration of the cut and the period during which the machine is running idle are the principal factors which should determine the flywheel effect necessary. As an example, the duration of a trimmer cut is very short, while the idle period is slightly longer. A slasher cut is similar to that of a trimmer, but considerably more power may be required when a butt slab is being cut. A gang-edger cut is considerably longer than either of the foregoing operations. A short interval exists between cuts which must be taken into consideration in the design of the flywheel and in deciding upon the size of driving motor to install.

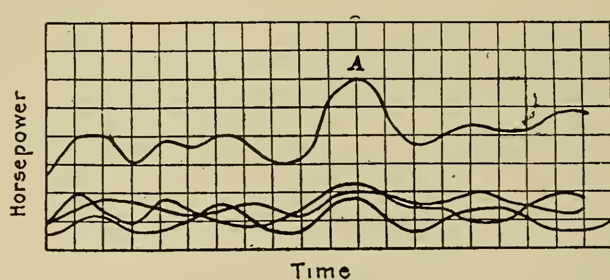


FIG. 61—INDIVIDUAL POWER-DEMAND CURVES OF THREE MOTORS WITH THE GROUP DEMAND PLOTTED ABOVE

None of these machines was equipped with a flywheel. The curves show that a concurrent group peak is possible which may require over-motoring of the group when flywheels are not used. In the plant at which these tests were conducted a total plant concurrent peak occurred on an average twice in ten hours.

Sometimes it is convenient to test the instantaneous power demands on the machine while operating it from a motor somewhat larger than is necessary. From these tests the average load and maximum peaks can be determined. If the test results are plotted as curves, it is comparatively easy to decide how many foot-pounds must be added to the motor power during peaks by a flywheel to bring the power demand on the motor down to a desirable value. During the period when the machine is not cutting the motor stores energy in the flywheel, which can later be used while the tool is cutting.

Another factor to consider when using flywheels is the rotor resistance of the driving motor when it is of the three-phase induction type. As the rotor resistance is increased the slip will increase, allowing a greater reduction of speed under heavy load and thus permitting the flywheel to give up some of its stored energy. If the load surges are frequent and pronounced, this characteristic of the motor tends to minimize the line disturbances, but if the peaks are of long duration a high-resistance rotor will allow the speed of the machine to drop too low for the proper action of the cutting knives or saws.

Machines on Which Flywheels Are Most Desirable. The woodworking machines on which it is most necessary and economical to install flywheels, when operated by individual motor drive, include circular rip and cut-off saws, edgers, trimmers, slashers, timber trimmers, some types of planers and flooring machines, "hogs," and in general any machine which has periodic loads and periods of non-production. Flywheels are not of much advantage on band saws, because these machines usually have sufficient flywheel effect in the band wheels which carry the saw.

As the friction load of any woodworking machine is practically constant, it is advisable to determine this load first, then the average power necessary to do the actual cutting. These two factors will determine the motor size if a flywheel is used to reduce the peaks to a value which can be handled by the overload capacity of the motor.

As a result of the tests indicated by Figs. 60 and 61 and others made upon different woodworking machines Mr. Shearer has come to the conclusion that better results would be secured with individual drive by the more general use of suitably designed flywheels. The necessary generating plant capacity would be decreased, the size of the individual motors could be reduced, the load factor would be improved, the efficiency increased and the power factor raised. Furthermore, flywheels will relieve the motors and starters from excessive stresses occasioned by the pronounced surges of power demand.

Power Needed in Woodworking. In the factory of the Rockwell Manufacturing Company, a woodworking concern in Milwaukee, tests were made on two machines in the company's plant, each of which is equipped with more than one driving motor. The first test was made on a 30-in. (76.2-cm.) Whitney planer, equipped with two 5-hp. motors. Each motor consumed 1.1 kw. driving the machine idle, the load rising to approximately 1.15 kw. per motor when the feed was started. The spindle speed of the planer was 3550 r.p.m. When the planer was taking a 1/16-in. (1.58-cm.) cut from four pieces of hard wood 2 ft. (60.96 cm.) in length each motor consumed 2 kw. The spindle speed of the machine at that time was 3500 r.p.m. There were occasional momentary surges to 3 kw. on each motor, but the load was fairly steady at 2 kw. during the cut. When the planer was operating with high-speed feed, taking a 5/16-in. (7.93-cm.) cut from a piece of maple 22 in. (55.88 cm.) wide, with a spindle speed of 3200 r.p.m., the motors took 6.5 kw. each, the load occasionally rising sharply to 10.5 kw. When this cut was diminished to 1/4 in. (6.35 cm.) with the high-speed feed the load was 6.5 kw., occasionally rising sharply to 9.5 kw. for each motor connected.

The other test was made on a three-drum, 66-in. (167.64-cm.) door sander, equipped with four motors. The 7.5-hp. motor attached to drum No. 1 consumed 1.2 kw. driving the drum idle. During the sanding operation the power consumption carried from 2.5 kw. to a trifle over 4 kw., but it was fairly steady during the majority of the time, being between 3 kw. and 4 kw. The 7.5-hp. motor driving drum No. 2 consumed 1 kw. driving the drum idle and required from 2 kw. to 8 kw. while operating the drum under load. The 7.5-hp. motor operating drum No. 3 consumed 1 kw. with the machine idle and took from 1.5 kw. to 5 kw. during the sanding process. The 2-hp. motor which operates the feed required 0.3 kw. for driving the feed idle and 0.5 kw. under load.

From this information it may be seen that it is advisable to consider the hardest kinds of woods which will likely be worked as well as the rates of feed. Of course momentary fluctuations in load can be handled by the overload capacity of the motor.

ROLLING MILL DRIVE

As most engineers know, the general problem of electric drive in rolling mills is now purely an economic one, the fundamental question being whether such a drive is or is not cheaper than a steam-engine drive, and, granted that it is, whether it is cheaper to generate or to purchase power. Large electrical supply companies are able to deliver energy on the scale demanded by rolling mills at a figure which permits competing with power locally generated. The great public supply plants can work on so big a basis and derive so much benefit from the diversity factor that they are in a particularly good position to sell power cheaply in large blocks. The average rate offered by twenty central stations furnishing power to steels works is, according to a recent report on the subject, between 8 mills and 9 mills per kilowatt-hour. The methods of charging adopted are usually based on certain requirements for maximum demand plus a flat rate. Only in rare instances is the latter system of charging used alone. As is well known the arrangements adopted for equalizing the enormously irregular loads in rolling mills are highly ingenious and on the whole very successful. For the present purposes it is sufficient to point out that the difficult problems presented have been very successfully solved, so that there is no sound reason for central stations in general being timorous about taking on rolling-mill load, assuming that its quantity is not so great as quite to swamp the station capacity. Generally, special provisions in the feeding system are necessary, and some extra care must be taken in the matter of regulation.

Advantages of Electrified Rolling Mills. The trend of evolution in iron and steel plants has been to electrify every machine up to and including the main rolls, owing to the greater flexibility of operation and control of the electrical machine as compared with the steam engine, says William Knight, formerly assistant mechanical engineer of the Crocker-Wheeler Company. Among factors which must receive consideration in the electrification of the steel mills are the following: First of all is efficiency. There is no doubt that in an electrically driven rolling mill the cost of the power can be conveniently controlled by using the most suitable arrangement in the electrical plant. Furthermore, the elimination of the losses in the boiler room and all along a steam pipe line which is made possible by buying the power from an outside source will still further reduce the cost of operation per ton rolled. The output of an electrically driven rolling mill is also larger than it would be with steam drive, owing to the rapidity with which the mill can be controlled and handled and the uniform torque exerted by electrical motors equipped with flywheels to carry them over peak loads.

The economy of space that can be effected by buying electricity from an outside power station instead of installing a steam-power plant in the works, and the possibility of measuring very accurately the amount of power needed for rolling a given section (thus allowing a very close estimate of the manufacturing cost of any product), are the two points that, in these days of high cost of land and keen competition, speak strongly in favor of electric drive in rolling mills.

It need hardly be said that in a rolling mill the demand of power generally varies rapidly between wide limits. When the ingot enters the rolls a large demand of power occurs, and as soon as it leaves the rolls the power demand may suddenly be reduced to that required for overcoming the friction losses in the mill itself and in the motor only. This rapid fluctuation of power which occurs during the operation of a rolling mill, if not corrected somehow, will create a very unfavorable condition for rolling at the lowest price, since this price is contingent on the condition that the power demand should be, as much as possible, maintained steadily at the full capacity of the generating plant. To meet this requirement, however, in some cases may mean an increase in capital cost and a large increase in friction losses which may not be offset by the saving effected by obtaining the power at a lower price.

The operation of a rolling mill, like any other engineering problem, is a commercial proposition aiming at the largest possible production obtained with the least expense, so that the best results are reached through a compromise between the advantages and the disadvantages arising from several general and local conditions, the maximum over-all economy being reached when the combined total capital charges and running expenses per ton rolled become a minimum.

Steam Versus Electric Drive. Before deciding whether to adopt a steam engine or an electric drive for a rolling mill the following points must be considered: (1) capital outlay; (2)

steady losses; (3) saving effected with electrical motors during reversal, in the case of reversing rolling mills; (4) power absorbed with partial load; (5) speed of mill as affecting production; (6) if the power is generated within the works, what investment or operating expense it involves, or if it is purchased from a public service corporation, under what conditions the purchase can be made.

In many steel plants the waste gas from the blast furnace may be used for generating the needed power. If the surplus of such waste gases is large enough, there is little doubt that it will be cheaper to generate the power inside of the works than to buy it from an outside generating plant. In plants which are purely rolling mills, where there are no blast furnaces in operation, and in small plants which do not have a very large production, the local generation of the power would not be in the majority of cases a sound economical policy, as advantages are usually derived by means of purchasing the power from an outside source.

When figures on the paper show that local generation of power would be cheaper than purchased power, the fact should be taken into account that the only object of a public service corporation is to sell energy and that, in order to accomplish this purpose, the combined efforts of a staff of specialists are used in the production of a reliable source of power at the lowest price. In a steel plant, instead, the main object is to produce steel, and the production of power is only a side issue which, generally speaking, could not be handled as efficiently and economically as if the power were produced by a concern established for that purpose only.

The load factor of a central station supplying energy to a steel mill increases with the magnitude of the plant. With small plants, however, the load factor is larger than would be expected, owing to the fact that the rolling is generally done in multi-stand mills and a larger number of passes are taken to produce a desired section. Also, in many mills, several pieces are rolled at the same time, the result being a more uniform load with multi-stand mills than with the large single-stand mill. The load factor is an important item and affects a good deal the cost of the power.

How Selection of Equipment Depends on Energy Contract.

TABLE XXIV—DATA ON PLANTS USING ILGNER SYSTEM [1]

Type of Mill	Work Done	Mill Motor Direct-Coupled: Normal Output, Hp.	Mill Motor Direct-Coupled: Maximum Speed, R.p.m.	Mill Motor Direct-Coupled: Maximum Torque, R.p.m.	Flywheel Motor-Generator Set: Maximum Speed, R.p.m.	Flywheel Motor-Generator Set: Motor Output, Hp.	Flywheel Motor-Generator Set: Flywheel Weight, Tons	Additional Information
34½ in. three-high mill with three stands of rolls	Rolling heavy beams	12,600	180	70	428	2,600	55	
29½-in. mill with three stands of rolls	Rolling beams and light rails	8,400	180	62	428	1,500	55	
29½-in. mill with five stands of rolls	Rolling beams and rails	7,300	180	52	428	....	75	Power supplied by a generator attached to an existing flywheel motor-generator set used for another mill.
32½-in. mill with three stands of rolls	Rolling beams, rails and sections	6,000	180	140	500	1,200	50	
22-in. three-high mill with three stands of rolls	Rolling rails, sections and rounds	2,400	...	120	...	....	..	Power supplied by a generator attached to an existing flywheel motor-generator set used for another mill.
20½-in. three-high roughing mill	Rolling billets	3,800	180	100	...	....	...	Power supplied by a generator attached to an existing flywheel motor-generator set used for another mill.
34 in. reversing blooming mill	Rolling ingots	3,000	70	...	500	1,800	50	At the Steel Company of Canada's works at Hamilton, Ont.
Reversing blooming mill	Rolling ingots	4,000	75	...	375	1,800	75	Algoma Steel Company of Sault Ste. Marie, Ont.

[1] Obtained from several papers presented before the A. I. E. E., the British I. E. E., and the Association of Iron and Steel Electrical Engineers.

When energy is charged for on maximum demand the introduction of a flywheel is necessary in order to minimize the load fluctuation and thus obtain the lowest possible rate. When a flat rate is offered there is no need of using an equalizer flywheel for reducing the cost at which the power is purchased. Instead, a motor large enough to take up the peak loads on the mill could be used, thus eliminating the bearing and windage losses of the flywheel. This, however, may be objectionable because of the large size of motor needed. A convenient compromise may be reached by using a comparatively small flywheel and a motor of a convenient size.

In the third case, when peak loads of a long duration only are objected to, a motor of varying speed may be used. In merchant mills it is an advantage, and practically a necessity, to be able to vary the speed of the mill motor. The roughing rolls of a merchant mill must be run at a high speed. The finishing rolls, on the contrary, must be able to run at different speeds, according to the size and the shape of the section being rolled.

With a direct-current power supply this is a comparatively simple matter, the speed variation being obtained by means of field regulation only. With alternating-current motors this requirement is not so easily met, and a serious loss is experienced, since the efficiency of alternating-current motors decreases practically in proportion to the decrease in speed when the regulation is attained by the introduction of resistances in the rotor circuit.

Assuming that the power is transmitted to the rolling mill by alternating current at high pressure, there is no question that induction motors should be used for driving the main rolls. There is, however, a difference of opinion as to whether the so-called auxiliaries should be driven by alternating-current or direct-current motors. This latter point was discussed by B. R. Shover and E. J. Cheney in the London *Electrician* of Oct. 18, 1912, where very careful estimates are published of the capital expenditure and working expenses under the two systems in a certain hypothetical case which is fairly representative of a large mill. The conditions under which the one system or the other is to be preferred and the advantages and disadvantages of both are fully stated. The authors conclude by stating that when the percentage of power required for auxiliary apparatus (exclusive of pumps) is 25 per cent or less of the total power delivered to the mill, and where the power factor of the entire mill, including main and auxiliary apparatus, is more than 70 per cent, the alternating-current system should be used throughout, a saving being thereby effected in working expenses and in the absence of complications.

TABLE XXV—COMPARISON OF FIRST COSTS OF STEAM AND ELECTRICALLY DRIVEN REVERSING MILLS

(40-In. Blooming Mill Rolling 60,000 Tons of Steel a Month)

ELECTRIC DRIVE WITH PURCHASED POWER	
Complete cost of reversing motor, flywheel motor-generator set, exciters and control equipment	$185,000
Foundations, wiring, etc.	10,000
Total	$195,000
ELECTRIC DRIVE WITH POWER GENERATED AT PLANT	
Complete cost of reversing motor, flywheel motor-generator set, exciters and control equipment	$185,000
Foundations, wiring, etc.	10,000
Proportion of power house cost, 2500 kw., at $50 per kw.	125,000
Transmission and outside wiring	5,000
Total	$325,000
STEAM DRIVE	
Compound reversing engine	$125,000
Condenser, exhaust piping, including pumps	25,000
Foundations	10,000
Boilers, 2500 hp., including stokers and coal-and-ash-handling plant, at $30 per hp.	75,000
Steam piping with covering, valves, etc.	15,000
Water tunnel for condenser, with discharge for 8500 gal. of water per minute	50,000
Total	$300,000

If the power is generated within the works, it is always a good policy to install motors which, in case a breakdown should occur in the generating station, could be operated from the plant of a local public service company, thus avoiding serious losses due to interruption of output.

The action of rolling-mill motors may sometimes create a sensible fluctuation in the voltage, thus disturbing the performance of other machinery. To obviate this inconvenience a flywheel of a convenient size may be provided with a suitable arrangement for slip regulation which, by decreasing the speed of the motor, will allow the flywheel to give up enough of its stored energy to make up for the difference between the maximum peak load on the mill and the overload capacity of the motor.

In some cases a flywheel of prohibitive size may be needed for this purpose, and this means large windage and bearing losses that are a constant burden on the cost of production. By increasing the slip of the motor more stored energy can be given up by the flywheel, and a smaller one could be used for the purpose. For instance, with a 10 per cent fall in speed 20 per cent of the energy stored up in the flywheel can be utilized, and with 20 per cent fall in speed 36 per cent of that energy can be used. When 20 per cent speed variation is figured on between no load and double full load (which is about the maximum momentary overload that commercial machines can stand), it does not necessarily follow that this variation will be experienced under actual working conditions, because when the work at the mill is being carried on fairly steadily the power demand never drops to zero, neither does it reach double full-load value except under very exceptional conditions.

Considerations Necessary in Applying Motors.[1] In many cases, owing to the low speed of the mill and to the high cost of a low-speed motor with good electrical characteristics, a high-speed machine is used and connected to the rolling-mill shaft by means of gears or ropes. When a directly coupled machine is used it is always desirable to use a flexible coupling in order to render less severe the shocks on the motor during the operation of the mill. With either coupled or geared motors the design of the motor bearings must be particularly good if serious troubles are to be avoided. Ropes or gear drives will allow the use of a higher-speed machine, which is both more efficient and less expensive.

The most suitable place to mount the flywheel is on the highest speed shaft, but this arrangement imposes an extra strain on the gears or ropes. To avoid this the flywheel can be mounted on a separate shaft directly geared to the mill. As stated before, by using a larger slip a smaller flywheel can be used for supplying

[1] In two articles published in the *Electrical World* on Sept. 30 and Dec. 16, 1916, the writer suggested a simplified method for calculating the proper size of motor and flywheel to be used when the demand of power on the rolls at any moment is known. The graphical solutions given should be found very handy in avoiding long calculations.

the required amount of energy during the peak loads. However, there is a serious objection against this practice—the increase in cost of production brought about by the reduction of the output of the mill and the drop in the efficiency of the motor, if an alternating-current motor is used.

The use of a separate motor-generator and flywheel set for supplying the power needed by the mill motor will obviate this objection. In this case a motor large enough to stand the peak-loads on the mill will have to be used. The motor-generator set can run at a considerably higher speed, and by regulating the field current of the generator the voltage of this machine may be varied, causing the speed of the mill motor to increase rapidly or decrease correspondingly.

This arrangement is generally known as the Ilgner system. With it, owing to the high speed of the motor-generator and flywheel set, a comparatively small flywheel may be used, and, although the loss of power taking place in the electrical machines is increased, the speed of the mill can be varied at any moment by any desired amount. The increased output of the mill will more than compensate for the increase in losses and the considerable increase of capital cost of the electric plant. An additional advantage with the Ilgner system is that any mill can be used as a reversing mill.

Particulars[1] of several successful electrifications of steam-driven, non-reversing rolling mills, together with data on power consumption for rolling different classes of materials, follow:

TABLE XXVI—STATISTICS OF MOTOR DRIVEN MILLS[1]

	Hamilton, Ont.	Bethlehem, Pa.	Massillon, Ohio
Size of ingot, in	15 x 17	19 x 23	18 x 20
Weight (lb.)	4,000	10,000	5,000
Size of finished material (in.)	4 x 4	4 x 4	4 x 4
Elongation	16	10–12	Up to 20
Number of passes	19	17–21	19–21
Capacity (tons per hour)	60	100	60
Roll diameter (in.)	30	30	30

[1] Obtained from a paper by W. F. Mylan read before the British Institution of Electrical Engineers and from another paper by Koettgen and Ablett before the Iron and Steel Institute.

[1] From paper presented before June 1916 meeting of A. I. E. E. by W. Sykes and D. Hall.

	Hamilton, Ont.	Bethlehem, Pa.	Massillon, Ohio
Pinion diameter (in.)	34	35	34
Speed, full motor field (r.p.m.)	70	40	50
Speed weakened motor field (r.p.m)	100	120	120
How driven from motor	Direct	Direct	Direct
Number of motors	2	2	1
Voltage across each armature	600	600	700
Maximum operating torque (ft.-lb)	900,000	1,550,000	750,000
Maximum motor horsepower	10,000	12,000	8,000
Number of generators	2	2	1
Rated hp. of driving motor of set	1,800	2,000 kw.	1,500
Weight of flywheel (lb.)	100,000	100,000	60,000
Speed of flywheel motor-generator set (r.p.m.)	500	375	375

Cold Rolling-Brass Merchant Mill.—This mill consists of one set of breaking-down rolls, one set of second breaking-down rolls and two sets of finishing rolls. The breaking-down rolls are 20 in. (50 cm.) in diameter, 30 in. (76 cm.) long, and all are driven at 6 r.p.m. by a long train of gear wheels. Originally this mill was driven by a single-cylinder horizontal non-condensing engine 28 in. (71 cm.) in diameter, 48 in. (122-cm.) stroke, and run with a boiler pressure between 60 lb. and 80 lb. per square inch (4.2 kg. and 5.6 kg. per sq. cm.). The usual size of ingots dealt with in this mill is 3 in. by 1½ in. by 7 ft. (7.6 cm. by 3.8 cm. by 2.1 m.) rolled down to various gages.

The motor used now is a 200-hp., 240-r.p.m., three-phase slip-ring motor, direct-geared by means of cast-iron gear to the mill. The gear ratio is about 4.8 to 1. No flywheel is provided. This equipment has proved extremely satisfactory, and a considerable reduction in the cost of operation and increase in the output has been obtained.

Iron and Steel Merchant Mill.—The mill consists of five pairs of 12-in. (30.6-cm.) rolls running at a minimum speed of 80 r.p.m. and is driven through double helical steel gears (ratio 1 to 2.5) by a 200-hp. direct-current motor at from 200 to 450 r.p.m. Since the mill was electrified an increase of output of over 30 per cent and decrease in the power consumed of 60 per cent have been obtained.

Power Consumption for Rolling Different Classes of Materials. Re-rolling 90-lb. (45 kg. per m.) rails to a section 16 lb.

(8 kg. per m.) per yard, each piece 30 ft. (9.1 m.) long, required 56 units of energy per ton. Total output of mill, 4800 pieces per twelve hours. Small mining rails were rolled from billets 5 in. by 5¾ in. (12.7 cm. to 14.7 cm.), weighing a maximum of 900 lb. (408.2 kg.). In the case of 28 lb. per yard (14 kg. per m.) this comes to an average of 650 lb. (294.8 kg.); in the case of 18 lb. (9 kg. per m.) rails the requirement is as follows per ton rolled: 28 lb. (14 kg. per m.), 38 units; 24 lb. (12 kg. per m.), 42 units; 20 lb. (10 kg. per m.), 45 units; 18 lb. (9 kg. per m.), 48 units. Smaller rails of 12-lb. and 8-lb. (6 kg. and 4 kg. per m.) section required from 49 to 54 units per ton rolled.

Girders 11 in. by 6 in. (27.9 cm. by 15.2 cm.) can be rolled for about 50 units per ton. Channels averaging 1½ in. by ¾ in. by 2 in. (3.8 cm. by 1.9 cm. by 5.09 cm.) require 66 units. Angles 3½ in. by 3½ in. by ⅝ in. (9.5 cm. by 9.5 cm. by 1.6 cm.) from 800-lb. (362.9-kg.) billets require 50 units. Sheet (iron) 8 ft. 3 in. by 33 in. by 0.064 in. (2.5 m. by 8.4 cm. by 0.16 cm.) require 95 units per ton; sheet (iron) 8 ft. by 48 in. by 0.08 in. (2.4 m. by 1.2 m. by 0.21 cm.), 70 units per ton; sheet (iron) 10 ft. by 48 in. by 0.067 in. (32.8 m. by 1.2 m. by 0.17 cm.), 80 units per ton; sheet (iron) 10 ft. by 48 in. by 0.125 in. (32.8 m. by 1.2 m. by 0.32 cm.), 60 units per ton; sheet (iron) 9.5 ft. by 42 in. by 0.09 in. (2.84 m. by 1.07 m. by 0.24 cm.), 84 units per ton, from billets of 7.9-in. by 7.9-in. (20-cm. by 20-cm.) section, weigh 388 lb. (175.9 kg.).

MOTORS IN THE TEXTILE INDUSTRY

There has been a rapidly increasing use of motors in textile mills, an art which dates back very nearly five-and-twenty years, but which has been rapidly improved as conditions have gradually led to the adoption of more and more independent methods of motor driving. In the beginning the cotton industry clustered about water powers where motive power could be cheaply obtained. As the steam engine became more highly developed in efficiency and as mills outgrew their normal supply of water power and fell back upon steam auxiliaries, the waterwheel found relatively less and less use. In the forty years from 1870 to 1910 it had fallen from 60 per cent of the total to about

20 per cent. Steam power had increased from some 40 per cent to 60 per cent, and the remaining 20 per cent was furnished by electric power. It has been estimated that by 1920 the percentage of electric power will easily have doubled. In the earliest electrical mill drives the steam engines were replaced by fairly large motors employed for group driving. The steady tendency of late years has been more and more toward individual drive, which is easily employed in new mills and gives greater possibilities of power economy than have been afforded by the methods that it supersedes.

Probably the typical mill consists of a combination group and individual drive, the former for certain machinery operated, so to speak, in blocks, each consuming no very great amount of power in the aggregate; the latter for the heavier and more independent work. For mill work the induction motor is chiefly used, since for most classes of work unusual flexibility of speed regulation is not required. At the beginning of the art competition with direct-current machinery caused the building of induction motors with extraordinarily low speed variation, a tendency which has of late given way to more normal design. In a few places in mills motors of special type have to be employed on account of the presence of large amounts of dust and lint in the air, and in some cases because of troublesome vapors that arise.

Experience shows that the electric drive for this work has not only the usual advantages of facilitating a cheap supply of motive power but also leads to a larger and more uniform output on account of the better operating characteristics of subdivided motive power. There is every indication that the use of motor drive in mills is going to increase steadily, bringing the greater water powers into active use in this class of manufacturing and superseding not a few of the steam drives now in use.

Loom-Motor Switches. In weave sheds where hundreds of looms are in service and tended by young girls with no electrical or mechanical training, simplicity of control, combined with entire safety of operation of operation, is of vital importance, particularly where the motors are wound for 220 volts and upward. In one installation the looms are mounted with ends reversed, and the adjacent motors are thus brought within 2 in. or 3 in. (5 cm. or 7.6 cm.) of each other. Near the floor in the intervening space is mounted a single fuse box and two heavy-duty snap switches serving the two loom motors.

Each switch is of the most rugged type, capable of withstanding much abuse. The handles are recessed in disks marked for "off" and "on" positions, and short connections are run to the motors with BX conduit. Nothing short of deliberate destruction is likely to affect the operation of these units. It is feasible by staggering the loom motors with respect to the intermediate aisle to provide for a quicker inspection than would be possible with a purely symmetrical arrangement. The space between loom ends is of insufficient value to justify reserving it for the passage of the operator or inspector, and the economy in wiring secured by double switch mounting close to the loom motors is considerable in a large installation.

ELECTRIC DRIVE IN THE PRINTING TRADE

Much of the electrical development work done in the printing trade is quite comparable to that in other branches of manufacture and involves nothing unusual in the way of motor equipment save ordinary care in the adaptation of individual drives. The presses require the closest attention to obtain successful results, and the problem in this case is quite like that encountered in the paper-making machine, where there is likewise necessity for good speed regulation, for heavy starting torque to overcome the inertia, and for inching the machinery along very gradually during certain stages of the operations. It is not unusual in large presses, indeed, to apply the same two-motor device as in the calenders, a small machine being used for the very slow movement, a big one for the regular running.

Barring starting torque, the power required by printing presses is rather surprisingly small. The press-driving problem is essentially one of varying speed, and the means adopted for this purpose are substantially those used elsewhere, of varying the field and resistance in the armature circuit enough in each case to give the required range of speed. The interpole motor lends itself particularly well to such control here as in other cases. Where alternating current has to be used one is generally driven to slip-ring motors with variable resistance. As the running load of a press is fairly uniform, this arrangement can be made to work successfully despite the fact that, as in series-wound continuous-current motors, the speed varies through a certain range with changes of load. The control adopted is generally of the push-button type and frequently from several points, the form and multiplicity of control being chosen for safety and convenience.

It is in the adaptation of this type of control to the requirements of the particular printing plant considered that the greatest ingenuity can be exercised by the engineer. Aside from this, the equipment of printing machinery is a very simple matter.

POWER REQUIREMENTS OF TRAVELING CRANES

The electric crane has become practically standard for all permanent work and for much temporary work. As its use has become more familiar the motor drive has been more and more refined. The things most imperative in its organization are unusual mechanical strength, accurate speed control and reliability. These have led to the development of many highly specialized devices and have resulted in apparatus which has proved exceedingly successful from every standpoint. One particular point in design to which attention should be directed is the question of efficient co-ordination between the speed and the requirements of the particular work for which the crane is designed. Here more than anywhere else is the finesse of the engineer needed in planning a successful crane equipment.

FACTORS THAT GOVERN ELEVATOR DRIVE

The electric elevator has been coming into its own within the last decade at a very surprising rate. As the demands of elevator service have increased both in speed and in lifting power, it was only natural to fall back on the general source of distributed energy for means of operation. The electric elevator is economical in operation, easy to keep up, simple and compact, and safety devices may be applied to it with the extreme facility which characterize most electrical modes of driving.

The principles of the design of the lifting gear are pretty much the same for all sorts of motive power. For most practical cases the winding drum or the traction sheave in some form or other is used, the latter more generally. So far as the motors themselves are concerned, the requirements are somewhat special, chiefly in the direction of high starting torque, and in direct-current machines sparkless operation even under extreme variation of load and overload. It is also rather necessary that the operation should be quiet, unless of course in freight service in buildings otherwise far from noiseless. The result has been the development of a somewhat highly specialized class of motors, generally now-a-days with commutating poles, designed for high overload capacity and with large mechanical factors of safety.

BLOWER AND COMPRESSOR SERVICE

The power requirements of fans and other devices for producing movement of air vary enormously with the requirements to be met. Ordinary fans of the type familiar to every one have for their special function the movement of a large bulk of air at relatively very low pressure. For moderate pressure blowers of the familiar centrifugal type are commonly used, and for high pressures the two-stage or three-stage units built along the general lines of the reciprocating steam engine. All such apparatus has one common characteristic in that the power required varies rapidly with the speed, practically as the cube of the speed for a given area of discharge opening. Consequently the starting torque is very slight, which separates blower service from almost every other variety of motor drive. The efficiency of the apparatus does not vary to any material extent with variations in speed, again an almost unique characteristic. The light starting torque greatly simplifies the equipment of motors and lessens the severity of their sudden requirement for power at the moment of starting.

Almost any sort of motor is, therefore, suitable for blower service. Single-phase alternating-current motors, often looked at askance on account of their low torque at starting, serve admirably in operating fans and blowers. Induction motors of the simplest kind are entirely adequate for this service. When the supply is direct-current either shunt or series motors may be used, the former being generally preferable. The control of fan and blower motors is obviously a very simple matter, the smaller sizes requiring nothing more than a connecting switch. Large machines should have at least a starting rheostat and now and then under exceptional conditions an overload release. Only in high-duty compressors is there special call for any elaboration of the starting equipment, such as is common with other motors. As the speeds required for rotating blowers of every sort are rather high, direct connection of the motor is very often practicable, although the best speed of fan may not agree well with the quasi-synchronous speeds of alternating-current motors. Large blowers should generally be planned for direct connection, while belting is very often convenient in the smaller sizes. It is perfectly practicable to use either method, and either can be made silent, an important characteristic in much ventilating work. Belted machines have some advantage in this respect when the fan speed is relatively low. It takes a good deal of finesse on the part of the designer to secure a silent fan of respectably large output and advantageous speed, but the trick can be turned successfully.

IMPROVING MOTOR DRIVE IN MAINE SHOE FACTORY

Several improved motor applications are used in the Lunn & Sweet shoe factory, Auburn, Me. In the stitching-room eight "Peerless" fold cementers were formerly belted to a 3-hp. motor which also ran twelve sewing machines. At present four cementers are mounted on a single bench, constituting a productive unit, each machine being directly belted to a 0.1-hp., 110-volt General Electric (Fort Wayne) induction-type motor. The eight cementers require but 0.8 hp. when all are in service, and these motors are more efficiently loaded than under the previous arrangement. A separate snap switch at each operator's position controls the motor, thereby affording maximum ease of control and saving energy.

A number of sewing machines were formerly driven in large groups by motors ranging in size from 1.5 hp. to 5 hp. This service has now been subdivided so that in a typical case five sewing machines are grouped on a 1-hp., two-phase, three-wire, 440-volt induction motor. In the older arrangement, which included more machines and larger driving units, control was effected by a four-pole fused switch mounted on walls or posts.

Subdivision has enabled a more compact switch to be utilized. The fuses are enclosed in a fireproof box under the table, and the motor switch is a three-pole snap-type unit of General Electric make, used largely in the latest individual textile-drive installations. Entire satisfaction has resulted from the use of these snap switches on 440-volt power circuits at this factory. The former motor arrangement was less convenient, the motors being mounted in perforated metal boxes on top of the benches. Here three 2-hp., 440-volt, two-phase motors operated twenty-six Singer sewing machines, the starting switches and fuses being placed on the back of the bench in each case.

Probably a 5-hp. motor is the most convenient size used in an ordinary shoe factory, on account of the convenience with which this size may be utilized either singly or in combination drives. Thus, a pair of such motors are belted to a line shaft from which are operated nine rotary shoe pounders. Special care in determining the proper pulley sizes enables this service to be handled between two units, each taking half the load. The two motors in this case are two-phase, four-wire machines and are protected by one fuse in one wire of each phase, or two fuses per motor.

ADVANTAGES AND METHOD OF INTERLOCKING MOTORS

In a great many manufacturing operations it is frequently found that a machine may require more than one motor in order that the different operations of the machine may be changed with respect to other operations of the same mechanism. This is true particularly with cutting machinery, where the rate of material feed should be adjustable in order to handle various sizes of stock. As examples of machinery in which this characteristic is necessary, planers, wood saws, diamond marble saws, sizers and other tools in which the cutting is practically constant but the feed variable may be mentioned.

As long as the cutting motor and the motor operating the variable feed are both running, the entire machine operates satisfactorily, but should the cutting motor blow a fuse, trip its relay or be stopped by the operator and the feeding motor continue to run, serious trouble is liable to follow. The feed will force material against the powerless cutters and either bend or break parts of the equipment. Most feeds operate rather slowly by being geared down many times from the motor shaft, so that the feed motor, though very small, may have enormous power on the slow-moving rolls or carriage handling the material.

Trouble can be obviated easily on any machine operating under power from two or more motors, David R. Shearer points out, by interlocking the no-voltage-release coils on the starters or compensators. The illustration in Fig. 62 indicates a driving and a feed motor operating in an interlocking manner on three-phase alternating current. It will be noticed that current

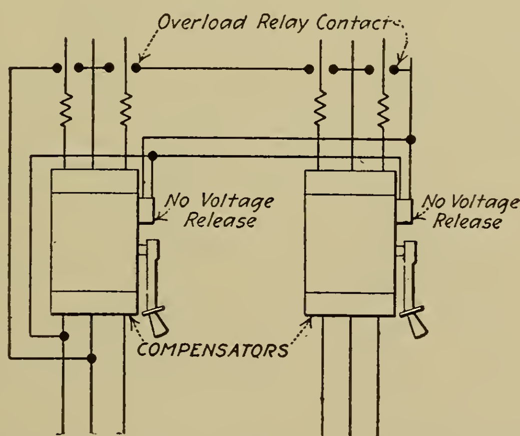


Fig. 62—Method of Interlocking Two Motors Through Their Compensators

is taken from the driving motor leads through both release coils and both relay trips on the two compensators. Thus, if the cutting or drive motor is stopped or fails, the current is broken in the release coil of the other machine and it stops also. Moreover, if either motor becomes overloaded sufficiently to trip the relays the entire set is at once brought to a stop.

By the addition of a double-throw switch the coil-operating current may be taken from the leads of either motor as desired. This is sometimes advisable when it is necessary to operate one of the motors singly for some specific purpose. This method of interlocking may be extended to cover several motors operating interdependent mechanism, and the actual arrangement of connections may be subject to many changes; but the principle remains the same.

METHOD OF PREVENTING CONCURRENT PEAKS

Sometimes a manufacturing plant will be found in which the connected motor load is greatly in excess of the plant generating capacity. When such a condition exists there is a possibility that the machinery may be subject to a concurrent peak which will mitigate against normal production. For instance, the voltage may drop to a point where the low-voltage releases trip out, thus stopping all the motors and introducing serious delays.

A case of this kind was called to D. R. Shearer's attention some time ago in a woodworking plant where it was exceedingly difficult to get the operators to understand the seriousness of allowing a peak to occur on several machines at the same time. Such a condition actually occurred once or twice each day. Each time this happened the manufacturer lost several dollars, so it was determined if possible to obviate the trouble. The blame could never be placed on any one man, and thus it was not feasible to get the desired result through discipline.

The trouble was corrected by placing a large ammeter in plain view of the operators of three of the largest machines. On the ammeter dial, which was printed in large figures and well illuminated, was placed a danger mark, and the operators were instructed never to allow the load to run the pointer above this mark. Since the entire motor load was indicated on this instrument, it was not subject to violent fluctuations, but remained very steady until several machines began to take heavy cuts at the same time, when the pointer gradually moved up toward the danger mark.

There was some fear that the use of this ammeter would curtail production, but this proved not to be the case. In fact, the production was increased, for not only were delays from overloads obviated but the load factor was improved. This is explained by the fact that the men could see when the load was dropping and so could increase the feeding proportionately.

It is possible that the use of an ammeter might be of considerable benefit even in those plants having abundant power by tending to better the load factor and consequently the production of all the machines. If a minimum point as well as a maximum were indicated on the dial and the entire plant load indicated on the meter, it would appear that great gains in economy might be expected with attendant increase of production, simply from the efforts of all the operators to keep the needle in its restricted space on the scale.

METHODS THAT FACILITATE PROMPT MAINTENANCE

Card Record System. In a large plant where more than 100 motors are installed much delay was experienced in answering breakdown calls and in making repairs through lack of knowledge of each particular motor. One of the first things done by the new chief electrician, says H. S. Rich, was to have all motors cleaned up and numbered plainly. Then he established a card system on which were kept all the specifications concerning each motor. These cards were kept in an open box on his desk in the electric repair shop, where all the helpers could refer to them instantly. Each card showed the following:

Number of motor.	Department.
Horsepower.	Revolutions.
Make.	Phase.
Manufacturer's number.	Diameter of pulley.
Face of pulley.	Diameter of shaft.
Length of shaft.	Size of key.
Type.	Serial number
Size of fuses.	Type of fuses.
Size and number of brushes.	Motor belted to.

The cards were arranged in the box by departments so that by referring to any one department all the motors in there could be seen at a glance. A few cards at the front of the pile had all the motors in the plant arranged by numbers consecutively, so that when any foreman telephoned in, for instance, that motor No. 15 was stopped the top cards showed what department this motor was in. Then by referring to the department card all the specifications concerning this motor were seen at a glance, and the repair man was supplied with the proper-sized fuses, test lamp and tools and dispatched to remedy the trouble.

Most jobs were completed in record time because the necessary things were taken along on the first trip, without running back and forth to see what was wanted, all of which formerly caused much delay. By "keeping tabs" on the cards all sizes of fuses likely to be needed by any motor could be provided ahead of time and kept in stock, so that no time was lost making up any when a motor shut down.

This card system was very handy to refer to when a motor burned out or broke down. Moreover, motors could be shifted around to better advantage by knowing all about them. Thus one department needed more horsepower and another department was found to have a larger motor at the same speed and pulley diameter. After seeing them both in operation an exchange was made with all knowledge of the details before either was stopped. Many times an exchange or temporary installation called for special-sized pulley with a particular bore and key. The card data made possible the assembly of this material ahead of time so that when the change was made there was no loss of time.

All new motors purchased, whether put into immediate use or into stock as reserves, had their record taken and listed along with the rest of the equipment on hand. In a space at the bottom of every motor card remarks were often penciled from time to time as trouble was found. Thus one busy 50-hp. motor was found to have very little clearance under the rotor when tested with a steel gage. This was noted on its card, and two new bearing linings were immediately made ready. On the first Saturday afternoon following, when the motor was shut down, the linings were examined and one was found to be badly worn. A new one was put in, and on Monday morning everything was ready for service with no loss of time.

Sometimes higher line-shaft speed was demanded, and by referring to the card the revolutions, pulley diameter, face and key were observed at a glance. A larger one could be made ready and slipped on the same day at noon; whereas to climb a ladder and take measures might have meant to shut down a motor which was carrying a large load; thus production would be curtailed. The time saved is the most valuable feature of this scheme.

When summer repairs are made each motor is taken in its turn and thoroughly overhauled. By following the cards none is overlooked. Also by listing the various sizes of shafts throughout the plant enough bearing linings can be ordered ahead of time and kept in stock so that no motor will be held up in an emergency for lack of them.

Motor-Data Sheet. To avoid the usual lack of complete data bearing upon motor applications in industrial plants, a Massa-

MOTOR

For ....Date..............191

Dept...............Bldg............Sect...........Floor.........Size H.P.........

Voltage - 230 D. C.....Duplicate of / Similar to Drive on Mach.No............Shunt / Compound Wound / Series

Constant / Variable Speed Normal Speed................By Armature................. / By Field....................

Direct / Clutch Connected. Back Geared.........Ratio...............Reversible..........

Pulley Diam.........Face............Teeth in Gear........Sliding Rail Base.........

Arranged for Floor Mounting / Ceiling Suspension Enclosing Covers / Mesh Enclosed

Make Recommended by Drafting Dept....................Type......................

Catalogue.............................Page....................................

Plain heavy Duty Starter with Renewable Segments
Armature Controller with Renewable Segments - Fan Duty.
Compound Controlled With Renewable Segments - Machine Duty
Starting Resistance and Field Control with Renewable Segments.
Overload Release
Printing Press Type
Self Starter - Lock and Key

Panel with Knife Switch and Fuses / Circuit Breaker

Reverse Switch...........................Dynamic Brake.........................

..........Single / ....Double Push Button Stations Number Steps Armature / Field...........

Ship to...

....

Wanted..............................Appropriation received....................

Ordered.............................From....................................

Remarks:

Our Number................

FIG. 63—COMBINED MOTOR ORDER AND DATA SHEET FOR USE IN INDUSTRIAL PLANT

chusetts factory uses the form reproduced herewith. On a sheet 8½ in. by 10¾ in. (21.5 cm. by 27.3 cm.) in size all the more essential data are listed, including the factory section, department and floor on which the motor is going, speed, pulley and suspension or mounting details, type of covers, make recommended by drafting department, type of controller and shipping directions.

On the original order it has not been customary to fill in more than the necessary information for the motor maker and control manufacturer, but the complete information desired by the plant is kept on the filed sheet, which is convenient in its provisions for all the important facts.

Fuse Rack. To facilitate restoration of service when an interruption occurs in the shoe factory of Lunn & Sweet, Auburn, Me., fuses are kept in a rack built of three pairs of slotted upright wooden bars of 1.5-in. by 3/8-in. (3.8-cm. by 0.96-cm.) stock. Each pair corresponds to a certain numbered section of the factory and carries the fuse sizes normally used on the motor circuits of that section. In case of a report of service interruption the maintenance man, who is informed of the factory section involved, seizes the fuses corresponding to that section without any loss of time, and upon arriving at the scene of trouble effects a replacement in minimum time. Even fifteen seconds saved in the restoration of service in a factory where intensive production is the practice counts in these days.

Rapid cooling of a burned-out motor, with consequent increased speed of replacement, is accomplished by the use of a Pyrene fire extinguisher, one of which is always kept at the front of the cabinet.

Map of Motor Layout. To facilitate layout and maintenance work, a series of roller plans has been prepared showing the location of every machine, shaft line, column, hanger and motor in the plant. The plans are drawn to a scale of 1/8 in. to 1 ft. (10.4 mm.-1 m.) and kept in the office of the superintendent of buildings and maintenance. who has charge of all electrical service. Experience shows that a scale of 1/4 in. per ft. (20.8 mm.-1m.) is preferable for future work of this kind. The plan is about 5 ft. (1.5 m.) long and saves many measurements in the field. The larger scale, however, is more convenient for all-around service. Such a plan can often be supplemented to advantage by a layout of distribution circuits with the sizes of the conductors indicated. This can be utilized in adjusting motors to circuits or vice versa.

Ernest Bragdon is the superintendent of buildings and maintenance.

SOME MOTOR TROUBLES AND HOW TO CORRECT THEM

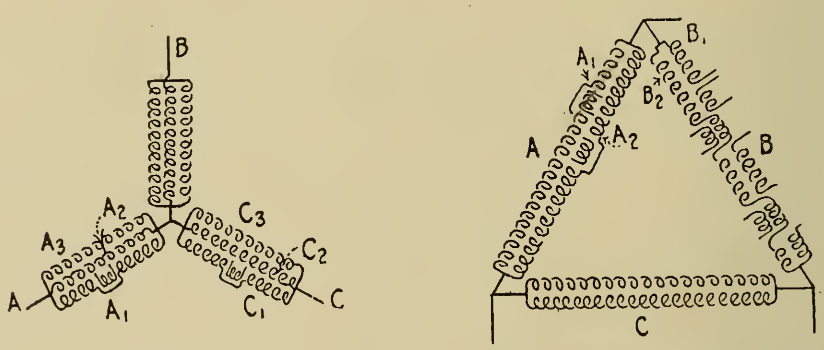
Methods of Making Temporary Motor Repairs. While most large industrial plants carry spare motors for use in place of those that are burned out, many small plants do not always have spare units on hand, and even when they have it frequently takes a long time to install them. Since only a few coils rather than the entire motor usually burn out when a motor ''breaks down,'' the machine can be kept running in many cases until it is convenient to make permanent repairs by cutting out the defective coils. Several methods of doing so are related by H. L. Hayes.

With small-size, low-voltage motors, which usually have single or two-circuit Y or delta windings, this does not involve much difficulty. Unbalanced current may be drawn from the line when coils are cut out, but as a rule this will not seriously affect the power system. It is simply a case of whether the motor can carry its load and whether the winding can stand the increased current. If the motor is not too heavily loaded, it is possible to cut out quite a large number of coils and still operate the motor. If a motor has a large number of coils, with only a few turns per coil, several coils per phase can be cut out, but in motors having comparatively few coils, with a large number of turns per coil, this cannot always be done.

Complications may arise when attempting to apply this emergency repair scheme to large motors which usually have multiple-circuit windings because cutting out a coil causes local currents. In such a case if coils are cut out of one circuit it is sometimes necessary to cut out coils in all circuits which are in parallel with this particular phase. While this change may leave the phases unbalanced with relation to each other, the individual circuits of the phases will be equal. For instance, consider Fig. 64, in which is shown a three-circuit Y winding with coils cut out of A-1 and C-1 circuits in phases A and C. In a winding like this, circuit A-1 and C-1 may be completely cut out, leaving only two circuits for these two phases, but this would reduce the capacity of the motor a great deal. If, however, an equal number of coils were cut out of the parallel circuits, the motor may carry practically its entire rated load.

The changing of the arrangement of connections, such as converting a two-circuit Y connection into a single-current delta type, may also often permit emergency operation. The different schemes outlined reduce the capacity of the motor, but if it is carrying a variable load, which is often the case, continued operation may be maintained because even though the winding will heat up on the peaks, it can cool down during the light-load periods.

Different applications of these principles have been made in a New England paper mill, where 25-cycle, 440-volt, three-phase motors are used and shutdown of one motor often means a large loss of production. Prior to cutting out coils or changing con-

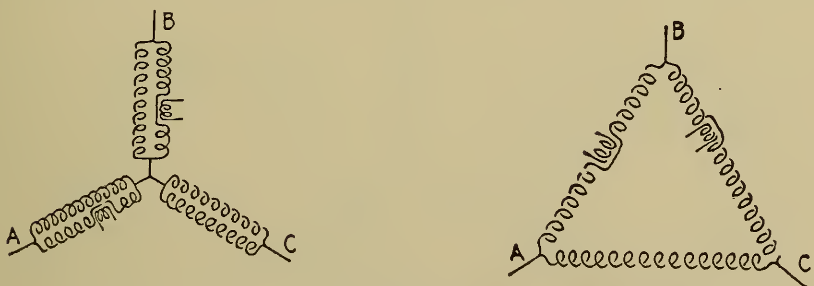


Figs. 64 and 65—Method of Repairing Three-circuit Y Winding and Two-circuit Delta Winding

nections, tests are made to detect open circuits, grounds or short-circuits between phases. This is done with an ordinary lamp extension having one wire open-circuited and connected with a 110-volt circuit. Although 110 volts can be used to indicate dead grounds or short circuits, and is relatively easy to handle, it is better to use the full motor voltage with a bank of lamps in series to make the final tests, because it frequently happens that 110 volts will not detect partial defects that the higher voltage will bring out.

With a motor having a single-circuit winding it is a simple process to disconnect the separate phases, but with multiple connections this is liable to involve considerable work. It is therefore much quicker to try operating the motor before disconnecting any leads, noting as nearly as possible where it flashes. The particular section which appears defective may then be disconnected and tested for faulty coils. The objection to this method is that more coils are liable to be damaged with every flash, but if time available for repair is limited such procedure permits a saving of several hours. Furthermore, small fuses can be connected into the circuit for the purpose of limiting the short-circuit current.

Following are a few examples of how motors have been kept running which would ordinarily have had to be taken out of service for rewinding. A 50-hp. motor having a two-circuit delta winding broke down, spoiling a number of coils. On examination it was found, as shown in Fig. 65, that no coils in phase C were damaged. However, circuit B-1 of phase B was badly burned, so that it could not be left in circuit. A few of its undamaged coils were connected with parts of circuit B-2 to



FIGS. 66 AND 67—BURNT-OUT DOUBLE-CIRCUIT Y WINDING RECONNECTED INTO SINGLE-CIRCUIT DELTA WINDING

take the place of coils burned out in the latter, thus making nearly a complete single circuit for this phase. As several coils in the A-2 circuit and only one coil in A-1 circuit were damaged, enough coils were cut out of A-1 to even it up with A-2. This motor would not have carried a heavy continuous load, but it was used for over two months during the cold weather to run a circular saw.

Another 50-hp. motor having a two-circuit winding broke down, injuring only two coils. With only these two coils cut out the winding heated up in a few minutes, though running light. The coils in this motor had an exceptionally large number of turns per coil and comparatively few coils per phase. Instead of trying this motor with coils cut out of other circuits, it was changed into a single-circuit delta winding. Thus changed, the motor was incapable of developing its rated power, but it did not have to carry a continuous load. The original and final connections with coils cut out are shown in Figs. 66 and 67.

In another case a motor with single-circuit Y windings, running a small pump, broke down, injuring one coil in one leg and several coils in another. Cutting out the injured coils permitted more than full-load current in one phase even with the motor running light. Ordinarily a small motor can easily be replaced, but there was no spare motor available at this time. Since this motor could handle the load when it was running single-phase, a switch was connected in series with the weak phase to permit starting three-phase. After the motor was up to speed the switch was opened and the motor left running single-phase. The final connections are shown in Fig. 68.

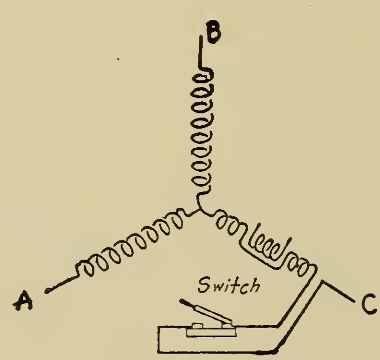


FIG. 68—DAMAGED Y WINDING CONNECTED FOR THREE-PHASE STARTING BUT SINGLE-PHASE OPERATION

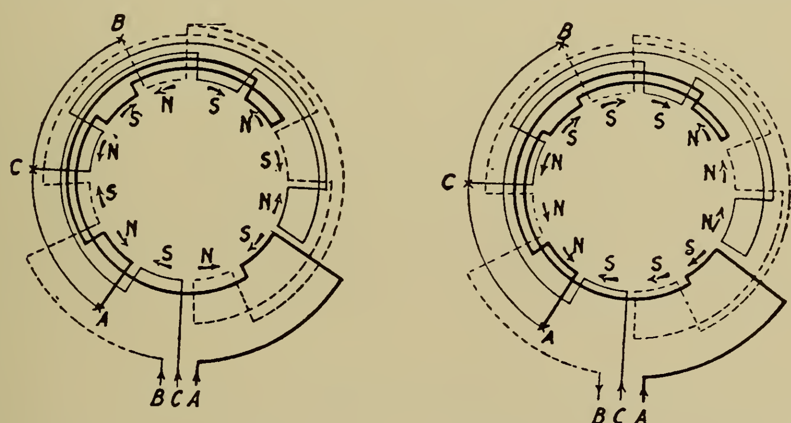
Rotors cause comparatively little trouble, but one case occurred at this paper mill where a coil-wound rotor rubbed on the stator and injured a number of coils. The bars which formed the coils in this winding had been bent after they were put into the slots, so it was impracticable to take them out for retaping. Since no new bars were available, the bad bars were disconnected and replaced by ordinary wire cables passed through the arms of the spider instead of through the slots.

The cases mentioned illustrate that a motor is not necessarily "down and out" because it "shoots fire." While it is surprising how badly a motor may be damaged and yet be capable of carrying its load, it is not advisable to run motors in such condition any longer than necessary, as there is a loss of efficiency in both motor and line.

Reversed Phase Causes Subnormal Motor Speed. While working in a power plant in a small Western town M. M. Clement had to reconnect a three-phase, four-pole, series star-connected motor so it would operate at a different voltage. Changes were made according to blueprints, but when the motor was tested it operated at only about one-third normal speed.

To locate the trouble the star connection was opened and opposite ends of each phase were joined to the terminals of a storage battery. By testing the poles of the armature with a small pocket compass while current was flowing in this manner it was found that the poles of each phase were symmetrically placed around the armature and that they were alternately marked "south," "north," etc., just as they should have been.

Next the star connection was joined again and current allowed



FIGS. 69 AND 70—CONNECTIONS AND POLARITES AS THEY SHOULD HAVE BEEN IN MOTOR WHICH WAS REWOUND

to flow in two leads and out the third. Under this condition and with a properly connected three-phase, four-pole motor the polarity of three consecutive poles should be in one direction (Fig. 70), while that of the next three should be opposite, etc., thereby forming four flights of alternately different polarities. In this motor, however, it was found that the adjacent pole faces had opposite polarities, indicating that one phase was reversed.

To determine which was reversed all of the leads were connected with the positive terminal of the storage battery, while the star connection was joined with the negative terminal. Under these conditions in a properly connected armature the polarities of adjacent poles should be opposite, but in this motor three consecutive poles had similar polarities, while the next three had the opposite polarity, etc. Since the only polarities that could be reversed to bring about the proper arrangement were those corresponding to phase *B,* it indicated that this phase had been reversed; that is, the terminal which should have been a lead was connected to the star point and vice versa.

Motor Bearings Should Receive More Attention. It is to be regretted that electric motor maintainers do not acquire the habit of feeling the bearings of motors and of their dependent machines when making the wiping-off rounds. If they did, much expensive trouble would be avoided. The following experience illustrates what the proverbial "ounce of prevention" might have done in the way of saving a pound of cure.

A freight elevator the electric equipment of which, though very old, had given years of satisfactory service began to blow fuses with such frequency as to become a nuisance. The motor and the control apparatus had been "gone over" several times and the commutator of the motor had been turned because sparking had roughened it. In the meanwhile the 25-amp. fuses had been replaced with 50-amp. fuses, which, while not to be commended, gave relief for a few days, then the outfit refused to do anything but blow fuses.

An elevator man was sent for who disconnected the motor, tested it and found it in proper condition. Then with a bar he tried to turn the gears that the motor pinion had engaged, but could not do so. Inspection then disclosed that two bearings not far from the motor had "frozen fast."

Rubbing of Rotor Will Cause Frequent Trouble. Ordinarily rubbing of the stator of an induction motor by the rotor is announced by the fuses blowing, the frequency gradually becoming greater as the arc of the rubbing contact increases. In course of time, if the condition is not detected, the extra load imposed by the mechanical friction and the local heating due to the friction will result in damage that can be repaired only at great expense. The most common method of testing for bearing wear of small motors is to lift the working end of the rotor shaft up and down by hand to note if there is any knock. In doing this the stress should be exerted sideways as well as upward, because the greatest amount of wear does not always take place on the bottom of the bearing lining. In any event, if there is any knock at all the rotor should be removed and stator pole surfaces inspected for rubbed areas.

In one case which came to the attention of E. C. Parham a 20-hp., 220-volt, three-phase induction motor was giving trouble due apparently to a hot bearing on the pulley end. The whole end of the motor would get too hot to touch, and it became impossible to keep oil in the bearing on that end. The owner hesitated about stopping the motor because its continuance operation was so important. Instead he tried to cool the bearing with a block of ice. Finally the fuses in the pole transformer that supplied the motor gave way.

The first abnormal condition noted was that the motor was not protected by means of fuses. Furthermore, the transformer fuses were large enough for ten such motors. Inspection disclosed that rubbing had worn some of the stator laminations almost through to the winding. Judging from the wear of the bearing on the other end of the motor, the excessive heating must have been due, not to a hot bearing but to the rubbing of the stator by the rotor. Fortunately, the stator winding was not injured, and after renewing the bearings on both ends of the motor normal operation was permitted again. The owner of the motor also hastened to order a fuse panel for his second-hand compensator.

Motor Air Gaps and Allowable Bearing Wear. Failure of operators to appreciate the fact that the air gaps of small induction motors are usually only a few thousandths of an inch often leads directly or indirectly to the trouble most common to these motors—rubbing of the rotor on the stator. Bearing wear equal to only the bearing clearance of direct-current motors will let the rotor down on the stator. Mr. Parham tells of one instance in which an inspector was called to look at a repulsion-induction motor on the inside of which sparks like those from an emery wheel occasionally could be seen. Inspection disclosed the fact that a very small area of the rotor which was not perfectly cylindrical had been striking a few laminations that projected from a part of the stator. Whether there would be contact or not depended on whether the rotor was at one end of its end-play travel or the other. In any event the pinion-end bearing lining had worn almost to the safe limit. If there had not been those few projecting laminations which gave a timely warning, the rotor probably would have been seriously damaged later.

Causes of the Jerky Notching of Motors. One of the commonest causes of jerky notching of motors is short-circuits in the resistance by means of which the motor is accelerated. Such short-circuits may be due to buckling of the resistance grids or to metallic foreign objects lying upon them. In either case acceleration will not be smooth. Another cause of unsatisfactory notching is the turning end for end of the frames of which the resistance as a whole is composed. The effect of such a reversal is to cut out small blocks of resistance on the lower controller positions and large blocks of resistance on the higher controller notches, where the motor is more sensitive to circuit resistance changes.

In one instance the resistor of a three-phase induction motor was disconnected for repair because some of the resistance grids were broken and others were distorted until they touched one another. The electrician who did the disconnecting was as familiar with the connections as he was with his own name, therefore he did not bother to tag any of the removed wires. When the time came for installing the repaired resistance frames the man who had disconnected the apparatus was on sick leave and no one else knew anything about the connections. Serious trouble resulted.

The moral of this experience, and of many other similar experiences, says Mr. Parham, is that when disconnecting any electrical device (it matters not how familiar one may be with the connections) the disconnected ends should always be marked or tagged in a very evident manner.

Causes of the Balking of Induction Motors. Sometimes a rotor will start and sometimes it will not, even when the controller is moved to an advanced position. Rotors of the squirrel-cage type will be consistently unresponsive when starting under load if the conductivity of the end connections for any reason becomes impaired, and the maximum speed will be below normal. Assuming that there is no rubbing, balking of rotors of the wound type generally is due to conditions not within the motor itself. Excessive load to be started or failure of a brake to release will cause any rotor to "hang" until a fuse blows or a breaker opens or until the controller reaches an advanced position. The first trouble is common to motors that drive rolls in which stock material becomes jammed. The second trouble may be due to low voltage, to want of proper adjustment of the brake clearance, or to baking of the brake coils.

Among the more commonplace causes of balking of wound rotors, Mr. Parham points out, is bad and prolonged sparking due to overloads, to defective brush rigging or to rough or eccentric slip rings. This action will sometimes cause a non-conductive skin to form on the surface of the rings. A loose brush holder will prevent the brush from making certain contact, because with one direction of rotation the contact may be bad while with the reverse direction of rotation it may be good. Sticking of a brush in a holder will cause action similar to that experienced under the same condition with direct-current motors. The starting becomes more and more erratic as the brush wears shorter and shorter, and finally one of the rotor circuits is opened by the brush failing to make any contact at all. Weak brush-tension springs and displaced tension fingers will cause irregular actions. Finally, disconnected, burnt-off or broken brush shunts have been known to affect seriously the promptness of starting and to cause brush-holder heating in normal operation.

Cause of Trouble with Single-Phase Starter. When trouble with single-phase starters having connections like those shown herewith occurs, Mr. Parham says, it will usually be found that the contact *a* fails to touch both *b* and b_2, or that there is an

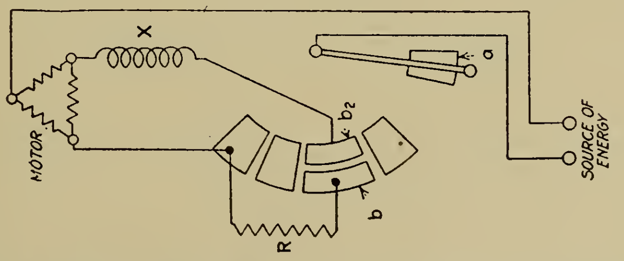


FIG. 71—SIMPLIFIED DIAGRAM OF SINGLE-PHASE STARTER CONNECTIONS

open circuit in the leads between these contacts and the motor. Failure of *a* to make contact with either *b* or b_2 may be due to a weak spring or blistered contacts. If any of the faults mentioned exist, the production of a split-phase for starting the motor is prevented.

Large Air Gap Cause of Excessive Speed in Motor. During a lightning storm two field coils were burned out and the armature was grounded on an interpole compound motor having a friction-saw blade mounted on the armature shaft. To save time, says R. L. Hearvey, the grounded armature coil was cut out and the two field coils were rewound. When reassembled the armature ran 2300 r.p.m. at no load instead of 1900 r.p.m., the increased speed causing the saw blade to wabble badly when sawing. The first test made was to determine if the shunt coils had the proper voltage drop across each and if their polarity was correct. Both were found to be right. The next test was to check the polarity of the compound field coils. This was done by opening the shunt circuit and starting the motor as a series machine. If the armature starts in the same direction as a series motor as it does as a shunt, the field coils are properly connected, as they proved to be in this case. This test requires considerable care as the field will be very weak and speed will reach dangerous proportions in a few seconds.

The above tests showed the voltage drop across the shunt coils to be uniform and the polarity correct for both the shunt and compound windings; hence there could be but one other cause for the high speed at no load—that is, a weak field. As there was about 3/32-in. (2.4-mm.) clearance between the armature and the poles, sheet-iron shims 0.04 in. (1.23 mm.) thick under each pole were tried, which brought the speed down to 2000 r.p.m. This was still too high, so the shims were increased to 0.055 in. (1.78 mm.), which gave a speed of 1900 r.p.m. At this speed the motor has been operating satisfactorily for over a year.

CHANGING HORIZONTAL MOTOR TO VERTICAL IN EMERGENCY

When the No. 1 Mine of the American Zinc Company of Tennessee at Mascot was accidentally flooded in the spring of 1917 suitable pumps were immediately available, but vertical motors to drive them were not to be had any place in the district. Some horizontal motors were available, however, so it was decided to adapt these to vertical operation. The two important problems that presented themselves were how to obtain a suitable thrust bearing to carry the rotor and how to lubricate the bearings in such a manner that the oil would not get into the windings of the motor.

To support the rotor it was first necessary to splice the rotor shaft to make it extend through the end-shield. Accordingly a suspension stud was fitted to the shaft with a right-hand taper thread (the direction of rotation of the rotor was opposite). The body of the stud was made the same size as the motor shaft.

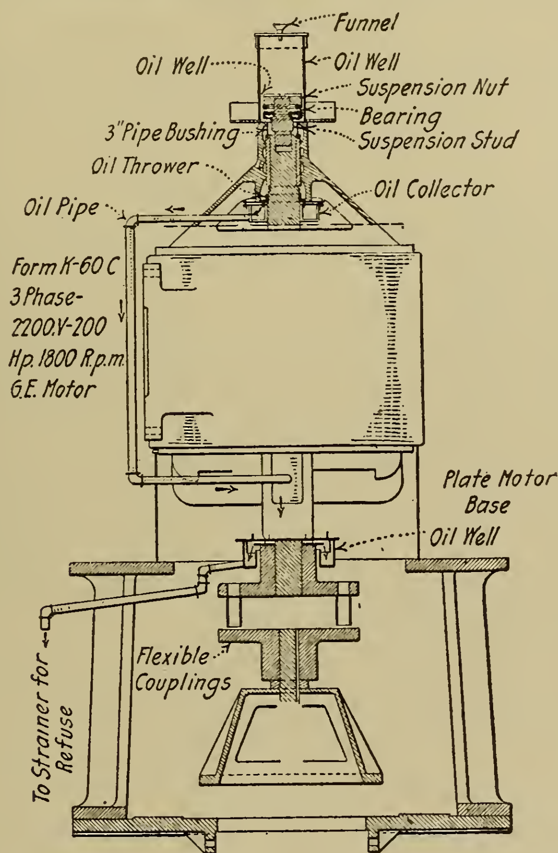


Fig. 72—Changes Made in Horizontal Motor to Permit Operation in Vertical Position

while the upper end was threaded to receive the suspension nut which carried the rotor. For the thrust bearing a No. 715 U. S. K. F. self-aligning ball bearing was selected. The internal diameter of the ball races was considerably larger than the body of the stud, but a bearing of the right dimension to carry the load at this speed was not available, and in order to center the ball bearing a shoulder was turned on the suspension nut to take the upper ball race. This was made a snug fit and the bearing performed nicely. The self-aligning washer rested on the end-shield, which was already machined.

Arrangements were made to lubricate first the thrust bearing, then the upper motor bearing, and finally the lower motor bearing. An oil well was made of a short piece of 5-in. (12.7-cm.) pipe screwed into an 8-in. (20.3-cm.) channel to prevent any splash. The channel was bolted to the end-shield with U-bolts that were passed around the arms of the shield. A hole was drilled in the cover of the oil well to receive a funnel-shaped pipe, the bottom of which entered a hole in the suspension stud. The oil supply was taken from an overhead tank and regulated with a petcock. On entering the stud the oil was thrown into the balls of the thrust bearings through a ¼-in. (0.6-cm.) hole. It was then dashed against the wall of the oil well by the revolving parts of the thrust bearing, from which it trickled down into the upper motor bearing.

To prevent oil running over the outside of the bearing bushing and consequently finding its way into the windings, a piece of 3-in. (7.6-cm.) pipe was bored and turned to fill the space between the end of the bushing and the inside of the end-shield casting. The slots in the bushing for the oil rings were filled with babbitt metal. Oil following the rotor shaft is thrown off by a centrifugal device into an oil collector. From this point the oil is piped to the lower bearing.

The oil-ring slots in the lower bearing were also filled with babbitt metal, and a hole was tapped in about the middle of the bushing for the oil pipe coming from the upper bearing. A spiral oil groove was cut in the babbitt to lead the oil to the upper end of the bearing, from which it was allowed to run down the shaft to an oil thrower. The oil which is drained off is filtered and used again. Albert Wettengal and R. P. Immel of the American Zinc Company of Tennessee worked out the foregoing arrangement.

Home-Made Tools for Armature Repair Work. Oftentimes when considerable coil winding must be done certain minor tools are needed which cannot be purchased ready-made. These tools, however, are usually small and can be constructed in the shops. M. M. Clement has suggested several. The coil-taping needle illustrated herewith consists merely of 1 ft. (30 cm.) of No. 14 banding wire shaped so that it can be used for taping coils in closed-slot stators. After the user is accustomed to this device high speed may be attained.

The coil raiser consists of a piece of steel, 16 in. by 1 by 3/16 in. (40.6 cm. by 2.5 cm. by 0.5 cm.) with a 4-in. (10-cm.) one-sided taper on one end for stripping open-slot armatures and stators. This also can be used to good advantage in removing grounded coils from a newly wound armature or in raising coils sufficiently to allow for insulating weak spots in the coils, the

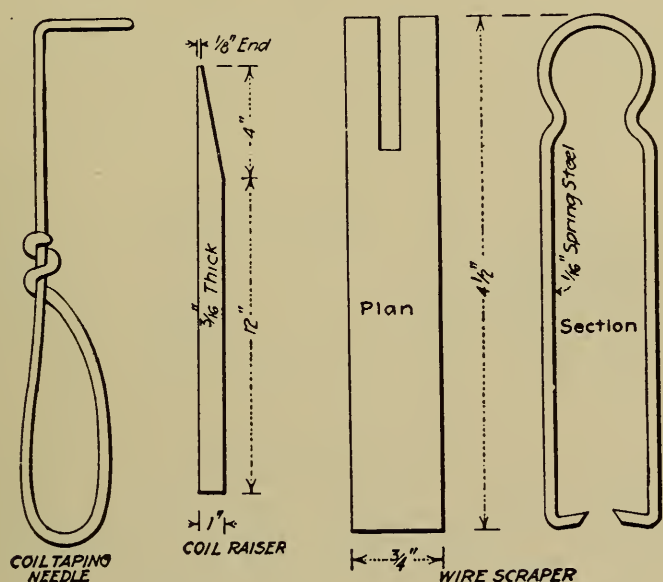


FIG. 73—TOOLS ALL MADE FROM COMMON STOCK

main object in this case being to lift out a tight-fitting coil without damaging the insulation.

The wire scraper is very simply made and very economical, because it eliminates the use of a knife, whose life is short on account of the rough treatment accorded it. This device is made of spring metal, 12 in. by 3/4 in. by 1/16 in. (30 cm. by 1.9 cm. by 0.2 cm.). The knife edges can be sharpened by means of a file and the tool used indefinitely. A section the shape of a rectangle is cut from the metal at the handle end, greatly increasing the spring effect of the device.

For driving fiber wedges between the top of coil and the lamination overhang in closed-slot machines a wedge drift, made of a piece of tool steel, 8 in. by 5 in. by 3/32 in. (20.3 cm. by 12.7 cm. by 0.23 cm.), over which is fitted a loose-fitting steel sleeve, 1/16 in. (0.16 cm.) thick, is very convenient. This is used by inserting the fiber wedge about ¼ in. (0.6 cm.) into the slot; then, with the drift pulled back into the sleeve, the sleeve is fitted over the wedge, which is driven into the proper place, the sleeve holding the wedge in position.

Handling heavy armatures in the electric repair shops is often found difficult or awkward on account of a lack of proper ready-made tools. An armature sling which is very simple to make consists of a piece of 1/16-in. (0.16 cm.) sheet iron, 2 ft. (61 m.) long by 10 in. (25.4 cm.) wide, with steel triangles attached to each end. These triangles, made of ¾-in. (1.9-cm.) steel bar which can be attached to the shop crane, eliminate any danger of the armature shaft breaking or springing.

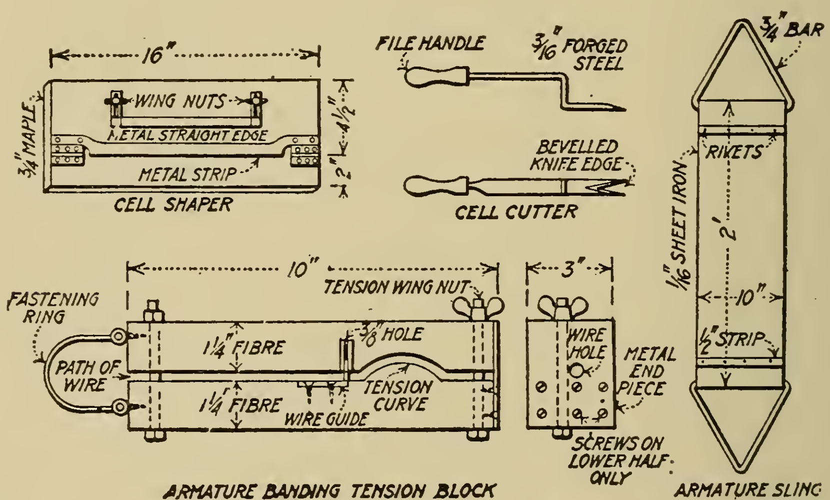


FIG. 74—TOOLS ARE SIMPLY AND EASILY MADE IN REPAIR SHOP

For shaping the fish paper in making cells for armature and stator slots the cell shaper shown in Fig. 74 is very useful. It consists of two pieces of wood hinged together so that they will make a neat 90-deg. fold. The permanency of the correct-fold maker is insured by means of a metal strip attached to the wood slot. The cell shaper is used by inserting a piece of fish paper in the opening between the two blocks of wood, which is the length of the slot plus twice the height and whose width is the width of the slots. The metal straight edge, which is adjustable by means of wing nuts, allows the paper to be folded so as to be made the height of the slot.

In cutting projecting insulations from slots of open slot windings after the coils have been assembled, the cell-cutter, which is composed of a piece of forged steel 14 in. (35.1 cm.) long by $\frac{3}{4}$ in. (19 mm.) wide by $\frac{3}{16}$ in. (4.8 mm.) thick, with a set of beveled knife edges at one end and file handle at the other, has been found convenient. The shape of the device facilitates the free movement of the cutting end.

Another device which does away entirely with the necessity of a banding lathe in a small shop where the armature winder does its own banding saves considerable time and labor. This armature banding tension block, as shown in the illustration, eliminates the necessity of the armature being removed from the stand to be banded. About one foot of stout line with a hook attached to one end is made fast to the ring on the tension block and hooked to an eye-bolt which is set in the floor for that purpose. The spool of banding wire is placed on a small stand beside the eye-bolt and the wire is passed between the two blocks at the rear end through the hole in the first wire guide over the tension curve and through the second wire guide hole and then to the armature. The tension can be regulated by the wing nut placed at the forward upper end of the block. By screwing down the wing nut both sides of the block are brought nearer together, thus narrowing the tension curve over which the wire must pass. This increases the tightness of the band when a pipe wrench is used to revolve the armature.

Device for Winding Coils of Any Shape. A device that was developed by Frank Huskinson for forming coils of practically any shape is shown in the accompanying illustration.

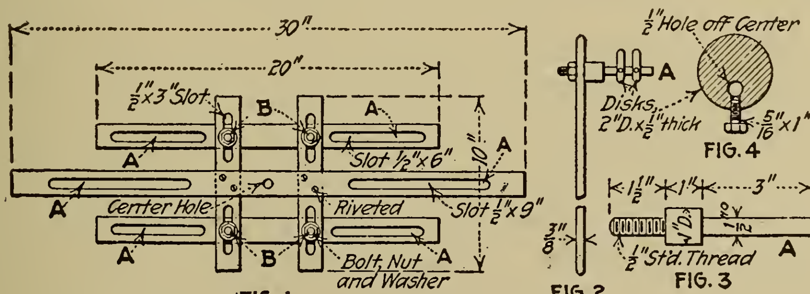


FIG. 75—FRAMEWORK FOR WINDING DIFFERENT SHAPE COILS

It consists merely of an iron framework fitted with several flat disks. By loosening the nuts (B) in Fig. 75, the two long rods can be adjusted vertically to give any width of coil within the limits of the device. Flat disks attached to the ends of each member of framework, as shown in Fig. 75, may be adjusted along the length of the rods to give the longitudinal dimensions of the coil to be wound. The wire is then wound around these disks.

The device can thus be arranged for nearly all shapes of coils and can be made in permanent form for winding a number of the same size coil. The coils can be easily removed by loosening several of the disks.

Switching Arrangement for Testing Motors. The arrangement of switches shown in Fig. 76 will be found useful in motor repair shops for testing purposes. By means of this arrange-

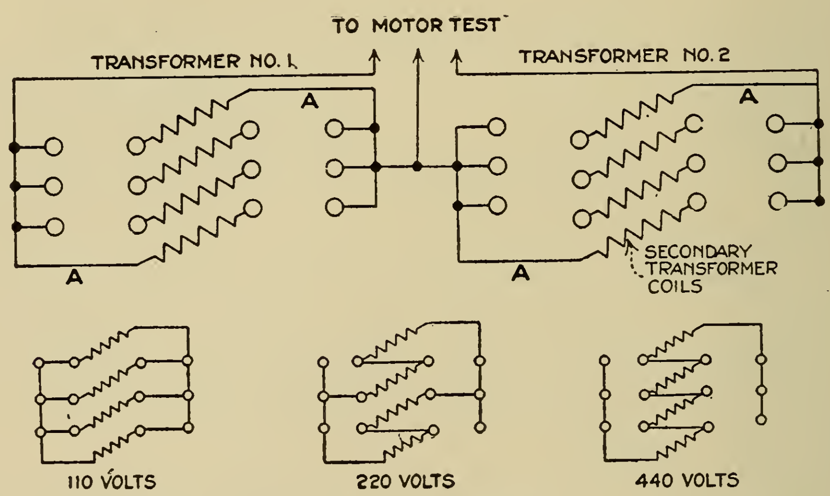


Fig. 76—A Switch Arrangement That Will be Found Useful for Testing Motors in Repair Shops

ment single or three-phase 110, 220 or 440-volt energy may be tapped from a pair of transformers connected in open delta, merely by switch operation, thus saving considerable time in changing connections to suit the various motors under test.

The installation requires a pair of transformers having 110-220-440-volt secondaries. Such transformers are sometimes constructed with eight secondary leads, sometimes with only four. In the latter case four special leads must be brought out, as it is necessary to have access to both terminals of each of the four secondary coils. The extra leads can be readily brought through porcelain bushings placed in holes drilled in the transformer covers.

It will be noted that the full capacities of the transformers are utilized at the standard voltages. In addition, a variety of single-phase voltages are obtainable across the outside leads for special testing by connecting the two transformers for different voltages.

This switching combination is not foolproof. Either transformer may be short-circuited by incorrect connections, but the arrangement is so simple that any tester soon becomes accustomed to it.

Standard single-pole, single-throw knife switches are installed, but half of the switches are used double-throw. If the handles of the switches which are used strike the bases of the others, the handles may be offset to clear laterally. The installation may be somewhat improved by the insertion of additional single-pole switches at points *A*, although these are not absolutely essential.

CHAPTER IV

ILLLUMINATION—SELECTION OF EQUIPMENT, ECONOMIES, AND SPECIFIC APPLICATIONS

ARTIFICIAL DAYLIGHT IN THE INDUSTRIES

Artificial illuminants which are generally adaptable to industrial lighting are usually so deficient in certain colored rays (notably the blue and violet) that many colors can only be distinguished with difficulty or are so distorted as to be unrecognizable to the eye trained to discriminate under natural daylight. These facts are easily demonstrated by experiment, and the importance of color in industrial lighting may be readily ascertained by observation.

The future will bring forth special illuminants for the purpose of aiding vision in various ways, but in the present article only the uses of artificial daylight will be discussed by M. Luckiesh of the Nela Research Laboratory, National Lamp Works, Cleveland.

Comments on Actual Installations. For the most accurate color discrimination north-sky light is generally used, and an artificial-daylight unit giving this quality of light is often called a color-matching unit. For less accurate color work noon sunlight is satisfactory, and artificial daylight units emitting light of an approximate noon sunlight quality are available both as an accessory to an ordinary illuminant and as the ''Mazda C-2'' lamp. The wide application of the latter, which approximates noon sunlight in integral quality, is proof that it is unnecessary to approximate daylight quality more closely than is required by the color-perceptive ability of most individuals. North-sky-light quality when emitted by an artificial lighting unit is generally considered too ''cold'' owing to the prejudices arising from continued association of a ''warm'' color with artificial light. Examples of the installations of the latter quality of artificial daylight will be drawn from a large number of installations of these units. These units will be termed sunlight units for the sake of brevity in expression.

Color Factories.—North-sky-light units are in use for the more accurate color discrimination and color matching, and sunlight units are employed for general illumination of processes less exacting in the requirements of color perception. The products of such factories when exhibited in stores or used in paint shops are also at present illuminated in many cases by means of approximate daylight units.

Paint Shops.—North-sky-light units for accurate color mixing and for the standardization of colors are used in considerable numbers, but in general in this field the approximate daylight units are used. The final product is well displayed under such illumination, and as a consequence many automobile display rooms, for example, are illuminated by these general-lighting units.

Textile Mills.—In dye mixing and testing, many color-matching units are in use at the present time. Rows of such units are also used parallel to the perches upon which the dyed materials are hung. An angle unit is found necessary in many cases in order to illuminate the material, which hangs vertically and is inspected by the light transmitted as well as by that which is reflected by the material. In accurate dyeing even the most experienced colorist who is thoroughly familiar with the spectral characteristics of his dyes is often unable to be sure of his ground without an illuminant of daylight quality. The sunlight units, or those emitting light roughly approximating daylight in quality, have found many applications in various textile mills. The same difficulties in discriminating the colors of textiles persist in the wholesale and retail stores, so that many of these establishments have been equipped with various types of artificial daylight units.

Garment Factories.—Both types of artificial daylight have been applied to these industries, including woolen mills and cotton mills.

Cotton Exchanges.—Although the discrimination of different qualities of cotton is included in the foregoing classification, this activity deserves special mention. Raw cotton is sorted into a vast variety of grades and the color is an important factor. The colors vary from a white to a yellowish white, and the tints are so weak in color that it is quite impossible to discriminate many of them from each other under ordinary yellowish artificial light. The more accurate artificial daylight illuminants are in use for this work.

Furs.—All the difficulties of color discrimination are met in the fur industries. Not only do the lighter tints present difficulties under ordinary artificial light, but especially the dark shades which are so commonly encountered in furs. Artificial daylight units are also being installed by wholesale and retail furriers.

Color Printing.—In mixing inks and in inspecting proof many color-matching units are employed. For the presses the approximate daylight units find wide application. An interesting feature of artificial daylight in color printing, besides the satisfactory rendition of the blues, violets and purples, is the resulting contrast of yellows upon white backgrounds under this quality of light. Under ordinary artificial daylight it is very difficult to distinguish the yellow impression on white paper in three-color printing. Pressmen find great difficulty in distinguishing flaws under such conditions, which often results in considerable spoilage. In lithography, art work on the original drawing and the work on stones is now being favorably done in many places under artificial-daylight illuminants. Wall-paper displays are well illuminated by the sunlight units, hence the latter have found their way into wholesale and retail wall-paper stores to a great extent.

Art Studios.—Many installations of artificial daylight have been made in studios of pure and applied art. Oddly enough, artificial daylight of a sunlight quality is often preferred, notwithstanding the general choice of natural north-sky light for such studies. This seeming contradiction is likely to lead one astray if further inquiry is not made. North exposure has not been chosen in general by artists for the sake of the quality or color of the light but because north-sky light is the most constant natural daylight both in intensity and quality of spectral character. Some discerning artists prefer to paint from models in the "warmer" light in order to have their paintings tend toward the warmer tone.

Metal Work.—The discrimination of the various colors of such alloys as brass and commercial gold is very difficult under ordinary yellowish artificial light because the various mixtures appear nearly if not exactly the same in color. Under artificial daylight the differences are readily distinguishable. Difficulties arise with other metals and alloys in which color discrimination is of considerable importance. The sunlight units are usually satisfactory in these cases. Lacquering is often more satisfactorily done under light of daylight quality.

Ore Refineries.—Color plays an important part in the selection and judgment of ore concentrates, and as a consequence this field has been invaded by artificial daylight units. An ore with a bluish-gray tint appears gray under ordinary yellowish artificial light, and a yellowish ore cannot be distinguished easily if at all from another specimen of a gray or yellowish tint. In the former case the specimen is found to be a blue-gray under artificial daylight, and in the latter case the yellows are easily distinguished. An actual case encountered in practice is the presence of yellowish pyrites in lead or zinc concentrates.

Chemical Analysis.—In such work color discrimination is often of importance. The requirements vary so that either the north-sky-light or sunlight units are satisfactory, depending upon the case. In titrating, the north-sky-light units appear to be more satisfactory. The concentration of a weak solution is sometimes estimated by the color of a considerable depth of the solution. An example of this is the yellowish color of chlorine solutions. When of low concentration this yellowish tint can be distinguished with difficulty if at all under ordinary artificial light.

Laundries.—Dirt, spots due to scorching and other blemishes which are generally yellowish in color are more readily distinguishable under artificial daylight than under ordinary artificial light. "Bluing," which is used to neutralize the yellowish tint of white fabrics, can be applied with more certainty under artificial daylight. The approximate daylight units are usually satisfactory in laundries.

Paper Mills.—In the manufacture of paper the problems of distinguishing delicate tints of approximately white papers and of tinting pulp to match certain standards are commonly met. Artificial daylight has met these problems satisfactorily.

Flour Mills.—In a similar manner various types of artificial daylight units are in use for distinguishing the delicate tints of flour.

Sugar Refineries.—Accurate color-matching units are in use for distinguishing the colors of sugars.

Jewels.—Color is an important factor in the value of jewels. The illuminant influences the colors of jewels quite markedly. Diamonds present special difficulties because commercial diamonds vary in color from blue-white to a decidedly yellowish tint. The former lose their bluish tinge and the latter appear less yellow under ordinary artificial light. The more accurate artificial daylight illuminants are desired for purposes of examination of jewels. Pearls and opals often lose some of their beauty under ordinary artificial light owing to the suppression of the blues and violets and to the shifting of the pinks toward red.

Dentistry.—Matching artificial teeth, cements, porcelain inlays, etc., presents difficulties both in factories and in the dental offices. North-sky-light units are in use for the more exacting work, but the sunlight units are found quite satisfactory for much of the work.

Medicine and Surgery.—Artificial daylight has found its way into hospitals and private offices for use in surgical operations and in diagnosis. Various types of units are in use, depending upon the requirements and upon desires of the users. It is difficult to distinguish the various tints of healthy and diseased tissue, and manifestations of skin diseases are sometimes unrevealed under yellowish artificial light.

The foregoing are only a few of the activities in which artificial daylight units have been installed. The different activities are far more numerous and include other classes of stores, show windows, barber shops, hair-dressing establishments, tailor shops, art galleries, etc. Many unique and unexpected applications have been met in practice, and it appears that the field for such lighting units will be greatly extended. Instances have been found in which users have declared that a light of a daylight quality is easier on the eyes for close work than yellowish light. In the absence of a decisive method of testing this point such statements must be given some attention, especially because they present a reasonable possibility when viewed from the standpoint of evolution and adaptation.

One of the most prominent features is the miscibility of artificial daylight with natural daylight. There appears to be an unsatisfactory condition of lighting when natural daylight must be reinforced with yellowish artificial light. As a result of this many installations of artificial daylight have been made in offices, drafting rooms, etc., where the discrimination of the colors of objects is of little or no importance. In all of these applications esthetic taste is a secondary consideration. Where this is a primary factor the scientific aspect, which this article bears upon, is subordinated. There are ways of using artificial daylight and yet satisfying the esthetic taste, but these cannot be discussed in this article.

SPEEDING UP MANUFACTURING BY IMPROVING ILLUMINATION

Results of tests which have been conducted by engineers of the Commonwealth Edison Company to determine quantitatively the effect upon industrial output of increased and improved illumination were outlined in a paper entitled "Production Lighting Intensities," read before the recent convention of the Illuminating Engineering Society by William A. Durgin. The ninety-three plants thus far surveyed total 17,400 employees, cover a floor area of 96 acres and aggregate a lighting load of 1420 kw. While the survey was largely inspectional, listing the number, style and condition of units used, and applying arbitrary utilization factors to obtain the intensities produced, very considerable confidence is felt in the average results, which show a mean of 1½ ft.-candles now in use with variations from 0.01 ft.-candle to 10 ft.-candles and an average consumption of 0.33 watt per square foot and 80 watts per employee. For these same plants the I. E. S. code would provide an average intensity of 5.5 ft.-candles, 3.66 times the present level. The intensity would vary from 2 to 12 foot-candles; the average watts per square foot would be 1, and the watts per employee 240, or three times the present consumption.

In order best to explain the method of making tests and to indicate results thus far obtained the original paper is quoted as follows:

"Such tests are much more difficult than at first thought appears. Our revised program contemplates a four months' run—the first month with the equipment as it exists, the second with proper equipment to give 50 per cent higher intensity than the maximum recommended by our code, the third month at the lower code level for ordinary practice or what is generally considered good present practice, and the fourth again at the higher or productive intensity level. For such a test the plant production records must be accurately kept and a fair percentage of the work must be done in hours of darkness. The chief difficulties are two—(1) to find plants with adequate production record systems, and (2) to induce the plant to return to the lower level of intensity at the end of the second month of the run after the advantage of good lighting has been once experienced.

''One test was run in a machine shop producing soft metal bearings, operations ranging from rough to fine. Only two months of the program were run, but in the month at which the intensity was maintained at 12 ft.-candles production in the several operations was increased from 8 to 27 per cent over that of the previous month, when an intensity of 4 ft.-candles was used. In this instance general lighting with deep-bowl reflector equipment was employed for both intensities and every precaution taken to eliminate commercial bias. The superintendent was so impressed with the value of the higher intensity that he had it extended to the other floors of the building.

In the second accurate test the program could not be followed carefully, the comparison being between bare lamps on drop cords and a properly designed reflecto-cap installation. The new equipment gave about twenty-five times the intensity previously used and showed an increased production of from 30 to 100 per cent in the several operations of a large pulley machine shop. Again the superintendent was enthusiastic.

In the other nine plants it has been impracticable to run tests, but in every case the superintendents and owners are fully convinced of the truth of our statement that the average effect will prove at least a 15 per cent increase in production at an increased cost of not more than 5 per cent of the payroll.

''To get results quickly it is impracticable to secure the absolutely best equipment for each installation. In our own company, therefore, we have adopted definite specifications employing three general types of equipment:

"1. Gas-filled lamps with steel reflectors and eye shields in the 200, 300 and 500-watt sizes.

"2. Gas-filled lamps with deep-bowl reflectors for extreme mounting heights.

"3. Vacuum lamps and deep-bowl reflectors for certain drop-cord applications.

"Our effort is concentrated upon the first class. In using these it is of first importance that the shields be sealed in place and only removable by the foreman or other authorized employee, for the ordinary workman believes but one part of the code. He wants more light, but he knows nothing of the effect of excessive brightness contrasts and if left to himself will remove the shield as a useless obstruction. Recent installations of all three units are equipped with such sealing wires.

"Of the three we are especially emphasizing the 300-watt unit. It has an efficiency of some 84 per cent, a maximum brightness of 7500 millilamberts on the interior of the diffuser ring, and is well adapted to installation on present outlets. In many plants it is hardly possible to rewire now; in others it is very questionable whether such rewiring is warranted. But with this unit giving its maximum candlepower at the 50 deg. angle it is entirely practicable to produce reasonably uniform lighting with spacings of 14 ft. to 16 ft. (4.2 m. to 4.8 m.) at mounting heights from 10 ft. to 16 ft. (3 m. to 4.8 m.).

"Where 12 ft. to 18 ft. (3.6 m. to 5.4 m.) mounting heights above the floor are possible, spacings as high as 20 ft. (6 m.) can be used with the 500-watt unit, with an acceptable result in uniformity of intensity and diffusion of light. This unit has an efficiency of 77 per cent and a maximum brightness of 2300 millilamberts, the view of the interior of the ring being largely cut off by the blades. Again it may be emphasized that our object is not ideal illuminating engineering; it is practical application with as little change in wiring as possible. In these installations we are to secure productive intensity quickly at minimum expense with equipment which will continue to supply that intensity during its life.

"Of primary importance, therefore, is the ease with which such equipment can be maintained. With drop-cord units, bare or shaded by the tin dirt collectors, even the extremely serious defects in intensity produced and brightness contrasts permitted are hardly as important as the extreme inefficiency which results after the machine has spattered them with oil or the workman has manipulated them with dirty hands. We have tested several such units taken directly from factories and have found the utilization efficiency less than 25 per cent."

EFFECT OF LIGHTING ON ACCIDENTS, SPOILAGE AND PRODUCTION

To be sure, the application of electric power to America's industries has made it possible to increase production in many plants; however, the effect of lighting, though perhaps less apparent, is none the less important.

With this thought in mind, the *Electrical World* canvassed a large number of the leading manufacturing and industrial plants in the United States in order to show as concretely as possible the value of good lighting. In all of the plants electric light in one form or another is employed. In a majority of the reports it was stated that new lighting systems had recently been installed, and in not a few cases it was stated that different forms of lighting were continually being tried out in order to get the best artificial lighting arrangement possible. It was particularly noticeable that manufacturers are changing from the inefficient carbon lamp to the tungsten lamp, and particularly to the gas-filled unit. Another change which is prevalent is from arc lamps to tungsten incandescent lamps.

The reports showed a disposition to depart from the use of bare lamps, and in quite a few cases it was reported that lamp candlepower was considerably increased. Instances were also noticed of changes from clusters to single lamps.

Better Spirit of Labor with Good Lighting. Manufacturers were asked in cases where changes in lighting had been made whether there was any noticeable effect on the workmen. In most cases no effect was noticed, but this cannot be taken at its face value. Manufacturers generally are sold on the benefits of good lighting and do not take the trouble to investigate the effects for the sellers. In a large number of instances, however, it was noticed that the workmen showed a better spirit and went at their work in a happier frame of mind when the lighting conditions were improved. The efficiency of employees was also better.

One factory making molded insulation on changing from carbon and arc lamps to tungsten and gas-filled lamps with reflectors noticed an increased output on the benches of 75 per cent. A sugar mill changing from carbon to tungsten lamps with reflectors noticed an increase in output of the night shift of 20 per cent, besides eliminating bad batches of sugar.

The great value of lighting to-day is its effect upon labor and therefore upon output both in quality and quantity. In this connection a superintendent of one of the largest explosives plants in the United States said:

"Since in our munition plants we are operating night and day, the question of lighting is an important one. In fact, one must have good lighting in order to keep up our production, avoid accidents and produce better esprit de corps."

There are any number of shops where every minute of occupied labor counts in the production. Consequently the element of man-hours assumes an importance not previously known. An accident, with the resulting loss in time by one or more operators injured, is no longer a dollars and cents proposition but rather one of output. Besides, when an accident occurs it is not only the injured who lose time. The psychological effect on the other workers is such that considerable time is lost and a large part of the day's output of those near the accident is lost through spoilage due to nervousness.

Accidents Decreased. It is apparent that anything tending to decrease industrial accidents has a very real value in increasing the production of a plant. That lighting is in the category of an accident preventer is evident from the replies received.

In one plant a new system of lighting so reduced the number of accidents that the company decided to carry its own insurance. A company engaged in the manufacture of zinc concentrates states:

"We have a remarkably small number of accidents, although more than 1000 men are employed. We attribute part of this to adequate lighting, which is in line with the safety first idea."

A leather manufacturer states: "Improved lighting naturally lessens accidents, particularly around elevators and machinery."

A statement from a plant milling low-grade copper is to the effect that "Light exposes danger. Good lighting is insurance against accidents."

Another copper-concentrate plant says: "We believe that better lighting has done its share in reducing our accidents more than 50 per cent."

Not only does better lighting prevent much of the loss of time resulting from accidents but also that resulting from poor health. With good and adequate lighting it is possible to keep the plant cleaner and more sanitary and to reduce eye strain and headache.

That good lighting helps to build up esprit de corps seems undebatable. The men are happier, take more pride in their work and in the appearance of the shop, and generally do better all around when the light is good. It also undoubtedly has its effect on keeping labor turnover from going higher. It is very doubtful if a few cents more wages will tempt skilled men from a plant that is well lighted to one that is poorly lighted.

Production Increased and Spoilage Reduced. There seemed to be a unanimity of opinion regarding the part good light plays in increased production, although there were no figures to substantiate the opinion. However, it had been noticed in many plants that the men start work more promptly in the mornings and work up nearer to quitting time. Less loafing has been noticed in plants that have installed better artificial lighting. As one manufacturer put it, "A poorly lighted mill makes the men sleepy and production suffers." One or two others instanced men going to sleep in dark places where the lighting was poor. In each case, however, this practice was eliminated by the installation of a better lighting system.

Spoilage and repairs are elements to be considered in any production program. The reduction of the former has a twofold significance to-day. It reduces production and also reduces the available amount of raw materials. Anything, therefore, which tends to lessen spoilage increases production and economy.

Manufacturers seem unanimous in expressing their convictions that better artificial lighting means less spoilage. A statement from a copper mill is to the effect that good lighting "is a necessity in cutting out excessive waste of copper through the tails." A manufacturer of glazed kid states that better lighting has "lessened to a considerable amount the number of mistakes."

Another angle is brought out by the general manager of a rubber plant who states that good lighting "helps the inspection department to throw out more bad pieces which otherwise would get shipped to customers to send back." The other side of this situation is, of course, the lessening of the burden on transportation systems by just so much.

A manufacturer of motors points out that good lighting reduces spoilage very much where the workman is working to micrometer dimensions.

A sugar-mill operator states that "good lighting reduces spoilage to a minimum in our case. It used to be quite a frequent occurrence to add cane juice to the ocean brine because of the overfilling and consequent overflowing of juice tanks, a thing that has been reduced through better lighting to practically nothing. The splashing and spilling of the massecuite about the centrifugal driers has been reduced to a minimum, thus making for less spoilage and a cleaner plant. While exact figures of the saving thus brought about cannot be given, it is safe to say that the saving pays for the whole lighting system in one season. The saving in lubricants due to the reduction of spillage amounts to 25 per cent."

A tire manufacturer states that, unless lighting for inspection is of the best, tires that should be rejected for defects are passed up.

In a number of cases the value of good lighting in making repairs was mentioned. Mention was also made of the fact that good lighting made it possible to catch irregularities in a machine operation sooner than would otherwise be the case.

There is a unanimity of opinion therefore among manufacturers on the value of good artificial lighting. The results of better lighting can be seen in increased output, fewer accidents, reduced spoilage and steadier labor.

LIGHTING ECONOMIES

While only about 2½ per cent of the total coal output of the United States (700,000,000 tons) is consumed in the production of artificial light, any part of this that is saved through lighting economies will assist in the conservation of coal. In view of this fact the committee on war service of the Illuminating Engineering Society,[1] at the request of the Fuel Administration through the National Committee on Gas and Electric Service, has compiled some very valuable suggestions on "War-Time Lighting Economies" in the form of a bulletin. Limiting the use of artificial light to the minimum necessary number of hours per day and promoting the most efficient use of artificial light during those hours are the general methods proposed. In various places it is suggested that local lighting companies be consulted.

Discussing the problem more in detail, the I. E. S. committee on war service points out that unnecessary lighting can be eliminated by making the maximum use of daylight and by avoiding useless lighting. Dirty glassware and fixtures, dark ceilings and walls and inefficient lighting equipment are also productive of waste. Excessive or extravagant lighting must be curtailed.

Fallacies to Be Avoided. There are certain fallacies which must be guarded against in effecting lighting economies and the committee refers to these saying:

Removing reflectors or shades from lamps in order to "get more light" defeats the object. The raw light from glaring bare lamps is less effective than a smaller quantity of reasonably diffused light not exposed to the eye.

Attempting to economize by reducing the number of lamps or by using smaller lamps indiscriminately is unwise. In nearly every case ample illumination is essential to useful accomplishment. The most successful conservation is elimination of waste of light, not reduction of use of light.

In war time human energy and financial resources are to be conserved as well as fuel. Except in the greatest emergency it is unwise to save a little coal at the expense of waste of labor or impair-

[1] Underlying the accepted principles of illumination are requirements for safety, conservation of vision, esthetics, comfort, convenience and economy. The Illuminating Engineering Society is committed to the preservation of these principles and to their application in lighting practice in the public interest. A number of recommendations here presented, particularly those advocating decreased use of light, are calculated to save fuel rather than to bring about most desirable illumination conditions. These are to be regarded solely as a war measure, justifiable in the present emergency, but otherwise not to be approved.

ment of health or menace to the safety of the public. Coal saved through the improvement of lighting equipment is clear gain. To diminish lighting standards in industrial plants, offices and other places where accomplishment depends in part upon vision is to reduce accomplishment or output. In such places, therefore, lighting should not be reduced. On the contrary, an increase in the standard of lighting may be the truest economy and in the best interests of the nation. The liberal use of light for protection of important property, munition factories, public works, etc., is likewise in the public interest, and under present circumstances no attempt should be made to save fuel through the reduction of such lighting.

In an acute local fuel situation an absolute lack of fuel may result in largely curtailed activities. If there is no fuel, industry must cease. Such a critical situation obviously demands radical curtailment of lighting beyond anything which is contemplated for general adoption.

In certain localities in the height of winter there may be a power shortage due to abnormally taxed generating capacity. This likewise may necessitate local lighting restrictions of a more extreme character.

In either event, when such a situation occurs, the problem is a local one, the handling of which must be governed by the particular circumstances.

Maximum Use of Daylight Saves Energy. Referring to the use of daylight, the committee says:

Refracting and diffusing glass in windows helps to spread the light to distant parts of the room.

Carry out operations requiring strong illumination near windows where plenty of daylight is available. Arrange machinery, furniture, etc., so daylight falls on objects to be seen, not on eyes.

Whitened surfaces on building exteriors (especially about courts of high buildings) give more and better daylight in opposite buildings. These may reduce the period of artificial lighting by several hours each day.

Keep windows and skylights clean. Dirty windows may absorb half the daylight.

Dust window screens frequently. Remove them as soon as the insect season is passed. They absorb one-third of the daylight.

Use light-colored ceilings and walls wherever practicable to conserve daylight and artificial light.

Areas at a distance from windows often require artificial light when natural lighting is sufficient near the windows. Connect the switches, if possible, so that the light sources may be turned on in rows parallel with the windows, and the artificial lighting thus used in the several sections only as is necessary. Place the responsibility of operating these switches on designated individuals.

Useless lighting caused by failure to turn off lamps when not needed is also a great cause of waste and can be eliminated to a great extent by inviting the coöperation of the occupants of the place, attendants, etc. This will be discussed later with relation to different installations.

Maintaining the most efficient use of artificial lighting requires in the first place the employment of the most efficient lighting units; second, their proper location; third, the correct application of reflectors and shades; fourth, a high utilization factor, and, fifth, proper maintenance of the equipment and reflecting surfaces.

Efficiency and Location of Lamps Important. With relation to the type of lighting unit to use the committee says:

Large lamps are usually more efficient than small lamps, and where practicable installation should be altered to consist of the fewest lamps from which uniform illumination may be obtained under the conditions of use. Where clusters of lamps are employed under shades replace them by a single larger lamp with suitable reflector.

Do not use electric lamps of the carbon-filament type where the more efficient tungsten-filament lamps can be employed. These substitutions will result in a saving of three-fourths of the fuel used for a given candlepower.

An intelligent choice of lamps makes it possible to reduce the consumption of fuel.

Lamps should be spaced to give uniform lighting and with reference to the work so as to avoid bad shadows. This permits the use of the minimum wattage in the general lighting and makes it possible to remove most drop lamps and local lighting. The latter are objectionable from the conservation point of view because they may be left burning when no necessity exists.

Factors Governing Use of Shades and Reflectors. Regarding the general use of shades and reflectors the report reads:

Modern lamps are so brilliant that they may injure the eyes if used without protective equipment. Shades and globes conceal them from view, soften the light, and where desired redirect a considerable part of the light in the direction needed. Shades and globes never increase the total quantity of light, but an efficient reflector will usually increase the light where it is needed. With such a reflector a smaller lamp may suffice, thus saving coal. The advice of the lighting company should be sought when selecting such equipment.

Flat reflectors allow much of the light to escape to the walls instead of directing it to the work. They also leave the bright light source exposed to view and the glare interferes with the vision, causing a demand for still higher intensities. Use reflectors of the dome or bowl shapes for greatest economy. Except where lamps are mounted in high bay areas use bowl-frosted lamps to reduce glare reflected from the work and to soften the shadows. Be sure that reflectors are deep enough to protect the eye from the glare of the filament.

Do not use indirect or semi-indirect lighting fixtures in conjunction with dark ceilings which absorb a large part of the light.

Light-Colored Walls and Ceilings Save Energy. As a rule, at least one-half, and sometimes practically all, of the light utilized in interiors is received by reflection from walls and ceilings. Good light-tinted paint when fresh rarely reflects more than one-half of the light which falls upon it. The proportion of light reflected from good white lead and oil paint under average conditions diminishes by about 10 per cent a year. The same is true of calcimine and similar coatings. It is apparent therefore that there is an opportunity for improving lighting efficiency through the employment of the best finishes for ceilings and upper walls. Painting white ordinary light-tinted surfaces may increase the light reflection by as much as 50 per cent. Therefore in order to save fuel in lighting wherever it is practicable paint ceilings white, employ light tints for the upper parts of walls, and use paint that is non-porous and easily cleaned. Light-colored surfaces reflect five to ten times as much light as dark surfaces.

Cleaning Too Often Overlooked. Maintenance of lighting fixtures and reflecting surfaces such as walls, ceilings, etc., is so often neglected that particular attention should be directed to it as a means of saving fuel. The report on "War-Time Lighting Economies" reads:

> The loss of artificial light due to dirty glassware and dark or dingy ceilings and side walls ranges from 30 to 50 per cent and may be avoided by renovation at necessary intervals. With indirect or semi-indirect lighting the refinishing of the ceiling and cleaning of the lighting units will frequently increase the intensity 50 to 100 per cent, permitting a reduction in wattage to the next lower size of lamp.

Keep lamps and reflectors free from dust by a regular schedule of cleaning at short intervals.

Suggestions Applying to Industrial Plants. The foregoing suggestions apply to all places and may be considered the fundamental requirements of economical lighting. However, many places have conditions which are peculiar to them so additional factors have to be considered. A few of these that apply to industrial plants are given below:

Industrial Plants.[1]—In almost every plant there is waste in the use of light, the elimination of which can be accomplished without retarding production, impairing the vision or menacing the safety of the employees. So far as possible do all lighting from a general overhead system out of the control of individual workmen. Make some individual in each department responsible for seeing to it that lamps are lighted only in such areas and for such periods as necessary.

STANDARDIZING FACTORY LIGHTING

The considerable increase in night work which has resulted from the war lays particular emphasis on the importance of the artificial lighting of factories. The efforts to standardize suitable lighting for industrial establishments therefore has direct value at the present moment. The I. E. S. code of 1915 was a long step in advance and served as a basis for some important legislation. The experience of the last three years, together with the greater amount and severer requirements of factory lighting, has rendered changes desirable. These were undertaken last year by the I. E. S., and their importance has been emphasized by recent legislation. Changes in the original code have been in considerable degree due to the greater importance now attached to artificial illumination and to a considerable degree have been in the direction of a more complete classification of the work to be done. Another very important change has been to direct more specifically attention to the question of glare, always recognized as a very important factor in successful industrial lighting, but hard to reduce to workable definitions. Indeed, whether it is possible to draft a regulation of a kind practicably enforce-

[1] For information in regard to good factory lighting practice consult the "Code of Lighting Factories, Mills and Other Work Places," Illuminating Engineering Society.

able which will properly cover the subject of glare is a question which does not yet admit of a definite answer.

A longer step forward is made in the strong recommendation of actual measurements of the lighting by a portable photometer. At the present time instruments of this kind, of sufficient accuracy for the purpose and convenient for use, are readily attainable, and there is no reason why legislation as to industrial requirements cannot be worked to a successful result. The four desiderata in industrial lighting suggested by the committee on labor of the Advisory Commission—to wit, conservation of eyesight, safety, increased labor efficiency and better quantity and quality of output—are the obvious things to be borne in mind in codes and statutes. As regards the general conditions of lighting, those which satisfy the last two requirements will also satisfy the first two, with due attention to the lighting of stairways and other areas of that kind.

If the minimum lighting requirements are specified in accordance with the suggestions of the I. E. S. and can be enforced, as is comparatively easy by the use of portable photometers, the whole situation will be effectively cleared up. Heretofore it has been far easier to say whether lighting was or was not good than to pin it down to definite intensities of illumination. Now, with the problem of photometry somewhat simplified, the necessity of training state factory inspectors in the use of instruments and in the fundamental principles of industrial lighting becomes obvious. At present they will have much less difficulty than was the case a very few years ago, since manufacturers are compelled to do much work by artificial light and have come rather generally to realize at last the importance of good illumination as a factor in the general success of the plant. Very little pressure intelligently applied by legislation and its judicious enforcement will work wonders.

New Industrial Lighting Code for Wisconsin. As a result of the appointment of an advisory committee to consider the revision of shop-lighting orders of the Industrial Commission of Wisconsin, a new code was adopted which is much more specific in its provisions and thus more readily understood and enforced. John A. Hoeveler, illuminating engineer of the Commission, says: All technical terms used are defined for the benefit of factory superintendents. More definite specifications provide for adequate light distribution for various classes of work, taking into account daylight as well as artificial illumination, and, for the elimination of objectionable glare, the brightest square inch of visible light source permitted is 75 cp. for overhead lighting and 3 cp. for local lighting.

In order that all interests might be represented and thus given the opportunity of advancing constructive criticism, the advisory committee was made up of ten members, including the superintendent of a lamp-manufacturing factory, the manager of a gas company, the illuminating engineers of a central station, of the city of Milwaukee, of the United States Public Health Service and of the Industrial Commission, the chief electrician of a manufacturing plant, the works manager of a manufacturing plant, an electrical contractor and an oculist.

This advisory committee at its first meeting did little more than decide that the shop-lighting orders of the Industrial Commission, in effect since 1913, should be repealed and an entirely new code adopted, patterned after the Illuminating Engineering Society "Code of Lighting for Factories, Mills and Other Work Places," and the similar codes of Pennsylvania and New Jersey. It was also decided to solicit the assistance of prominent illuminating engineers, both in and outside Wisconsin, and of the committee on lighting legislation of the I. E. S., of which L. B. Marks of New York is chairman.

Concerning the proposed new orders, the committee recommended that "the scope of the new orders be extended to include all portions of industrial plants—(1) roadways and yard thoroughfares; (2) stairways, passageways, aisles, storage spaces; (3) manufacturing spaces; (4) offices.

The parts of the new code, as recommended by the committee, which differ from provisions of other industrial commissions are specified as follows:

The new lighting code differs from the 1913 orders and many existing codes in that it defines terms used; definitely specifies the intensity of illumination to be provided at the work for the different classes of work (the unit of illumination employed is the foot-candle); provision is made for adequate properly applied natural illumination (a feature other states have not adopted as yet); shading of lamps is mandatory under certain conditions which are recognized to be bad when lamps are permitted to be exposed, and thus provision is made to minimize glare; the distribution of light on the work must be reasonably uniform; emergency lighting is required; pilot or night lights and easily accessible control are specified; and maintenance is made mandatory.

The committee states as its opinion "that these orders, if adopted, will make it possible to secure lighting in industrial plants which will reduce avoidable accidents, and if the industrial commission, through its deputies, will urge employers to provide the intensities of ordinary practice, working conditions will be greatly improved to the benefit of both employer and employee."

Although the committee agreed that all new buildings preferably should be constructed so as to make proper provision for adequate natural lighting, it was also agreed that this frequently is impossible (no matter how much glass area may be provided) in congested districts. Therefore a general requirement (Order 2110) was worded so that either natural or artificial light may be used. Obviously it is to the advantage of the owner to utilize as much natural light as possible, and when the code is published [1] by the industrial commission it is proposed to include an appendix which will point out the advantages of natural illumination and briefly discuss economical means of securing it in adequate intensity, properly applied.

Illumination Intensities Specified. The illumination intensities at the work, specified for different classes of service in Order 2112, are the same as recommended by the I. E. S. committee on lighting legislation, with the exception of "(d) Toilets and Washrooms," which was added at the suggestion of Mr. Hoeveler, after having seen it included in a draft of proposed lighting standards for federal industrial establishments formulated by the Bureau of Standards. The committee felt that toilets and washrooms were important enough spaces in the industrial plant to warrant a separate specification, as all too frequently these are the darkest and most unsanitary parts of a factory.

[1] The code is now in print.

Extracts from the Wisconsin Lighting Code.

Order 2112—Artificial Light.

When the natural light is less than twice the minimum permissible intensities of illumination set forth in the following table, artificial light shall be supplied and maintained in accordance with the table. The intensities of recommended practice indicate the desirable illumination for best working conditions.

ILLUMINATION INTENSITY AT THE WORK IN FOOT CANDLES.

	Minimum Permissible Intensity	Ordinary Practice
(a) Roadways and yard thoroughfares	0.02	0.05– 0.25
(b) Storage spaces	0.25	0.5 – 1.0
(c) Stairways, passageways, aisles.............	0.25	0.75– 2.0
(d) Toilets and washrooms	0.5	1.5 – 3.0
(e) Rough manufacturing, such as rough machining, rough assembling, rough bench work, foundry floor work	1.25	2.0 – 4.0
(f) Rough manufacturing involving closer discrimination of detail	2.0	3.0 – 6.0
(g) Fine manufacturing, such as fine lathe work, pattern and tool making, light colored textiles	3.0	4.0 – 8.0
(h) Special cases of fine work, such as watchmaking, engraving, drafting, dark-colored textiles	5.0	10.0 –15.0
(i) Office work, such as accounting, typewriting, etc.	3.0	4.0 – 8.0

Note.—The measurements of illumination are to be made at the work with a properly standardized portable photometer.

This table of lighting intensities required in industrial processes with the exception of part (d) was issued by the Illuminating Engineering Society and subsequently adopted by the United States Bureau of Standards for the National Safety Code and government plants. With the same exception the table has likewise been incorporated in the factory lighting codes or regulations issued by several of the state industrial commissions.

The minimum foot-candles specify the lowest illumination intensity with which the employees can be expected to work with safety when artificial light is used. It is to the advantage of the employer to provide the intensities of the ordinary practice, as this results in less eye strain, greater accuracy of workmanship, increased production for the same labor cost and less spoilage. When part daylight and part artificial illumination is used, it is desirable to use even higher intensities than those of ordinary practice in the table above. (See note accompanying Order 2111 in Code.)

In order that the illumination intensities shall never fall below the minimum during the interval between inspections, installations should be designed to produce initial values at least 25 per cent higher.

Order 2113—Shading of Lamps for Overhead Lighting.

Lamps suspended at elevations above eye level less than one-quarter their distance from any position at which work is performed must be shaded in such a manner that the intensity of the brightest square inch of visible light source shall not exceed 75 cp. (See appendix of Wisconsin Code for method of measuring brightness.)

Exception.—Lamps suspended at greater elevations than 20 ft. above the floor are not subject to this requirement.

Note (a).—Glare from lamps or unduly bright surfaces produces eye strain and increases the accident hazard.

The brightness limit specified in this order is an absolute maximum. Very much lower brightness limits are necessary in many interiors illuminated by overhead lamps, if the illumination is to be satisfactory. In some cases, the maximum brightness should not exceed that of the sky (2 cp. to 3 cp. per square inch.)

Note (b).—Where the principal work is done on polished surfaces, such as polished metal, celluloid, varnished wood, etc., it is desirable (but not mandatory at present) to limit the brightness of the lamps in all downward directions to the amount specified in this order.

Order 2114—Shading of Lamps for Local Lighting.

Lamps for local lighting must be shaded in such manner that the intensity of the brightest square inch presented to view from any position at which work is performed shall not exceed 3 cp.

Note.—In the case of lamps used for local lighting, at or near eye level the limits of permissible brightness are much lower than for lamps used for overhead lighting, because the eyes are more sensitive to strong light received from below, and because such light sources are more constantly in the field of view.

Order 2115—Distribution of Light on the Work.

The reflectors or other accessories, mounting height and spacing employed with lamps shall be such as to secure a reasonably uniform distribution of illumination, avoiding objectionable shadows and sharp contrasts of brightness. If local lighting is used, there shall be employed in addition a moderate intensity of overhead lighting.

Exception.—Where the light from the local lamps falls principally upon surfaces which are white or nearly so and the ceiling and walls of the room are light, there is often a sufficient general illumination received indirectly by reflection to obviate the necessity of additional overhead lighting.

Note.—When local lighting is used as the sole source of illumination of an interior, the field of illumination from each lamp is in contrast to the surrounding darkness, thereby causing eye strain and increasing the accident hazard.

Order 2118—Maintenance.

All lighting equipment and windows shall be periodically cleaned, inspected, kept in order, and when defective replaced, so that the intensities of illumination will never fall below those specified in Order 2112.

The reduction of harmful glare with artificial lighting systems occupied much attention on the part of the committee. As mentioned by Prof. C. E. Clewell in the *Electrical World* some time ago,[1] the Wisconsin advisory committee was of the opinion that the I. E. S. glare specification ("Lamps shall be suitably shaded to minimize glare") is too indefinite, and that a more definite rule would aid the inspectors who are called upon to determine when the limits of glare are exceeded. The glare specification, as embodied in Order 2113 ("Shading of Lamps for Overhead Lighting") and Order 2114 ("Shading of Lamps for Local Lighting"), is the outcome of correspondence with the I. E. S. committee on lighting legislation and a sub-committee which was appointed to investigate this matter and of which Ward Harrison was chairman.

The committee fully realized that the glare rule adopted may require revision after being tried out, but that is the reason the State of Wisconsin has abandoned making safety and sanitation laws by statute and instead has created an industrial commission and given it full powers to issue orders which have the legal force of statutes on these subjects. The state government realized that advances in industry bring about change in conditions of employment, and that an elastic method of dealing with such changes would be the only successful one. The I. E. S. continued the above mentioned sub-committee to coöperate with the Industrial Commission, and it is expected that this coöperation will result in gaining more information on this important problem. Although the advisory committee knew that there was not sufficient knowledge to state definitely the maximum allowable brightness permissible, it was convinced that the maximum set was not unreasonable.

Since opaque metal or mirror reflectors are chiefly used in the industries of Wisconsin, this requirement will insure good eye protection because of the fact that for locations coming within the scope of the rule reflectors which screen off all light within approximately 14 deg. below the horizontal of necessity will be used.

[1] "Changing Aspects of Factory Lighting Legislation," Vol. 71, No. 13, p. 666.

When glass reflectors are used they must be dense enough to reduce the brightness to less than 75 cp. per square inch. Light sources of lower brightness than 75 cp. per square inch, as, for instance, mercury-vapor lamps with a brightness of but 14.9 cp. per square inch, may be used exposed; but, as explained in the accompanying note, conditions of individual installations may require the shading of light sources of even such low brightness.

As regards the distribution of light on the work, the advisory committee considered the wording "a good distribution of light on the work" of the I. E. S. code too indefinite, and, as mentioned by Professor Clewell in the article previously referred to, several attempts were made to make the rule more definite. Finally the matter was settled by wording the rule as in Order 2115 ("Distribution of Light on the Work"). The term "reasonably uniform distribution," it was felt, would give the inspectors a better idea of what is considered satisfactory light distribution. Local lighting only is not permitted, except where the light from the lamps falls principally upon light surfaces and where the ceilings and walls are light under which condition there is often sufficient general illumination.

The question of emergency lighting caused much difference of opinion among the committee members. All were agreed that some emergency lighting is necessary, but that the necessity varies much with the different industries, that large plants need it more than small plants, and that the character of emergency lighting which may be secured at reasonable cost varies considerably in different localities. A general rule (Order 2116) was agreed to, but it was considered essential that explanatory notes be included in an appendix to indicate what the Industrial Commission would consider satisfactory compliance with the order.

Maintaining the Equipment. When all is said and done regarding the proper requirements of a lighting system, either natural or artificial, and the factory is properly equipped, of what use is the lighting if it is not maintained? To meet this objection, Order 2118 ("Maintenance") was included in the code. The committee realizes that this provision can be enforced much less rigidly than the others, because the Industrial Commission has too few inspectors to make it possible to visit all the factories at frequent intervals, as would be necessary if the maintenance of the lighting were to be checked up. In fact, an inspector at present can hardly cover his territory in a period of a year.[1]

However, if when the inspector visits a plant, he finds the lighting facilities poorly maintained, he will be clothed with the authority to order a general clean-up and replacement of defective equipment. It is calculated that this will in time help matters, especially in view of the fact that the inspectors do their work in a coöperative way and spend much time educating the plant superintendents and foremen in safety, sanitation, lighting, ventilation, welfare and supervision of male, female and child labor and in arbitrating disputes between employer and employee.

The various orders were read and discussed at a public hearing in Milwaukee, and practically no objections were raised. On the other hand, some favorable comments were expressed. On May 20 the Industrial Commission adopted the code, which took effect on July 1, 1918, for new construction and will be effective on July 1, 1920, for additions to existing lighting systems. Replacements of existing systems not in accordance with the code must be prosecuted as rapidly as circumstances permit. In the latter matter the Industrial Commission will exercise its best judgment as to how rigidly to enforce the provision. When these orders are published in bulletin form, which is being done now, it is proposed to include an appendix which will discuss each order in detail and suggest how it may be complied with. The purpose of this appendix will be to assist architects, electrical contractors, shop superintendents and electricians who design lighting installations to interpret the code properly.

[1] The Wisconsin inspectors do their work in an intensive manner. Each factory inspected is given careful study. Meetings of the foremen are called, at which the unsafe practices of the plant are discussed and remedies suggested. The foremen are made to realize that it is their duty to instruct their men how to perform their work safely, to see that machines are guarded, that the shop is sanitary and that the many other requirements of the commission are carried out; that these requirements have been drafted by committees of practical shopmen and experts in various lines, only upon due consideration, and that as a result they represent what is considered a minimum to make the conditions of employment better. Consequently fewer factories are visited each year than if the work were confined merely to looking for violations of the commission's orders and issuing an order for the correction of the violation.

THE EFFECTIVE APPLICATION OF PROTECTIVE LIGHTING

Edmund Leigh, chief of plant protection, Military Intelligence Bureau, has stated that of the important means of protection against fires, explosions and sabotage in our industrial establishments, utilities, storage and forwarding systems, the value of lighting and its effective application are least appreciated and understood. An inspection of numerous plants and a consideration of current recommendations in this field of illumination confirm Mr. Leigh's statement and suggest the desirability of emphasizing the points covered in the following notes by H. H. Magdsick.[1]

A protective lighting system to be effective must be comprehensive. The chance of trouble from within a plant is no less than that from without. Therefore, in the majority of installations provision should be made to light not only the boundaries and approaches, but every part of the yards and all interior spaces, so that no one can approach the plant from the outside or attempt to work destruction anywhere within its limits without being easily observed by armed guards or loyal employees. Occasionally the guards may be so stationed that, while themselves concealed in a shadow or dark area, sufficient surfaces about them will be lighted so that any one passing where no light falls directly upon him will nevertheless always be between a guard and a well-lighted surface and will therefore be distinctly outlined in shadow. More often the safe and practical way is to light every part of the plant.

The intensity of illumination which is provided must be adequate to meet conditions of visibility which are short of the ideal. The amount of light required in a clear atmosphere must be considerably increased to be effective when haze or smoke is present. A higher intensity is necessary when street lamps, brightly lighted windows or other sources are in the field of vision than when the background is always black. If the buildings are dark, more light is required than when their surfaces have a high reflection factor. An intensity entirely too low to reveal a menace quickly is one of the most common deficiencies

[1] Engineering Department National Lamp Works of General Electric Company.

in yard and boundary lighting. By providing illumination generously the drain on man power for guarding purposes is greatly reduced.

Ineffective Distribution of Light a Fault of Many Installations. Much of the expenditure for protective lighting is wasted because the light is ineffectively distributed and directed. In general, illumination should be obtained at every point from more than one unit and from more than one direction. Bad shadows will thus be obviated and the failure of individual lamps will not leave large areas unprotected. Glare often nullifies the value of lighting. Particularly is this true where one encounters exposed sources or the direct beams from projectors at a low mounting height. To facilitate vision, glare should be minimized so far as possible by using accessories which shield the eye from the light source or by mounting units high above the usual line of vision. Diffusing globes reduce the contrast in brightness between the source and its background and thereby lessen the glare somewhat in interiors or when placed near light walls of buildings. Their glare-reducing value is slight, however, when they are viewed against a black background such as usually obtains out of doors, for the ratio of brightness is not greatly reduced.

Several types of equipment employed extensively for protective lighting are listed in Fig. 77. In selecting any of the equipments for out-door service one should be careful to secure well constructed, weatherproof fixtures. In a few cases the deep-bowl type of enameled steel reflector is of value in giving the maximum protection against interference with vision. Usually the dome type gives ample protection and is to be preferred because of the wider spread of light and greater output. In order that glare may be reduced with prismatic refractor fixtures, they should be ordered with the socket so placed that the maximum candlepower is delivered at angles from 15 deg. to 20 deg. below the horizontal. The intensity at angles near the horizontal will then be greatly reduced.

It may be noted that floodlighting units are available for a wide range of beam spread, permitting a selection to meet varied requirements. With the specially concentrated filaments of the floodlighting lamps, accurate control of the light is possible, so that beams of small as well as large angular divergence can be obtained. The projectors shown at *c* and *d* in Fig. 77 are designed for use with such lamps. Equipments illustrated in *a* and *b*, which employ the regular multiple lamps pendent in the reflector, do not permit confining the beam to so narrow an angle because of the greater area of the light source.

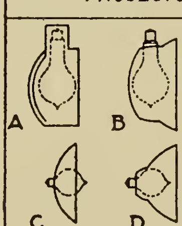
The percentage of light directed into the beam varies greatly. Two characteristics determine the efficiency of projectors—the reflection factor of the surface and the depth of the reflector, *i.e.*, the percentage of the light from the lamp intercepted. Mirrored glass is becoming the standard reflecting surface, for it has a high efficiency which can be permanently maintained. The reflection factor is from one-fourth to one-third greater than that of the polished aluminum and nickel surfaces commonly employed in metal-reflector units.

Searchlamp and Floodlamp Requirements Are Different. A large number of floodlighting projectors are still sold with shallow parabolic reflectors, directing only 18 to 25 per cent of the light into the beam. This condition exists because many designers have followed searchlighting practice without differentiating between floodlight and searchlight requirements. In designing or using searchlamps one is concerned only with securing the highest possible intensity at the center of the beam. It is desirable to suppress the light radiating at wide angles from the center of the beam so that the observer watching the distant illuminated area from his station near the searchlight may suffer the least interference with vision. The spread of the beam is determined by the angle which the light source subtends at the reflector; hence best results are obtained by using a paraboloid of relatively long focus, and therefore shallow, for a given diameter. In floodlighting one is concerned with delivering as large a percentage of the light from a lamp as possible to an area at a relatively shorter distance and viewing this area at closer range. Therefore a greater divergence of beam is usually required and the scattered light does not become detrimental, but on the contrary is frequently useful.

For most floodlighting it is possible to employ the deeper reflectors with contours formed and combined in such a manner as to redirect a large proportion of the light from the lamp. Such deeper projectors are illustrated, for the ordinary multiple and floodlighting lamps respectively, in *b* and *d* of Fig. 77.

The common practice of employing the shallow paraboloid with the ordinary multiple lamps of large light source, as in *a*, is obviously very wasteful, when with an intelligent design it is possible to increase the output in the beam by from 50 to 100 per cent.

With the possible exception of the opal-globe equipments, all

EQUIPMENT FOR PROTECTIVE LIGHTING		
ACCESSORY	LAMP	PER CENT OF LIGHT FROM LAMP DELIVERED BELOW HORIZONTAL
 DOME TYPE ENAMELED STEEL REFLECTOR	Mazda B and Mazda C; Multiple of all sizes to 1000 watts	75 – 80
 ANGLE TYPE ENAMELED STEEL REFLECTOR	Mazda B and Mazda C; Multiple of all sizes to 1000 watts	60 – 65
 PRISMATIC REFRACTOR FIXTURE	Mazda C; Multiple of 75 to 1000 watts Mazda C series of 60 to 1000 candlepower	60 – 70
 OPAL GLOBE UNIT	Mazda B and Mazda C; Multiple of all sizes to 1000 watts Mazda C series of 60 to 1000 candlepower	35 – 50
FLOOD-LIGHTING PROJECTOR		PER CENT OF LIGHT FROM LAMP DELIVERED IN BEAM *
 BEAM-SPREAD 8°-15°	Mazda C flood-lighting 200 and 400 watts	20 – 40
BEAM-SPREAD 12°-24°	Mazda C flood-lighting 200 and 400 watts	30 – 50
BEAM-SPREAD 40°-50°	Mazda C flood-lighting 400 watts	40 – 45
BEAM SPREAD 15°-50°	Mazda C; Multiple 300 to 1000 watts	20 – 40
Incandescent Searchlight	Highly concentrated filament Mazda C	1,000,000 to 5,000,000 Beam candlepower

* In addition, some light is emitted at wider angles directly from the lamp itself or scattered from the reflector. This may sometimes also be useful

FIG. 77—TYPES OF EQUIPMENT EXTENSIVELY USED FOR PROTECTIVE LIGHTING

types of units listed in Fig. 77 can be used advantageously under many conditions, although each is better adapted than the others for certain applications. Many people have come to regard floodlighting units as the one type of equipment suited to protective service. The fact that they are relatively new and that they opened up new possibilities in lighting seems to have led to an exaggerated estimate of their performance and value. From Fig. 77, it is apparent that a projector mounted at a remote point actually delivers less light to a given area than would be secured from ordinary types of equipment in this area. However, it does not follow that the latter are always to be preferred; due weight must be given to other factors as well. The relative advantages of lighting with floodlamps and with distributed systems of the other types of lighting units may, in a general way, be summarized as follows:

Floodlighting Versus Distributed Systems. Dome and angle enameled-steel reflectors and prismatic refractor fixtures must be distributed at moderate spacings on supports relatively near the area to be illuminated. This distribution of units results in the marked advantage that at a given point light is usually received from several lamps and from different angles, thus obviating dangerous shadows and minimizing the effect of the outage of an individual lamp. Such equipments are efficient and their cost is relatively low. To mount the fixtures, however, it is sometimes necessary to erect additional poles or other supports and extend the lighting circuits.

With projectors a different practice may be adopted, for the control of light in narrow beams gives the advantage of mounting equipment at a few favorable points, often on existing circuits, and delivering the light to areas at a distance. Thus the cost of additional poles and wiring is frequently saved, but this advantage is usually more than offset by the relatively high cost of the projectors themselves and the somewhat lower utilization of light flux. This is particularly likely to be the case if a sufficient number of lamps are installed at different points to eliminate long, sharp shadows. Furthermore, it is difficult to arrange floodlamps so that objectionable glare will not at times be experienced, nullifying much of the value of the light. Nevertheless, when they can be carefully located and mounted high on pole brackets, platforms or roofs of buildings excellent lighting may be secured. The outage of individual projectors is likely to be far more serious than that of a unit of the other types in a more distributed system; also, where a number of projectors are mounted on a platform there is danger that all of the lighting for a large area may be put out at once. Floodlamps are particularly valuable for providing light quickly in an emergency, for supplementing the ordinary systems and temporarily reinforcing the intensity at certain points. They fill a great need in illuminating locations in or near which no wiring can be carried or no supports placed for the older types of lighting fixtures.

At one plant located directly on a city street angle enameled-steel reflectors with 300-watt lamps are attached to the building. For mounting heights of 25 ft. (7.6 m.) or more, and spacings not more than twice the height, this system is a desirable one, although sometimes it may be improved by tilting the units in slightly to minimize the glare. Where the building surface is light and for lower mounting heights, dome reflectors are preferable, spaced not more than three times their height.

Dome reflector fixtures with 200-watt units mounted 20 ft. (6 m.) above the pavement reinforce the street lighting. On the building face are two angle units which help to illuminate the space in front of the building and assist the watchman in identifying persons approaching the plant. A similar installation of dome reflectors is carried on the pole line along the fence bounding another side of this property. In either case the spacing should not be more than four times the height of the units. Higher mounting is advantageous; a height lower than 20 ft. (6 m.) is likely to be objectionable except for lamps as small as 100 watts. When cars are left standing adjacent to a building, units should be added along the face to prevent deep shadows.

Dome reflectors like those just referred to but equipped with 100-watt to 500-watt-lamps are also particularly suitable for protecting the boundaries of large inclosures. Prismatic refractor fixtures are also desirable for this service. They illuminate a wider zone, and the spacing may be increased to eight times the mounting height. The largest sizes of lamps are therefore often employed with such equipment.

When projectors are used to protect an inclosure one edge of the beam is directed along the fence, allowing the patrolman to walk inside in comparative darkness. The projectors are placed 12 ft. (3.6 m.) above the ground, one every 200 ft. (60.9 m.), and the beams pointed in one direction around the inclosure. So long as the patrolman is able to walk in the direction in which the projectors are pointing, conditions for vision are excellent. If, however, it becomes necessary for him to turn around and face the units, the glare he experiences will make the lighting ineffective. Therefore it is better to mount the projectors high on pole brackets or elevated platforms. When they can be placed 30 ft. to 60 ft. (9.1 m. to 18.2 m.) above the ground the interference from glare is very greatly minimized.

An error which is commonly made is to space projectors at too great a distance. The range is rapidly reduced as the atmosphere becomes hazy; also the outage of a unit becomes more serious as the spacing is increased. Where mounted low, as in the illustrations, the maximum spacing recommended is about 250 ft. (76.2 m.), and this value should be reduced for the widest-angle units. Under favorable conditions, where the projectors are mounted high and the largest lamps are employed, the spacing may be increased.

For lighting the yard proper, various types of accessories may be utilized. Angle reflectors attached to the buildings may be employed to light adjacent spaces, if mounted 25 ft. (7.6 m.) or more above the ground. Dome reflectors and prismatic refractors on brackets attached to buildings, poles distributed throughout the yard, etc., meet the requirements best in the majority of properties. When floodlighting projectors can be placed sufficiently high and at various points so as to deliver light from several angles, good results may be obtained by their use. However, there is always danger that glare will not be sufficiently minimized and that piles of material or other obstructions in the yard will cast long, dark shadows, creating an accident hazard and affording a place of concealment. With a greater number of smaller wattage lamps in dome reflectors distributed about the yard, these dark shadows are eliminated and the guard is able to detect the intruder. The conditions could also have been improved if projectors had been directed at this point from both sides.

Narrow-angle floodlamps on building roofs or elevated platforms are valuable in lighting long approaches to a plant or sweeping open fields or waterfronts about a property. Incandescent-lamp searchlights greatly increase the range. With one of these the attendant will be able to "pick up" a man at distances as great as one-half mile (8 km.). Occasionally it is of value to have a beam which is wider horizontally, while any greater spread vertically would be wasted. Under these conditions a piece of factory-ribbed glass may be substituted for the clear-glass cover, resulting in a band of light of wide horizontal divergence but little vertical scattering. The intensity at the middle of the beam and the range of the unit are of course considerably reduced.

STANDARDIZATION OF LIGHTING CAN EXPEDITE SHIPBUILDING

The admirable efforts which have been expended toward expediting the building of ships should not be relaxed just because peace has been declared. Great opportunities are opened along this line by the standardization of the electrical equipment for the temporary lighting of vessels under construction, particularly where the same or similar types of ships are being built. This work may be divided into three subdivisions, says William G. Hexamer, who was formerly electrical engineer of the Chester Shipbuilding Co.:

1. The permanent wiring on the permanent ways, which can be so constructed as to cover almost any electrical demand.

2. The lighting of vessels which have not as yet reached the stage of construction where a regular standardized temporary system can be installed.

3. The regular temporary wiring system, which must be so constructed that it can be repeatedly used from one vessel to another without much more than minor changes.

Considering these subjects consecutively, permanent ways can be wired from a three-wire 110-220 volt system. At the Chester (Pa.) Shipbuilding Company's plant it has been found advisable to run three No. 2 mains from a junction box at the head of the ways through 1¼-in. (3.16-cm.) conduit to a point where the water line makes it impracticable to continue. This covers practically two-thirds of the ways. At 20-ft. (6-m.) intervals in this line are installed YX condulets each containing a three to two-wire double-branch cutout fitted for 30-amp. plug fuses. Two No. 8 wires feed a Q. H. A. condulet on each side of the ways through ¾-in. (1.86-cm.) conduit.

In conjunction with this system there is also installed at the head of the permanent stocks a Burns water-tight box containing a three-wire single-throw 100-amp. knife switch. The box is

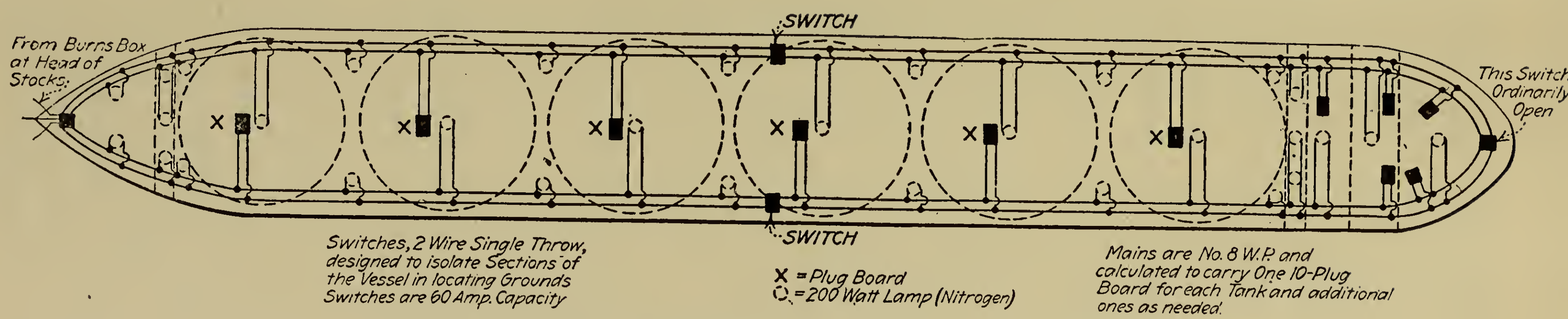


Fig. 78—Lighting Circuits Advisable During Ship Construction

mounted at the approximate height of the new vessel's forecastle and is intended for temporary wiring when the vessel has reached that stage of construction, making its own temporary system necessary. The permanent ways in this installation are approximately 430 ft. (170 m.) long.

Lighting of the hull while it is in the first stage of construction is of minor consideration, as there is usually plenty of daylight before the decking is placed. However, as double bottoms and various tanks reach completion temporary lighting by means of portable lamps is necessary. At this point of construction a specially designed plug board, with provision for ten outlets, is placed at the point of greatest demand in the Chester (Pa.) Shipbuilding Company's plant. The plug board is as nearly foolproof as one can be made, and is fed from a Q. H. A. receptacle by means of an R. Q. plug and the necessary length of two-wire deck cable. These boards are kept in stock, made up, and are a part of the standardized electrical equipment of the yard.

Portable taps made in 50-ft. (15-m.) lengths and equipped with specially designed plugs of very rugged construction are taken from the plug boards previously mentioned. The plugs are designed to be tapped into one of the outlets of the plug board. One end of the "portable" is attached to a weatherproof receptacle equipped with a 60-watt lamp and a locking guard. Carbon lamps are preferable for portable work as their filaments are more rugged, and, in the writer's opinion, riveters are not the gentlest of workmen.

As the writer's experience has been mostly with vessels containing six cylindrical tanks, the lighting of such vessels from the time that the decking is placed until the permanent electrical equipment is in service will be discussed. In the writer's estimation a tank vessel is one of the worst types to light in a proper way temporarily. After considerable experimenting a solution to the problems presented was reached. Upon the deck of the vessel—or, rather, at the edge of the main trunk deck—a set of No. 8 weatherproof mains is installed. The mains are mounted upon heavy porcelain knobs previously attached to a block about 2½ in. by 8 in. by 6 in. (6.35 cm. by 20.32 cm. by 15.25 cm.) and fastened to the edge of the trunk deck by means of a universal girder clamp. The blocks are made in large numbers and are kept in stock as part of the standard temporary equipment.

The mains are stretched on each side of the vessel and are fed from the permanent outlet previously described and installed at the head of the ways. This circuit is then again subdivided into four sections by means of 60-amp. single-throw knife switches. The sections are ordinarily connected but may be isolated to facilitate the finding of grounds. Ordinarily the switch at the stern is, of course, kept open, but it can be closed in case either side of the three-wire system is blown out, thus keeping the loop complete until repairs can be made. While the switches previously mentioned are part of the standard temporary equipment, they are mounted in strongly made wooden boxes of weatherproof construction. The ordinary slate base switch is used with standard cartridge fuses.

From the mains the taps are taken for the plug boards and for a standardized temporary lighting unit, consisting of an X-5423 Benjamin shade, the usual suspension loop, a No. 1388 guard and a 200-watt nitrogen lamp. This unit is also used in the tank vessels. One unit is placed at the top of each cylindrical tank, one in each wing tank, three in the engine room, three in the fuel tanks and five in the forecastle, making thirty units in all. The units are so arranged electrically that the circuit is as nearly balanced as possible. These units are only for general illumination.

For close work the "portables" previously described are relied upon, one plug board being installed in each tank, and as the work progresses in the other portions of the vessel. As the plug boards have provisions for ten outlets and the standard "portable" has a length of 50 ft. (15 m.), quite a working radius is obtained. The plug boards before mentioned are built in the yard and are each equipped with 20-amp. link fuses protected by an iron plate.

In freight vessels the problem is very much simplified as the hull is not subdivided as much as in tankers. While the standardized mains are used the general arrangement is much simpler, a single set of heavy mains installed down the center of the main deck being sufficient. Since fewer lighting units are used only half as many plug boards are required. To locate grounds it is, however, advisable to subdivide the mains as in the tankers and use ground detectors. The mains are of ample size for electrical drilling and reaming.

CHOOSING LIGHTING UNITS FOR INDUSTRIAL PLANTS

Even in times of normal activities manufacturers have found that scientific illumination increased the efficiency of their plants by making possible (1) greater output, (2) better workmanship, (3) less spoilage, (4) fewer accidents, (5) less sickness, (6) reduced labor turnover, and (7) reduced overhead by twenty-four-hour utilization of equipment. These benefits are of greater importance than ever before, says Davis H. Tuck, electrical engineer of the Holophane Glass Company, because every manufacturer is confronted with increased costs of materials, shortage of labor, and the problem of increasing production without reducing the quality.

While expert advice is necessary to secure the best illumination, owing to the different requirements in different places, observing the following suggestions will bring better results than not having consulting advice at all.

Lamp Efficiency. The lamp should give the maximum number of lumens (light flux) per watt.

Life.—The life of a lamp is its economic life and not the period which elapses from the time it enters service until it fails. The efficiency (lumens per watt) of a lamp falls off with use until finally a point is reached where the lamp has become so inefficient that it is advisable to throw it away and buy a new lamp. The best lamp is, therefore, the cheapest lamp which will burn the longest time with the least fall in efficiency (lumens per watt).

Color of Light.—The light should have a color suitable for the work to be performed.

Reflector Efficiency. The ratio of total lumens from the combined lamp and reflector to the total lumens from the lamp alone should be high.

Distribution of Light.—It is principally the light in the 0-deg. to 60-deg. zone that is of use, therefore the light shown by the distribution curve of the reflector should fall as closely within these limits as possible. The greater the candlepower of the light in the 60-90 deg. zone the greater the glare, and the nearer the high candle-power is to the 90-deg. zone the more objectionable it is. Some light, to light upper portions of the room, should be contained in the 90 deg. to 180-deg. zone, as it causes a strain on the eyes to have too great a contrast between the lighting unit and its surroundings.

Shield Light Source.—The light-producing surface of the lamp should be shielded from the eye, as modern light sources are too intense for the eye to view with safety. Furthermore, the brightness of the lower surface of the reflector should be low.

Maintenance.—The reflector should be durable and the reflecting surface should not deteriorate with age, heat of the lamp or fumes of the shop. It should withstand frequent washing and after washing should present a surface equal to the surface which existed initially.

Reducing Shadows. Commenting on the selection of lighting units Ward Harrison of the National Lamp Works says:

In order to take care of the problem of shadows in a satisfactory manner, it is not only necessary that a sufficient number of fixtures be installed, but at all points the light from two or more units should overlap. When this plan is followed and the spacing between units is made not more than one and one-half to one and two-thirds times the mounting height, one can select reflectors which give their maximum candlepower directly downward and still secure practically uniform illumination over the working area. If uniformity depended upon one particular form of distribution curve, indirect-lighting systems, where the ceiling becomes the effective source, would be hopeless from this standpoint.

Hardly any reflector equipped with a clear-bulb lamp would give satisfaction for the general illumination of a machine shop or any other industrial establishment where polished surfaces must be worked upon.

Again, in almost every factory it is desirable that the light on the work should come from sources of large area in order to avoid sharp shadows.

A true comparison of efficiency must be based upon utilization factors found by actual test. For a given unit these vary widely between small rooms and those of extended floor area.

RATING ARTIFICIAL LIGHTING SYSTEMS

When making lighting surveys in industrial plants the equipment will be found in various stages of deterioration. Lamps may be dirty and bulbs black; lamps may be used in reflectors that are too large or too small for the given size of lamp; lamps may be missing, broken or have their filaments "shorted." Reflectors may be dirty; reflectors may be loose, resting upon the bulb for support; the fixture may be defective owing to worn insulation; the reflector may be broken or missing. All of these items decrease the illumination to some degree, and it is important to gain an idea of the percentage decrease in illumination which may be ascribed to the combined effect of these factors. Obviously it would not be practicable to measure the loss of light due to each item for each lighting unit, as this would be an enormous task in even a small shop. Therefore an approximate system of rating becomes desirable. Such a system, which Davis H. Tuck, formerly illuminating engineer for the United States Public Health Service, has used in making lighting surveys in the industrial plants of Wisconsin, will be presented, together with comments on the results secured with it.

The term "efficiency of maintenance" was decided upon as a term which could be represented by a percentage figure and which would represent both the degree of maintenance that an artificial lighting system had received and the percentage of the available light that was being received on the working planes.

In formulating the discounts for various defects in maintenance it was decided to make the discounts conservative, so that a resulting efficiency of maintenance of 100 per cent would represent an installation which had received good care but which would not necessarily be in perfect condition. Thus a lamp may have been in use for 800 hours, and, while not a new lamp, it would not be blackened and would be rated at 100 per cent.

Carbon, metallized and tungsten-filament, mercury-vapor, arc, open-flame and mantle lamps become inefficient owing to the following causes: (1) Continued use; (2) dirt and dust accumulations on lamps and reflectors; (3) burn-outs and breaks; (4) reflectors becoming cracked, broken, loosened or missing, and (5) mechanical injury to connections. Various other items of deterioration take place so gradually that in many cases they are given no special attention in the practical economy of the shop.

Continued Use.—The life of a lamp is not, as is generally supposed, the elapsed time between its entering into service and its burning out. The life of a lamp is given by its manufacturers and is its economic life. Thus when a lamp burns a certain number of hours it may be shown that its energy consumption per light unit has increased to such a degree that it is economy to replace it with a new one.

Dirt and Dust Accumulations on Lamps and Reflectors.—It has been shown by actual measurements that the loss of light due to absorption by dust and dirt for average conditions is about 50 per cent for equipment that has not been cleaned for four months; also that a small quantity of dust, so small as hardly to be noticeable, will cut down the light by 20 per cent.

Burn-outs and Breaks.—It is evident that a burn-out or break may cut down the light by 100 per cent. Often, however, a burn-out or break may be of such a nature that the light source does not fail entirely but that the light is greatly diminished.

Cracked, Broken, Loosened or Missing Reflectors.—The addition of a suitable reflector to a lamp generally adds about 50 per cent to the light delivered in useful directions. When a reflector is cracked or broken the light from the unit is diminished according to the nature of the damage to the reflector. When a reflector is loosened from the fixture or bent out of shape the distribution is altered and the efficiency of the reflector is lowered. It is evident that when a reflector is missing the light that would be gained by its use is totally lost.

Mechanical Injury to Connections.—The loss of light due to mechanical injury to connections will vary with the nature of the injury. Often the injury is of such a nature as to cause a flickering or intermittent light. It may cause a total failure of the light together with all other lights on the same circuit.

Lighting installations are designed to give desirable initial intensities at the work, and it is assumed that the equipment will be maintained so as to produce this intensity. From cost considerations the initial intensity is made as low as possible for work to be done efficiently and to insure prevention of eye strain and accidents. It is readily seen that when deterioration of the lighting equipment sets in the intensity of illumination falls off and that if this deterioration is not arrested serious efficiency losses follow. Often lighting systems are allowed to deteriorate to an extreme point, and nothing is done unless complaints come in from employees after the lighting facilities throughout the shop have become so poor that work has to be temporarily discontinued. The production losses from such circumstances when added up throughout the year greatly exceed the expense of systematic maintenance in advance.

Even when systematic maintenance is carried out the deterioration between inspections is marked, and for this reason it is desirable to allow a factor of safety when planning lighting installations, as is the general practice in other engineering problems. The author has frequently found general overhead direct and indirect lighting systems which after a trial of six months or more have been condemned by the factory management as unsatisfactory. In the majority of these cases the trouble lay in that the maintenance had been neglected, and in the minority it was due to faulty engineering. The stronghold that local lighting has in many factories to-day is due to the fact that the initial intensity is many times that required for the work at hand, and although deterioration is much more rapid for local light units than for overhead general units, the factor of safety has been made so large that only in extreme cases will the illumination fall below requirements. When local lights deteriorate to such an extent that they become unsatisfactory the individual workman usually makes repairs himself. Thus the trouble is not brought to the attention of the management. With overhead general lighting, however, the individual workman has no control over the units, and when the intensity fails, because of lack of maintenance, the job has assumed such proportions that the attention of the management is called to the matter.

In making illumination surveys of shops it was found desirable to note how well the lighting equipment was maintained and to arrive at an approximate figure by inspection that would denote the degree of maintenance. The term "efficiency of maintenance" is used to designate the percentage of the initial intensity that a lighting equipment will give, the loss in intensity being due to the lack of proper maintenance.

Example of Applying Method. The following table shows the method adopted for rating artificial lighting equipment.

The efficiency of maintenance in each case represents approximately the percentage of light given by the equipment after the loss of light due to the corresponding condition is deducted:

Condition	Efficiency of Maintenance, Per Cent
Lamp dirty	80
Lamp very dirty	70
Lamp blackened, due to aging	80
Lamp too large or too small for reflector	80
Lamp missing, broken or having filament "shorted"	50
Reflector dirty	80
Reflector very dirty	70
Reflector cracked or bent	80
Reflector broken or missing	50
Connections loose, fuse out or drop cord bare	80

There follows an example taken from one department of a shop recently inspected and referring to general overhead units in a tool room: twelve units, lamps dirty, reflectors dirty; three units, lamps dirty, reflectors missing; two units, lamps dirty, reflectors very dirty; nine units, lamps very dirty, reflectors very dirty; one unit, lamps very dirty, reflectors missing; one unit, lamps dirty, reflectors clean; two units, lamps dirty and blackened, reflectors dirty.

To arrive at the efficiency of maintenance for the tool room referred to it is necessary to multiply the number of units having the given condition by the values of the efficiency of maintenance for those conditions, expressed as a decimal, and to take the weighted mean:

12 × 0.80 × 0.80	7.68
3 × 0.80 × 0.50	1.20
2 × 0.80 × 0.70	1.12
9 × 0.70 × 0.70	4.40
1 × 0.70 × 0.50	0.35
1 × 0.80	0.80
2 × 0.80 × 0.80 × 0.80	1.02
30	16.57

(16.57 × 100) ÷ 30 = 55.2 per cent efficiency of maintenance.

By measurement with an illuminometer the average illumination was increased in the ratio of one to two by bringing the efficiency of maintenance up to 100 per cent. By making such measurements in a large number of shops, it has been observed that the efficiency of maintenance of local units is approximately one-half that of the overhead general units.

A department of maintenance of artificial lighting equipment should be inaugurated in every factory and workshop. This maintenance work should be made a part of the electrical department, which is in the best position to make periodic inspections of lighting equipment. Reports of inspections, using a system similar to the one outlined above, should be made to the factory manager and efficiencies of maintenance of 100 per cent maintained. The ratings given above are liberal, and efficiencies of maintenance of 100 per cent are not unreasonable.

By adopting such a practice a large economic waste caused by consumption of energy without adequate return in light production, losses due to decreased production, inferior products, accidents and defective eyesight could be avoided.

ADAPTING 220-VOLT CIRCUITS TO 110-VOLT LAMPS

Lamps rated at 110 volts or 125 are more efficient than those for 220 volts or 250 volts, give a more satisfactory life performance and are lower in price than the higher-voltage units, for the reason that the higher voltages are nearer the upper limit

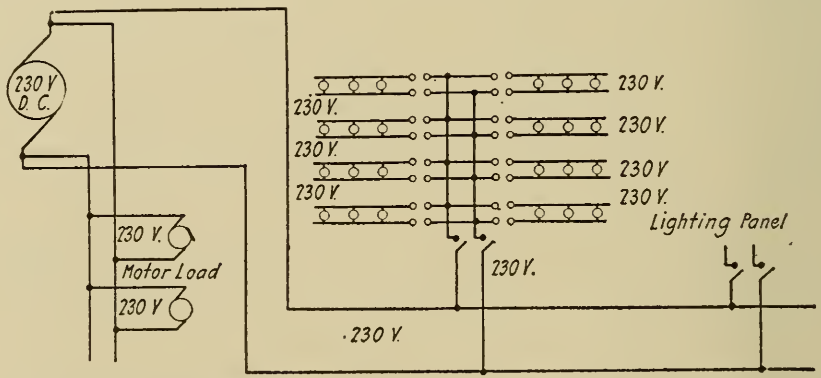


Fig. 79—Undesirable Method of Distribution Often Used for Lighting in Industrial Plants

at which it is possible to manufacture incandescent lamps that will be commercially satisfactory. Notwithstanding these facts and that there are simple expedients, such as the installation of a balancer coil or a motor-generator set, whereby most installations where 220–250 volt circuits are used for lighting can be changed over so as to use 110–125 volt lamps, there are still a

TABLE XXVIII—DIFFERENCE IN COST OF 110–125 VOLT AND 220–250 VOLT LAMPS WHEN LAMPS ARE PURCHASED ON CONTRACT

Based on Schedules in Effect June 15, 1917

Lamp Size in Watts	List	Std. Pkg. Quantity	$150 Contract	$300 Contract	$600 Contract	$1,200 Contract	$2,500 Contract	$5,000 Contract	$10,000 Contract
	Difference in Cost on Purchase Basis of								
Vacuum-type tungsten lamps:									
25	$0.0600	$0.0540	$0.0498	$0.0474	$0.0456	$0.0438	$0.0426	$0.0414	$0.0402
40	0.0600	0.0540	0.0498	0.0474	0.0456	0.0438	0.0426	0.0414	0.0402
60	0.0900	0.0810	0.0747	0.0711	0.0684	0.0657	0.0639	0.0621	0.0603
100	0.1500	0.1350	0.1245	0.1185	0.1140	0.1095	0.1065	0.1035	0.1005
Gas-filled-type tungsten lamps:									
200	0.2000	0.1800	0.1660	0.1580	0.1520	0.1460	0.1420	0.1380	0.1340
300	0.6000	0.5400	0.4980	0.4740	0.4560	0.4380	0.4260	0.4140	0.4020
400	0.8000	0.7200	0.6640	0.6320	0.6080	0.5840	0.5680	0.5520	0.5360
500	0.9000	0.8100	0.7470	0.7110	0.6840	0.6570	0.6390	0.6210	0.6030
750	1.2000	1.0800	0.9960	0.9480	0.9120	0.8760	0.8520	0.8280	0.8040
1000	1.4000	1.2600	1.1620	1.1060	1.0640	1.0220	0.9940	0.9660	0.9380

great many of the higher-voltage lamps in use. It is to be assumed, therefore, that the cost in money or inconvenience is the one obstacle that has continued to stand in the way of changing these systems over. If this be true, says J. R. Colville of the National Lamp Works, the conclusion follows that the greater economy effected by adapting 220–250 volt circuits to lamps of the 110–125 volt class—a saving that will in general pay in a few months the cost of changing the system—is not so generally recognized as it might be.

The difference in cost between lamps of the 110–125 volt class and those of the 220-250 volt class when purchased on different contract bases, according to schedules in force June 15, 1917, are given in Table XXVIII. It may be noted that the difference

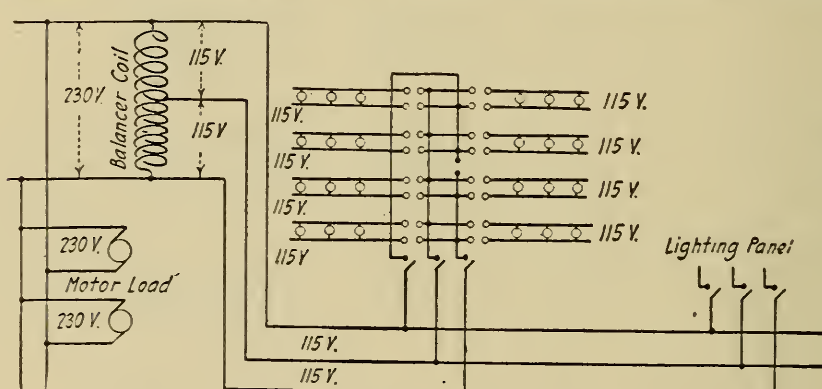


Fig. 80—One Method of Adapting 230-volt System to 115-volt Lamps

in cost ranges from about 4 cents per lamp for the smaller lamps when purchased on large contracts to as much as $1.40 when the largest lamps are purchased at list price.

Table XXIX shows the difference in luminous output of corresponding wattages of lamps of the two voltage classes. It is seen from this table that on the average the higher-voltage lamps give only about 90 per cent of the light which corresponding sizes of the lower-voltage lamps give. Hence for equal illumination intensities more wattage is required with the 220–250 volt lamps.

In the design of new installations the number of units which may be used advantageously is sometimes closely limited by the constructional features of the building. In such cases 220–250 volt lamps of higher wattage, and frequently the purchase of more expensive reflector equipment, are required. On the other

TABLE XXIX—COMPARATIVE DATA ON 110–125–VOLT AND 220–250–VOLT MAZDA LAMPS

Based on Schedules in Effect June 15, 1917

	Vacuum-Type Tungsten Lamps (Watts)				Gas-Filled Tungsten Lamps (Watts)						
Size of Lamp in Watts	25	40	60	100	100	200	300	400	500	750	1000
List price, 115-volt........	$0.27	$0.27	$0.36	$0.65	$1.00	$2.00	$3.00	$4.00	$4.50	$4.50	$7.00
List price, 230-volt........	$0.33	$0.33	$0.45	$0.80	....	$2.20	$3.60	$4.80	$5.40	$7.20	$8.40
Approximate cost of 230-volt in per cent of 115-volt...	122	122	125	123	....	110	120	120	120	120	120
Lumens, 115-volt	226	372	575	995	1260	2920	4850	6150	8050	12,800	18,000
Lumens, 230-volt	190	330	515	900	....	2520	4100	5600	7400	11,500	16,100
Light of 230-volt in per cent of 115-volt	84	89	90	90	....	86	85	91	92	90	90

hand, if considerable latitude in the location of the units is afforded, a greater number of the higher-voltage lamps of a given wattage will have to be installed to obtain the same degree of illumination as might be obtained with the 110–125 volt lamps. This will mean the installation of more outlets, the purchase of a greater number of reflectors, sockets, etc., and a heavier maintenance expense. The difference in cost of lamps of the two voltages, together with the fact that fewer 110–125 volt units are required—that is, the difference in first cost of the installation—is often of sufficient magnitude in itself to pay for the installation of equipment to provide the lower voltage for the lighting circuit. The yearly saving in lamp renewals and energy is then pure profit.

A disadvantage of simply operating two low-voltage lamps in series is that failure of one means the outage of both; thus a relatively large area is left without sufficient light and the time of several persons may be lost while the defective lamp is being located and the replacement made. Obviously in industrial plants and shops accident risk under these conditions is increased over that when only one lamp is out. Furthermore, slightly less than normal life is to be expected from lamps burning in series, since one lamp naturally fails sooner than the other, and when a replacement is made the resistance of the old lamp will be higher than that of the new one. Hence the new lamp will receive slightly less than normal current and will give less than normal candlepower, while the old lamp will be forced to carry a somewhat heavier current than it would normally carry at that period of its life and will therefore fail earlier than it otherwise would. The better way of obtaining the advantages of the lower-voltage lamps is to provide 110–125-volt circuits through balancer coil, motor-generator set or other voltage-bisecting device.

Attention is called to the fact that, in addition to effecting maximum lighting economy and obtaining superior service performance, the user of 110–125 volt lamps receives the benefits resulting from the use of a more highly standardized product. Lamps of the 220–250 volt range are manufactured primarily to supply a small demand which does not justify the stocking of quantities of lamps to fill emergency requirements. Furthermore, improvements are less readily incorporated because of the greater manufacturing difficulties presented by high-voltage conditions. Lamps of the 110–125 volt class compose at present approximately 85 per cent of the output of Mazda lamp factories, exclusive of miniature lamps, as compared with a figure of less than 7 per cent in the case of 220–250 volt lamps. For this reason emergencies may be more readily met.

SOME PHASES OF INDUSTRIAL LIGHTING

Clothing Factories and Similar Workshops. A government report dealing particularly with the women's garment factories in New York City brings out the serious fact that over 50 per cent of such workshops are inadequately lighted, according to the investigations of the United States Health Department. Those who are familiar with industrial conditions in New York City will, of course, recognize that the situation is probably worse there than almost anywhere else, chiefly on account of the narrow streets, high buildings and the very common location of clothing workshops in lofts.

Even when the exposure of the windows is fairly good, the areas of the working spaces are often so large that the inner portions receive very little light. Of course this situation seriously aggravates the difficulties of artificial lighting, as it is a commonplace of scientific illumination that spaces requiring large aid from artificial light are not easy to deal with, and that natural and artificial light do not, so to speak, mix well from the psychological and possibly the physiological standpoint.

Aside from generally insufficient light, the commonest trouble in such factories is serious glare, both directly from the illuminants and sometimes indirectly from the work as well. This trouble comes from the usual cause of bare or insufficiently shielded lamps. Comparatively few of those controlling this particular industry have as yet seen the economic importance of good lighting, and innumerable cases may be found where bare gas burners or incandescent lamps are hung low and shine fairly in the faces of the workpeople. In not a few other instances the lamps originally in the installation may have been tolerably well shaded, but later changes have placed, for example, a 100-cp. tungsten lamp in a shade suitable for a 16-cp. carbon lamp, with the result that might be expected.

With the variety of first-class glass and steel reflectors now available there is very little excuse for glare, although in rare instances the situation of the working spaces is such that ordinary reflectors prove somewhat inadequate. In this case special reflectors may advantageously be used, and we have even seen thoroughly good results on a cutting table obtained from the original lamp and reflectors by adding a diffusing skirt deep enough to keep direct light out of the operator's eyes. The importance in the clothing industry of a good and uniform product turned out rapidly is such as to justify considerable expenditure in remedying imperfect lighting conditions. These are bad enough in dealing with white fabrics, but when dark-colored cloths are used the situation becomes much worse. As between white goods and dark blues, reds or blacks the illumination required for efficient working is somewhat in the ratio of one to four or five. For the former between 1 ft.-candle and 2-ft. candles for ordinary work seems to be reasonably sufficient; for the latter 5 to 7 ft-candles will prove to be none too much.

There is great need for reform in the lighting of clothing factories, although now and then a very admirable example may be found in which the working conditions as well as the product are of the best, but such conditions are unfortunately exceptional.

Workshop Lighting. The adequate lighting of machine shops and foundries is to-day one of the important branches of artificial illumination. Owing to the relations existing between natural and artificial lighting there is frequent necessity for making preparations for the latter in order to secure all-day efficiency. Daylight factor—that is, the ratio of the inside to the outside illumination—impresses one at first thought as somewhat indefinite, yet it is the best measure which we have of the practical efficiency of the lighting arrangements in a given shop. Outside, in full daylight, the illumination may be of the order of one or several thousand foot-candles according to the day, the hour and the time of year. Within the building there is comparative darkness, perhaps 20 to 50 foot-candles in very favorable locations, a tenth of this or less in the darker parts of the shop. The daylight factor is merely the ratio of the average illumination inside to what it would be if walls and roof could be deftly lifted off. The measurement of this factor, involving as it does the averaging of interior conditions, is a somewhat laborious matter. Possibly it could be considerably facilitated by the use of an actinometric method; but however measured it does express the broad facts, and the startling thing about it is the very small value of the factor usually found, very rarely 10 per cent, not infrequently down to 1 per cent or even a tenth of this small quantity. In other words, in full daylight one may easily have only one or two foot-candles at certain points within the building. Hence it happens that on dark and cloudy days and during the weak light of winter one may often have within a workshop far less light than is necessary for efficient operation.

Now, it seems to be a well-established fact that with modern gas-filled lamps well arranged, particularly where off-peak rates can be obtained, the cost of artificial light is less than the overhead on extra space required to increase output, so that in more cases than one would at first suppose artificial light may be economical where only a day shift is in operation. A fairly strong and well-distributed light can be secured at a very moderate expense. The intensities which seem to be necessary generally are from 2 to 4 foot-candles, with for special purposes excursions to considerably higher figures. The method most effective is general overhead illumination giving the nearest approximation to the distribution of light obtained by day.

The most difficult practical problem is that which often arises in the case of large working spaces of which portions are inadequately lighted. The mixture of daylight and artificial light is not altogether agreeable, and perhaps only for psychological reasons there is often a feeling that the artificial light is inadequate when it is really quite as strong as that previously obtained by day. The contrast between light near the windows and light within the interior of a shop lighted only from the sides is of course striking. Shops with monitor roofs and plenty of light from above fare better, but the general indication is that an artificial lighting equipment powerful enough to give a night shift opportunity to work to its highest efficiency is an extremely good investment.

COST OF FACTORY LIGHTING

Within limits, a few lighting units form a cheaper equipment than do many, this being subject to the varying conditions imposed by the necessities of distribution and the grade of illumination required. In making or analyzing any estimates of this kind the construction costs will, of course, vary enormously, depending on the class of building, the uses to which it is put, the costs at the moment of material and labor and a good many other factors, so that one may say at the start that it is difficult to find two cases exactly comparable. The best that can be done is to analyze each case so thoroughly that one can accurately deduce its relation to other cases. A great deal of this cost reckoning is a matter of bookkeeping; in one example the cost per outlet was carried clear back to the transformer and switchboard equipment. Such an all-inclusive scheme may be at times justifiable, but is likely to involve considerable errors and certainly is not a ready basis for the comparison of lighting installations as to initial cost.

What is much more important is the figure for a complete installation of wiring, lamps and accessories up to the switchboard. In some cases further segregation in the costs compared is necessary, as when the new system is operated from old mains. One cannot in the long run do much more than furnish general data for which rough estimates of cost can be made, just as the complete solution of the illumination problem in any given factory cannot wholly be trusted to general average but must involve factors based on local circumstances.

UPKEEP OF INDUSTRIAL LIGHTING SYSTEMS

It is well known to illuminating engineers that many an installation thoroughly satisfactory at first proves inefficient in the long run. Part of the difference may be charged up perhaps to the psychological factor which makes the human mind discontented with its wonted conditions, but there is in addition a very real depreciation in service due to lack of care and the inevitable incidence of dirt. According to data which has been accumulated on a typical factory case it pays, from the standpoint of efficiency versus cost of upkeep, to clean lamps and reflectors about every two weeks. Where dirt is more than usually severe the interval should be shorter than this; where less severe it may be somewhat longer. From a practical standpoint the fact which stands out conspicously is that if the clean lamp in its reflector is operating on the basis of 1 watt per candle as short a period as three weeks without cleaning may reduce the lamp to a rating of about 2 watts per candle. If it were suggested to the factory manager at the present time to use lamps having so low a rating he would be astonished and incensed; yet from ignorance of the facts losses of this magnitude may be going on right under his nose all the year round.

Lighting a Loom Room for Overtime Operation. Being confronted with the now common problem of overtime operation, the Vogt Manufacturing Company recently had to rearrange its looms and improve the illumination. In one part of the factory a direct-lighting system had been tried out. This consisted of three 60-watt lamps with extensive reflectors hung about 4 ft. (1.2 m.) above the bar of the loom and equally spaced along it. The rear of the loom was illuminated by a 60-watt lamp. This direct system was found to cause shadows and did not give satisfaction.

In the new loom room the looms are illuminated by 200-watt type C lamps in Druid No. 3031 11-in. (28-cm.) semi-indirect glass fixtures. The ceiling and walls were covered with two coats of Rice's "mill white." To provide for portable lights a drop was hung over each loom within easy reach of the operator so that he could plug in an extension cord equipped with a trouble lamp. However, when the semi-indirect system was installed it was found that the intensity of light and the lack of shadows made a trouble lamp superfluous.

It is interesting to note that this semi-indirect system of illumination cost less to install than any other system and gave better results, according to F. C. Taylor, who contributed this information.

Lighting Crane Areas. The lighting of crane areas in machine shops and foundries often presents a difficult problem. On account of the necessary clearance for the crane, it is customary to install the lighting units close to the roof or even with the bottom of the trusses. Owing to the height, either 750-watt or 1000-watt lamps are necessary. In nearly all cases it will be found that better results can be obtained by the use of angle reflectors when placed about 14 ft. to 15 ft. (4.3 m. to 4.6 m.) above the floor and between the columns and arranged to deflect light rays toward the center of the crane-way. This arrangement will not only cause better distribution, but will do so at an appreciable saving in energy.

The suggested method of lighting will be found very adaptable to ordnance buildings, where the rifling machinery is generally placed in the crane area and very close to the columns. It will be found that porcelain-enameled reflectors will give better results and at the same time will require less cleaning. Tests show that the width of the area as well as the height of the unit will determine the shape of the angle reflector best adapted for each individual case. Care must be exercised in designing such a lighting system so that no dark areas result along the floor on the center line of the building, says Leo Dalkart.

How to Avoid Moving Factory Wiring. Quite frequently in industries doing light manufacturing it becomes necessary to move the tables, benches or machines at which the workers stand or sit. If the scheme of illumination includes a combination of general and localized lighting, it then becomes necessary to move the localized lighting equipment to accommodate the new location of the tables or machines, which adds considerably to the expense of making the change. In some of the manufacturing industries operated by Marshall Field & Company of Chicago a large part of this expense has been eliminated by attaching the conduit, wiring and lighting fixtures to the tables instead of to the ceiling above the tables. With this scheme the only change in wiring that needs to be made when the tables are moved is the one connection from the overhead conduits to the conduit above the table.

CHAPTER V

ELECTRIC FURNACES, WELDING, ETC.

ELECTRIC FURNACE FOR NON-FERROUS METALLURGY

Certain fundamental principles, upon which the success of electric brass melting directly depends, have hardly received, at least in public, the consideration which they deserve, so they will be discussed in this paper by H. M. St. John of the Commonwealth Edison Company, Chicago. In discussing them particular attention will be called to the bearing which they have upon electric furnace design and development.

In 1914 it was estimated by Gillett [1] that there were in the United States at least 3600 plants engaged to some extent in melting brass and bronze. It was further estimated that the value of the metal annually melted by these plants was in the neighborhood of $120,000,000, and that of this total the value of the metal lost beyond recovery during the melting operation was not less than $3,000,000. When one considers the extensive use of brass and bronze in warfare and the enormous industrial expansion along metallurgical lines which has taken place in this country since 1914, it should be evident that corresponding figures for the present time are much larger. Even if the total amount of metal melted annually were no greater now than then, the increase in market value of the metals concerned would of itself nearly double the value of the metal produced. The avoidance of waste in melting, which was even then considered important, therefore becomes particularly so at this time.

As has long been known, it is theoretically possible to eliminate much of this loss by the use of electric melting, particularly in the case of yellow brass and other alloys high in zinc. Most of the electric furnace development in the copper-alloy field has

[1] H. W. Gillett, "Brass-Furnace Practice in the United States," *Bureau of Mines Bulletin No. 73*, p. 9 (1914).

been carried out with this end in view. Metallurgically speaking, the problem is not a simple one and progress has been rather slow. Important advances have been made since 1914, however, and the present outlook is rather optimistic.

Two widely different types of electric furnace are now on the market and in commercial use for melting yellow brass. One is highly efficient but limited in its use to a portion of the field only; the other is less efficient but otherwise more widely applicable. At least one other type of furnace has been experimentally successful and is reported as about to enter the commercial field. Two or three additional types are being actively developed and give some promise of eventual success.

So far as yellow brass is concerned, it cannot be said that an entirely satisfactory furnace has yet been produced, but the field has been partly covered, and the prospects for further advancement in the art are good.

Previous to the war the use of electric furnaces for melting copper alloys did not seem feasible except in cases where a large metal saving helped to counterbalance the higher cost of electric heat. Under present conditions the high cost and poor quality of crucibles, the high cost and shortage of important metals, the high cost and scarcity of labor and the insistent demand for a high rate of production at any cost are factors which combine to make electric melting profitable in many cases where it would previously have been unprofitable. Whether electric furnace installations which owe their existence to these peculiar conditions will continue to show a profit when normal conditions once more prevail is still an open question. No one can say when conditions will again become normal, or, for that matter, what sort of conditions will be considered normal in the future. Much will depend upon the progress made in furnace design and in operating methods during the continued existence of the economic conditions which at present make possible the electric melting of copper alloys containing little or no zinc. The necessary progress can only be made by the combined efforts of such individuals and companies as are now profiting, and expect to profit in the future, from the increased use of electric furnaces.

Advantages of Electric Melting. Electric heat is expensive at best, and although it can be applied much more efficiently than heat derived from fuel, especially at high temperatures, it cannot profitably be employed except in cases where its use makes possible substantial savings of one kind or another to offset its added cost. The advantages which may naturally be expected to accrue from electric melting, as compared with melting in fuel-fired furnaces, are roughly as follows:

Metal Saving.—The saving of metal otherwise unavoidably lost is the principal economic advantage which the electric furnace is required to show in the melting of copper alloys, particularly in melting yellow brass. It has been completely demonstrated that such a saving can be made in the electric furnace by virtue of the fact that the furnace chamber can be tightly closed during the melting period and a neutral or reducing atmosphere maintained. As will be shown later on, it does not follow that every electric furnace is capable of a favorable performance in this respect. Conditions resulting from the war have greatly accentuated certain other advantages of electric furnace operation.

Improved Quality.—It has been found in most cases that a more uniform quality of metal can be produced in the electric furnace than in fuel-fired furnaces operating under similar conditions and that it is easier to produce an alloy of closely specified composition. In general, these advantages can be accepted as inherent in properly conducted electric furnace operation, resulting from the greatly reduced loss of volatile metals and from the elimination of contaminating combustion gases. So far as copper alloys are concerned, it is still undecided whether or not a higher quality of metal can be produced in the electric furnace as compared with the best of fuel-fired practice. It is beyond question, however, that high quality can be achieved more easily and with greater certainty. The successful electric furnace must be at least as satisfactory in these respects as the best fuel-fired furnace.

Exact Temperature Control.—The production of perfect castings, with the least possible number of defective pieces, depends in large degree upon the use of metal at a temperature which conforms closly with that known to be most favorable for the work in hand. The electric furnace lends itself readily to exact temperature control, which is an important advantage.

Increased Production.—In general, the speed of melting is greater in electric furnaces than in fuel-fired furnaces, because of the higher operating temperature and greater efficiency obtained. Furthermore, larger units can usually be employed than when fuel-fired furnaces are used.

Elimination of Crucible Cost.—The cost of crucibles is an item of considerable magnitude even in normal times. Under present conditions this cost is very high. Electric furnaces, which require no crucibles, therefore eliminate this expense. Large fuel-fired furnaces effect the same saving, but from a metallurgical point of view are seldom as satisfactory as fuel-fired crucible furnaces. Electric crucible furnaces deserve little consideration at the present time.

Incidental Savings.—The operation of large units results in an economy of floor space and labor, and increased production is attended by decreased overhead and interest charges per ton of metal produced.

Better Working Conditions.—More favorable conditions for the workmen, tending to increase their efficiency as well as their comfort, result when excessive heat, noise and fumes are eliminated. Properly selected and correctly operated electric furnaces are almost ideal in this respect. In installations where the reverse is true the trouble is due to the use of an unsuitable furnace, or to careless operation, or to both of these as contributing causes.

It should not be understood that these advantages necessarily follow from the use of any electric furnace which may happen to be selected. The furnace must be of suitable type, properly designed and correctly used. A misapplied electric furnace may prove worse in almost every respect than the fuel-fired furnace which it replaces.

First consideration must always be given to metallurgical requirements. Steel may be heated as rapidly as desired during the melting operation, provided that it is not exposed to contaminating elements during the process, but with copper alloys the case is quite otherwise. Copper is somewhat volatile and oxidizes much more readily than steel when in the molten state. Lead is also quite volatile, more so than copper, and oxidizes very easily. Zinc is exceedingly volatile at molten brass temperatures. All copper alloys must be treated carefully during the melting process in order that losses of metal by oxidation and volatilization may be kept at a minimum.

Requirements of Electric Melting. Yellow brass for thin castings must be poured at a temperature not far below its boiling point in order that the metal may be sufficiently fluid. At this temperature zinc, which comprises 30 to 35 per cent of the alloy, has a tendency to vaporize rapidly. So long as the metal is contained in a tightly closed furnace chamber, which can easily be done in the electric furnace, this tendency is counterbalanced by the vapor pressure of the metal which has already been vaporized and with which the furnace atmosphere is saturated. When the furnace is opened for pouring the metal or for any other purpose the vapor pressure is released and additional zinc will escape from the metal without restraint. If the heating has been perfectly uniform and all portions of the melt are at approximately the same temperature, the loss of zinc which ensues will constitute an unavoidable minimum. If the heating has not been uniform, some portions of the melt will be at a temperature higher than the desired pouring temperature, and such portions will lose zinc at a higher rate. If the lack of temperature uniformity is very great, the loss which occurs after the furnace is opened and during pouring will be decidedly excessive. If the metal is seriously overheated during melting the high vapor pressure formed within the furnace will force considerable quantities of zinc vapor through crevices in the furnace structure. In some cases it may be practically impossible to keep the furnace chamber closed, even to a reasonable degree. Under such conditions the zinc losses are likely to be quite as serious as in fuel-fired crucible furnaces, or even more so.

What is true of yellow brass poured at a temperature near its boiling point is also true, although in less degree, of yellow brass poured at lower temperatures and of other copper alloys. The lower the percentage of volatile metal the more easily the alloy will withstand uneven heating, but it can be accepted as an axiom of copper alloy melting that heat must be applied to the metal as uniformly as possible, whether the alloy under treatment is brass, bronze or some one of the less common alloys. If the application of heat in the furnace lacks uniformity to a serious degree, an excessive loss can only be prevented by some method of stirring the metal, and this stirring must be effected within the furnace, but without opening the furnace doors.

The metal as poured from the furnace must be uniform in composition, with its various constituent metals thoroughly well mixed and alloyed. In some cases a rigidly specified composition must be closely met. The finished casting or ingot must be of a quality at least as good, with respect to strength, freedom from cracks, blow-holes, etc., as that obtainable from fuel-fired crucible furnaces.

Since electric heat is more costly than that derived directly from fuel, it is important that the thermal efficiency of the electric furnace should be as high as can be obtained consistently with other requirements. A high thermal efficiency in electric melting, unless heat is generated in the metal itself, requires a high temperature heat source, placed as close as may be to the metal, under conditions which offer the least possible opposition to the flow of heat from the source to the metal. At the same time the walls of the furnace must be sufficiently thick and of high-heat-insulating quality in order that heat may not be dissipated uselessly from the outer walls.

In some types of furnaces these requirements are directly opposed to the metallurgical requirements already considered. In such cases thermal efficiency must be sacrificed to as great a degree as may be necessary in order to satisfy the metallurgical requirements. The highest efficiency consistent with good metallurgical results should be maintained; any higher efficiency is false economy. Of course, other things being equal, the more efficient type of furnace will meet with greater success.

The electric furnace, to reap the full benefit of its economic possibilities, must operate in large units and must not use crucibles. The higher its speed of melting the better, so long as speed is not detrimental to metallurgical results.

The electrical characteristics of the furnace must be such as to make it a desirable load for the central-station company or the factory power plant. Its power factor must not be abnormally low and its power fluctuations must not be so violent as to endanger transformers and other electrical equipment or to interfere with satisfactory service to other customers of the central-station company that may be connected with the same power line.

It hardly seems necessary to add that the successful electric furnace must be sturdy and reliable, quite as capable of performing its function, day in and day out, under regular operating conditions, as are the best types of fuel-fired furnaces. The furnace and its adjustments should be as simple as possible, although with a large electric furnace it is permissible, and nearly always desirable, to use a higher grade of operator than would be employed to tend fuel-fired crucible furnaces.

A great variety of electric furnace types have been proposed and tried out for melting brass. It is hardly an exaggeration to say that every known method of applying electric heat to a metal has been utilized by one or another of the various designs which have reached at least an advanced experimental stage. Some of these types have been eliminated as inherently unsuited for the purpose; some have been abandoned because of difficulties which may eventually be overcome by other investigators; others, partially successful, have apparently reached the height of their development; still others seem to possess greater possibilities of ultimate success than have yet been demonstrated.

TYPES OF ELECTRIC FURNACES FOR NON-FERROUS METALLURGY

The obvious method of reaching a high thermal efficiency without overheating an alloy is to generate heat in the metal itself by the passage of an electric current through it—either by a direct resistance furnace, in which electrical contact with the metal is made through electrodes, or by means of an induction furnace, in which case the metal forms a complete circuit for the flow of an induced electric current, without the use of electrodes. In either case it is practically necessary to establish the circuit through molten metal previously melted in some other furnace.

Direct-Resistance Furnaces. The "pinch-effect" direct-resistance furnace was the first type in which this principle was utilized. Virtually all of the heat is generated in the molten metal temporarily occupying channels or tubes. The main portion of the metal, occupying the furnace chamber above, is heated by contact with the hot metal, and solid metal added to the bath is melted by the same means.

The stirring action of the moving streams of metal is vigorous, and the temperature of the main portion of the bath rises uniformly. There is no difficulty in restraining the vaporization of zinc, and, in fact, it may be said that the metallurgical requirements of any single alloy are almost perfectly fulfilled.

Generation of heat in the metal itself, where its presence is desired, is theoretically ideal from the standpoint of efficiency, since no part of the furnace is any hotter than the metal, and wall losses are reduced to a minimum. With this type of furnace, however, the massive metallic electrodes require a considerable water cooling. Consequently a large quantity of heat escapes from the furnace, and the thermal efficiency is much lower than it would otherwise be. Considerable difficulty has also been experienced in constructing satisfactory transformers for use with the extremely low voltages and high currents required. So far as is known to the writer this furnace is not now used extensively.

Induction Furnace. The next step in the development of electric furnaces was the application of a similar principle to the induction furnace. In this the use of electrodes and troublesome transformers is avoided, since the furnace serves as its own transformer. The generation of heat takes place as before in the resistor channels, and the same vigorous circulation of metal results. Whether this action is due primarily to the pinch phenomena or to a motor effect resulting from the flow of current through the continuous molten resistor is open to question. It is difficult to tell where one phenomenon leaves off and the other begins.

The thermal efficiency of the induction-type furnace, operating, as it does, without electrodes, is very high, probably higher than that of any other electric furnace ever tried out for copper-alloy work. Its metallurgical characteristics are also excellent. It offers a perfectly steady, uniform load at a power factor which is satisfactory, at least in the relatively small sizes so far built, the largest requiring a 60-kw. input and pouring 600 lb. of metal per heat. In larger sizes there might be trouble with low power factor, as is so frequently the case with large induction furnaces.

The induction furnace is in commercial use and is said to be giving satisfactory results. It has, however, pronounced limitations which are partly inherent in its design and partly remediable. Its small size is one disadvantage, but it is probable that somewhat larger sizes can be successfully built. So far it has not been found practicable to use the furnace with alloys high in lead, because that metal has a tendency to penetrate minute cracks in the lining of the resistor channels, causing short circuits. The remedy for this is the development of a lining especially suited for use with lead.

The more serious limitations of the furnace are its lack of flexibility in changing from one alloy to another and the practical necessity of operating it continuously, never allowing the furnace to cool oftener than once a week. The length and cross-section of the resistor channels are especially designed to accord with the electrical resistance—in the molten state—of the alloy which is to be used. These same resistor channels cannot be employed with another alloy of widely different resistance, which, accordingly, requires the installation of new channels of properly modified design. In changing from one alloy to another, even if the resistance is approximately the same, it is necessary to pour the furnace clean and start with a molten charge of the new alloy, melted in another furnace.

The linings of the resistor channels stand up very well under continuous use but deteriorate rapidly under the daily heating and cooling of ten-hour-day operation. This can be obviated by maintaining over night sufficient power to keep the channels filled with molten metal, which, of course, results in some addition to the cost of operation.

The limitations mentioned tend to prevent the use of this furnace in commercial foundries, which melt a wide variety of alloys and do not work nights, but form no bar to its use in yellow-brass rolling mills, to the purposes of which it seems well suited.

There has been proposed a new design of induction furnace which would not be subject to the foregoing limitations. In this type a spark gap and an arrangement of condensers connected in series and in parallel are used in the primary circuit of the furnace, which operates at about 10,000 volts and some 15,000 to 20,000 cycles. The secondary of the furnace consists of a crucible or melting chamber with electrically conducting walls. The metal within the crucible also carries part of the secondary current, to a minor degree when it is first charged in the form of solid pieces, to a much greater degree when it becomes molten. The primary circuit is arranged around the melting chamber and is separated from it by suitable refractory and heat-insulating walls. The furnace is, in a sense, an eddy-current rather than an induction furnace, since no iron cores are used and the metal itself, lying in a circular pool, completely short-circuits what, in an induction furnace, would be called the secondary circuit. This unique arrangement is made possible by the exceedingly high frequency used.

According to last accounts, this furnace had been built only in very small sizes, capable of pouring not more than 45 lb. (20.4 kg.) of metal per heat. There is no apparent reason why the metallurgical characteristics should not be good, and the construction of the metal-containing portion of the furnace is desirably simple. It is obviously unnecessary to use molten metal in starting the furnace. Any alloy or even non-conducting material, such as glass, can be melted without changing the furnace design. The furnace is suitable for intermittent operation and need not be kept hot overnight.

Arc Furnaces. Next to the methods already described the most direct way of applying heat to the metal is by means of a heat source outside but in direct contact with the bath. The direct-arc furnace is the only type which utilizes this principle.

The application of direct-arc furnaces to copper alloy melting has been rather limited. One or two furnaces designed for steel melting have been tried, but no new type of direct-arc furnace has been developed for this specific purpose. No furnace of this general type has ever succeeded in satisfactorily melting yellow brass or other copper alloys containing an appreciable percentage of zinc. The high-temperature heat source in direct contact with the bath overheats the metal in its immediate vicinity and always causes excessive loss of zinc.

With copper alloys containing no zinc conditions are somewhat different, since lack of uniformity in heating is less likely to result in serious loss. In a direct-arc furnace of small size it has been found possible to melt a copper alloy containing as much as 15 to 20 per cent lead with less loss than is commonly the case with the same alloy in fuel-fired crucible furnaces. In larger furnaces the greatly increased rate of heat input supplies heat to the metal in the neighborhood of the arch more rapidly than it can be conducted away to more distant portions. As a result the surface of the metal becomes overheated while other parts of the bath are still much below the desired temperature.

Advantage of Direct-Arc Furnace. The direct-arc furnace has the advantage of simplicity and high thermal efficiency. Its design has been more highly developed and perfected than that of most other electric furnace types. Since it is so widely used in the steel industry, several reliable and readily available furnace designs are on the market. It is very doubtful, however, if any direct-arc furnace deserves wide application for melting copper alloys. Its use is limited to only a few of the common alloys, and, if large units are employed, the metal loss, even with these alloys, is likely to be serious. Small units are more satisfactory in this respect, but are subject to the disadvantages of lower efficiency, higher fixed charges and higher operating costs per ton of metal produced.

Such direct-arc furnaces as are now in use in this field—and there are a few—hold their place by virtue of their simplicity, their elimination of crucible cost and their high rate of production, at a time when these qualities are at a premium.

The intensity of heat application to the metal is lessened somewhat by using an arc between two or more independent electrodes above the bath, heating the latter by direct radiation. The arc does not come in direct contact with the metal, and the latter forms no part of the electric circuit. It is apparent that in this type of furnace the surface of the metal is not so seriously overheated as in the direct-arc furnace, but such overheating as exists is, nevertheless, too severe to permit the use of such furnaces in melting yellow brass. The indirect-arc furnaces can be used economically with alloys containing 5 to 10 per cent of zinc, possibly as high as 20 per cent, but certainly not for higher values.

Indirect-Arc Furnace. The design of the indirect-arc furnace is invariably somewhat more complicated than is the case with the direct-arc furnace, and its thermal efficiency is not so high, but in the melting of copper alloys it can be economically used in large units and seems to be in general a more satisfactory tool for the purpose.

Several indirect-arc furnaces are now in use in this country for melting copper alloys which contain small percentages of zinc or none at all. In a new type of indirect-arc furnace the metal, as soon as it becomes molten, is agitated by rocking the furnace mechanically, in order to avoid overheating of the surface layer. In this way non-uniformity of heating is largely rectified, and it is possible that alloys high in zinc can be melted without excessive loss. The furnace has received a comprehensive commercial test, the results of which have been published by the Bureau of Mines, Washington, D. C. This type gives considerable promise of success and should be applicable to a wide field of alloy melting.

Indirect-Resistance Furnaces. Resistance furnaces which do not utilize the metal itself as an electric resistor may be grouped in three classes—(1) those which radiate heat directly to the metal, similar in principle to the indirect-arc furnace; (2) those which radiate heat to the furnace roof and thence to the metal by reflection and secondary radiation; (3) those which deliver heat to the metal by conduction through a refractory wall.

Heating by direct radiation is the most desirable of the three from the standpoint of efficiency. For this purpose it is practically necessary to support the resistor above the bath in some manner, and this has never been done successfully in furnaces of any size. In small furnaces it has been possible to utilize this principle and to melt brass satisfactorily without overheating the surface of the metal to an undesirable degree, since, as compared with an arc, the resistor has a large area and operates at a much lower temperature. At the same melting speed the application of heat to the metal is more uniform but the efficiency is somewhat less.

This type of furnace is applicable to the melting of yellow brass but is not in commercial use because of the mechanical difficulties involved in its construction. The possibility of its eventual use depends upon the development of a resistor material which is at once highly refractory, homogeneous, mechanically strong at high temperatures and possessed of a fairly high electrical resistance at the working temperature of the furnace.

The second type of indirect resistance furnace named ranks next in order of thermal efficiency. In this design a refractory wall separates the resistor from the metal, although not necessarily in contact with the metal, and the major portion of the heat is radiated from the resistor to the furnace roof, the latter acting as a secondary heat source which reflects and radiates part of the heat which it receives to the bath beneath it. The heat has to travel a rather long path, and much of it is lost by the wayside. As a result the furnace is not so efficient in principle as those previously discussed. In order to stimulate a reasonably rapid flow of heat the resistor element must be much hotter than the roof, and the roof, in turn, much hotter than the metal. Thus the possibility of a high rate of production depends upon the use of a resistor capable of operating at a temperature very much above that of the metal, even at the pouring point. The furnace roof must be exceedingly refractory, and the brickwork in the immediate neighborhood of the resistor must be even more refractory than the roof.

This furnace, in common with other indirect resistance furnaces, has another disadvantage, somewhat minor in character but worth considering, which does not exist with direct-resistance furnaces, nor to any great degree with arc furnaces. The heat storage of the furnace is large and the stored heat is at a higher temperature than that of the metal. Consequently, the temperature of the metal will continue to increase after power has been shut off so that the metal must be poured promptly when it has reached the desired pouring temperature in order to avoid overheating.

This is the only form of indirect resistance furnace which has been used commercially for melting copper alloys. In its present form it is simple, reliable, easy to operate and can be used for practically any alloy, with either intermittent or continuous operation. Its metallurgical characteristics are excellent, with the single exception that it is somewhat difficult to secure thorough mixing. It is also especially suitable for melting alloys high in zinc. However, its production rate is not rapid and it is not so efficient as the types of furnaces already described.

A similar type of furnace exists in which a combination of arcs and resistance elements is utilized, all radiating heat to the furnace roof, which, as in the furnace just described, serves as a secondary heat source. The use of arcs makes possible a considerably higher power input, more rapid melting and probably a slightly more favorable efficiency, provided that a sufficiently refractory roof is used. A very high efficiency cannot, however, be expected from this type of furnace. Certain difficulties in furnace design have been encountered which have so far postponed the commercial use of this furnace. It has been under test for some time, but the results obtained have not yet been made public.

The least efficient method of transferring heat from its source to the metal is to force it through a refractory wall, even though this wall be that of a clay-graphite crucible, a mixture which has a fairly high heat conductivity. Theoretically, the least undesirable arrangement under these conditions is to inclose the resistor in the refractory wall or to use the wall itself as a resistor. In the latter case the wall must be separated from the metal by an insulating layer to prevent short-circuiting. It is not an easy matter to make this insulation permanent, so this factor has been a serious source of difficulty. A resistor inclosed in a refractory wall tends to reach excessively high internal temperatures, and no material, satisfactory in other respects, has yet been found which will not destroy itself under these conditions. Another troublesome difficulty results from the ease with which most resistor materials unite chemically with the furnace refractories at high temperatures, thereby destroying both themselves and the refractories. Some two or three furnace types have been designed to make use of this principle, but they have been collectively unsuccessful. At present there is no real activity along this line.

Crucible Furnace Low in Thermal Efficiency. Finally, it is possible to melt brass in a crucible by means of resistor elements which surround but do not touch the crucible. Perhaps the most perfect results, from a metallurgical standpoint, can be obtained in this manner, but the thermal efficiency is at a minimum, and in any case the electric crucible furnace lacks most of the secondary advantages upon which the electric brass-melting furnace must depend in part for its successful use. In cases where perfection of metallurgical results is by far the most important consideration it is possible that an electrical crucible furnace can be employed profitably, but, so far as is known to the writer, no commercial installation of this kind exists.

So far as thermal efficiency is concerned, the crucible furnace takes its place at the bottom of the list. Its energy consumption per ton of metal produced is about three times that of the induction furnace. One or two attempts have been made to improve the efficiency but owing to the facts just stated its development has been discontinued.

Present Progress and Development. The development of electric furnaces for non-ferrous metallurgy has been studied by Dwight D. Miller, formerly with the Society for Electrical Development, who says that the furnaces which have been designed and are now under experimentation include the Gillett furnace (indirect-arc type), patent assigned to the government, Department of the Interior, Bureau of Mines; the Conley furnace (molded-resistor type), controlled by Florance & Hampton, 1270 Broadway, New York; the Thomson-FitzGerald furnace (reverberatory resistance type), controlled by John Thomson, 253 Broadway, New York; the Northrup furnace (induction type without iron core), controlled by the Ajax Metal Company, Philadelphia, and the Hering "pinch-effect" furnace, controlled by Carl Hering, Philadelphia, although an option is held by the Ajax Metal Company for handling brass in the furnace. Other furnaces are under experimentation, but the companies interested in them are averse to giving any information thereon.

The Gillett furnace, invented by Dr. H. W. Gillett, is an indirect-arc furnace so designed as to bring about a violent agitation of the charge by a rocking motion. Instead of rotating the furnace through a complete revolution which would involve difficulties in keeping the metal out of the joint between the door and the door opening and in making bus contacts to the electrodes, it appears simpler to rock the furnace back and forth so that the molten charge just fails to reach the door at either end of the rocking angle. Accurate temperature control is very easy in the rocking furnace, since the walls are no hotter than the metals and there is no heating up of the sides from hotter roof and walls. After cutting off the arc the temperature falls very slowly, about 2 or 3 deg. C. per minute. By running the arc a minute or so every ten or fifteen minutes, the charge can be held at pouring temperature for an indefinite period. Where automatic electrode control is used one man can probably attend to two furnaces.

The Conley furnace, invented by William H. Hampton, is a resistance furnace of the molded-resistor type, in that the charge is melted in an open graphite crucible which closes the secondary circuit. The voltage is applied directly to the sides of the crucible, the latter being inclosed in an iron-plate casing packed with Kieselguhr. Hand control is used for varying the voltage in the primary circuit and consequently in the secondary circuit. The furnace is capable of melting 100 lb. (45.3 kg.) of copper with 12 kw.-hr. input. The power factor is practically unity—98 to 99 per cent.

The Thomson-FitzGerald furnace, invented jointly by John Thomson and Francis A. J. FitzGerald, is a resistance furnace of the reverberatory type, the heating effect being produced by radiation from especially formed resistors and reflection from the walls and roof of the furnace inclosure. The apparatus, which is designed for the purification of spelter containing metals, has been tested chiefly for the fuming of impure zinc. While the furnace has been successful in producing extremely pure zinc, no performance data are available for publication.

The Northrup furnace, invented by Prof. Edward F. Northrup, has been under experimentation for the last year, during which time some data have been obtained. The furnace is an absolutely new departure in furnace design and principle of operation. It employs oscillatory current at very high voltage, the oscillation being produced by discharges from a condenser and being conducted to a series of closed coils which are mounted concentrically on cylindrical crucibles and insulated from each other. A 20-kw. Northrup furnace will melt 45 lb. (20.4 kg.) of brass scrap in thirty-five minutes, starting from the cold. Temperatures as high as 1600 deg. C. are readily obtained. The furnace is admirably adapted to make melts in vacuum and is now being used for melting both glass and electrically conducting materials.

''So far as the writer is aware,'' said Mr. Miller, ''nothing is being done at present with the Hering 'pinch-effect' furnace, which has been fully described in the technical press.''

Furnaces in Commercial Use. The furnaces that are in actual commercial practice for handling copper-zinc alloys include the Ajax Wyatt furnace, controlled by the Ajax Metal Company, Philadelphia; the Foley furnace, controlled by Charles B. Foley, Inc., 170 Broadway, New York; the Baily furnace (reverberatory resistance type), controlled by the Electric Furnace Company of America, Alliance, Ohio; the Rennerfelt furnace (indirect-arc type), represented by Hamilton & Hansel, 17 Battry Place, New York; the Snyder furnace (direct-arc type), controlled by the Industrial Electric Furnace Company, 53 West

Jackson Boulevard, Chicago, and the Hoskins furnace (resistance type), controlled by the Hoskins Manufacturing Company, Detroit, Mich.

The William A. Rogers Company, Ltd., which uses Baily furnaces, states that virtually no metal losses are involved when handling silver using two crucibles holding approximately 500 oz. (14 kg.) each, that the metal appears more homogeneous, and that a better melt is obtained. The first heat takes about one hour and thirty minutes, while the others take approximately one hour, the average total time for charging, melting and pouring being approximately one hour and seven minutes. The company can get about eight heats (of two crucibles each) in a day of ten hours.

The pouring temperature is around 2200 deg. Fahr. (1209 deg. C.), although no pyrometer is used, the temperature being judged by the color. The furnaces operate with a constant input of 30 kw., which figures out 960 kw.-hr. per ton. The electrodes in the silver furnace are replaced once every three months, but as they use the butts left over from the annealing furnaces this renewal costs them practically nothing.

The Otis Elevator Company has two Baily annealing furnaces of 300 kw. and 150 kw. capacity for treating steel and brass castings. About the only trouble experienced has been an occasional cracking of the resistor troughs, thereby necessitating patching. These two furnaces are energized by one three-phase transformer, the large furnace operating two-phase and the smaller one single-phase. The troughs are in series, thus producing an even balanced load.

The castings treated vary from 3 lb. (1.4 kg.) up to 7000 lb. (3175 kg.) each. The larger furnace can handled a charge up to 12,000 lb. (5443 kg.) of metal, while 7500 lb. (3402 kg.) can be charged in the small furnace. The metal is treated at a temperature ranging from 1500 deg. Fahr. to 1850 deg. Fahr. (815 deg. C. to 1026 deg. C.) and heated for from sixteen to twenty hours. Starting with a furnace temperature of approximately 750 deg. Fahr. (398 deg. C.) and running up to an annealing temperature of 1600 deg. Fahr. (871 deg. C.), at which time the current was shut off, the cost per ton was approximately $7, the total time the power was on being nineteen and three-quarter hours.

At the Lumen Bearing Company, Buffalo, copper, lumen metal, phosphor and manganese bronze are being handled in Baily furnaces. The charge is 600 lb. (272.2 kg.), consisting of scrap and ingots. Short test runs on both lumen metal and phosphor bronze under far from ideal conditions resulted in a consumption of 12 kw.-hr. for lumen and 22 kw.-hr. for phosphor bronze per 100 lb. (0.49 kw.-hr. per kg.). The company states, however, that as soon as it gets to running ten hours per day six days in the week it expects to reduce these figures to 10 kw.-hr. and 17.5 kw.-hr. respectively, basing this expectation on making the hardener used with lumen metal, and which forms 28 per cent of the melt, separately in a crucible.

The lumen metal is poured from 1250 to 1600 deg. Fahr. (754 to 871 deg. C.), the phosphor bronze at approximately 2200 deg. Fahr. (1209 deg. C.). The heats average about one hour so that eight or nine heats can be made in a ten-hour day according to conditions. The metal loss will vary from 2½ to 3½ per cent for the lumen metal, the test on the phosphor bronze showing 2 per cent.

With the idea of getting the hearth in good condition a melt of copper amounting to 1512 lb. (685 kg.) was run just previous to the test run on phosphor bronze. This was held for four hours and twenty minutes with a consumption of 24.8 kw.-hr. per 100 lb. (5.5 kw.-hr. per kg.), starting with the furnace hot. The charging was done in nine separate lots extending over three hours while six pours were made, ranging from 2000 deg. to 2100 deg. Fahr. (1094 deg. to 1150 deg. C.) in forty minutes. Under these conditions the figures given should not be considered as a true indication of the performance of the furnace when handling copper. It is possible to charge manganese bronze immediately after a lumen heat since the zinc which might be left in the furnace would have no injurious effect on the manganese bronze.

Of the two furnaces installed one has been in operation for six months and the other for two months. During this time there has been only one renewal of the bottom, costing about $50, with some slight patching in addition. The second furnace, however, is not run every day.

Regarding savings the statement is made that with coke costing $4 and crucibles 4 cents there is a saving made by using electricity at 0.75 cent per kilowatt-hour, which is virtually what is paid. In addition, the labor of carrying the coke and ashes is eliminated together with the space for their storage.

The Hoskins Manufacturing Company gives the following information regarding the performance of several of its furnaces: "The smaller, holding one crucible, usually gives four to five heats of 23 lb. (10.4 kg.) each per day, but we have no power figures on it. It is lined with 4½ in. (11.4-cm.) magnesite back of the resistor and 4½-in. (11.4-cm.) firebrick back of this. This brick lining has to be rebuilt every six to eight weeks and is patched every Saturday. The larger furnace, taking two crucibles, is lined with 4½-in. (11.4-cm.) carborundum bricks just back of the resistor, with 3-in. (7.6-cm.) powdered silica back of this, and finally with 2½-in. (6.4-cm) Kieselguhr brick back of this. This furnace has to be rebuilt every three to four months, and it is patched every Saturday. In it the current is turned on every morning at 4.30, increased at 7 A. M. to probably 40 kw., when charging begins, and later run at 50 kw. to 60 kw. Five heats of 23 lb. (10.4 kg.) each are usually turned out per day, the first at about 11 A. M. and the others every one and a third to one and a half hours, using for the day from 450 kw.-hr. to 525 kw.-hr. These alloys are poured at about 2900 deg. Fahr. (1589 deg. C.)."

Results of Tests on Brass. The results of five tests on yellow brass (65 to 85) showed an average of 49 kw.-hr. per 100 lb. (1 kw.-hr. per kg.), pouring at 1950 deg. Fahr. (1063 deg. C.). The melt was made in a 70-lb. (31.8-kg.) crucible in an FC furnace. The total time per heat outside of the first, which took two and a half hours, was approximately one hour. Eight tests on red brass showed an average of 36.5 kw.-hr. per 100 lb. (8 kw.-hr. per kg.), pouring at about 2150 deg. to 2175 deg. Fahr. (1170 deg. to 1190 deg. C.). The first and average heat took the same time as for yellow brass. No metal loss was given in either case.

"The only installation of Snyder furnaces handling nonferrous metals of which I am aware," said Mr. Miller, "is that at the Chicago Bearing Metal Company. The power factor is in the neighborhood of 60 per cent." The furnaces have a capacity of about 2000 lb. (907 kg.) of metal per heat, and the average power consumption is not over 300 kw.-hr. per ton (333 kw.-hr. per t.). They operate twenty-four hours per day, Sundays excepted, and handle a heavily leaded bronze such as is used for railway car and locomotive bearings. The composition of the metal is approximately 75 per cent copper and the balance is lead, tin and miscellaneous impurities in that order of importance, the lead running about 15 per cent. The metal is poured at approximately 2100 deg. Fahr. (1148 deg. C.), and while the metal loss is fairly high, mostly lead and some copper, about $12,000 net is saved per month by doing away with the crucibles, since these two furnaces replace forty to fifty coke and oil-fired furnaces. The high metal loss follows naturally from the use of a direct-arc furnace, since it is bound to produce a superheated top layer in the bath.

Rennerfelt furnaces of 1/3 ton (302 kg.) and 1200 lb. (544 kg.) capacity are in operation at the Gerline Brass Foundry Company's plant, Kalamazoo, Mich., and at the Philadelphia Mint respectively. At the mint some French and Italian coins composed of almost pure nickel have been handled, the lining standing up very well although the melt was at a high temperature. They use a ganister bottom with silica brick linings. This furnace should give a very good account of itself in handling alloys of this nature.

In the furnace at the Gerline brass foundry red brass, enamel tank (half red and half yellow brass with not over 22 per cent zinc content) and monel metal have been handled, but not much success was attained with yellow brass ingots. The furnaces could not handle yellow brass borings at all. This was only to be expected since neither the direct nor the indirect arc type of furnace is suited for handling alloys containing metals which volatize at comparatively low temperature unless some method is provided for overcoming the superheated top layer.

While too much reliance should not be placed on operating figures obtained as the result of experimental runs, and this remark will apply to those previously given, still as an indication of what may be expected the following results are given:

Out of four heats making monel-metal castings, three showed no metal loss and the fourth heat a loss of 3.3 per cent. The average of the actual melting time was three hours and forty-eight minutes, with a kilowatt-hour consumption of approximately 1300 kw.-hr. per ton (1444 kw.-hr. per t.). The average charge was 549 lb. (249 kg.) with an average electrode consumption of 5 lb. per ton (2.5 kg. per t.).

The results of seven heats making enamel-tank castings under fair operating conditions showed an average metal loss of 3½ per cent, with an average of actual melting time of one hour and forty-eight minutes. The average kilowatt-hour consumption was 537 kw.-hr. per ton, while the electrode consumption was 2.8 lb. per ton (1.4 kg. per t.). The average charge was 580 lb. (263 kg.).

Ten heats were selected from those making red brass castings as representing fair working conditions. The results show the average charge to be 532 lb. (241 kg.), with an average of actual melting time of one hour and fourteen minutes. The average kilowatt-hour consumption was 437 kw.-hr. per ton (485 kw.-hr. per t.) with an electrode consumption of 2.8 lb. per ton (1.4 kg. per t.).

It should be noted that the kilowatt-hours required for making red brass castings are less than those for enamel tank, which simply goes to show that experimental figures cannot be relied on for commercial practice. In order to obtain figures of value full and complete data as to all conditions should be recorded.

Regarding the whole question of labor savings, it can be stated that arrangements have already been worked out whereby pouring castings or blanks direct from the furnace can be accomplished. In the case of small furnaces these can be picked up bodily and brought to the pouring floor, while in the case of the larger-sized furnaces the molds can be arranged to pass under the spout by means of a conveyor system.

It should also be noted that very little use is made of the pyrometer for accurate recording of temperature of melt. "This, in my opinion," said Mr. Miller, "is a mistake and much to be regretted, since the primary object of the use of the electric furnace is to reduce metal losses by more accurate control and to keep full and complete daily records which can be used in determining the best practice and eliminating preventable losses."

THE PROPERTIES AND USE OF FURNACE ELECTRODES

In an issue of the London *Electrical Review* appeared an interesting article on the properties and utilization of electric furnace electrodes. The article dwells on the rate of consumption of electrodes, methods of protecting and cooling, means of attaching conductors, and arrangements for controlling the electrodes. Extracts therefrom are given in the following paragraphs:

Consumption of electrodes is due primarily to the following causes: Dissociation by current; the working voltage may be either too high or too low; chemical combination of the electrodes with oxygen; solution of the carbon in the metal, and direct oxidation by atmospheric oxygen. The electrodes should not be burned too close to the terminal clamp nor should they be rejected as new electrodes may cost £17 ($82.50) per ton and stumps may be worth only 32s. ($7.35) per ton as raw materials for fresh electrodes. The scrap value is thus only 10 per cent of the value new. To utilize the stumps arrangements can be made for fastening them to the new electrodes, using screw connections or lap-joined construction.

The most effective protection for electrodes consists of a sheath of incombustible material. Mixtures which have been proposed for this purpose are retort coke and sodium silicate; lime and limestone with carbon, and potassium or sodium silicate with chalk. These mixtures applied cold form a covering which is a good resistant to heat. Other protective coatings used are asbestos wool with silicates, milk of white clay, and silundum. The last is an amorphous compound resembling carborundum. It is refractory, incombustible, and, being a compound of carbon and silicon, it is useful for protecting electrodes in ferro-silicon furnaces. An iron netting may be used to support a paste of sodium silicate and clay or of gaolin and asbestos. Sometimes granular material unaffected by oxidizing gases is embedded in the surface of the electrode. Quartz, alumina or carborundum may be used, according to the nature of the products made in the furnace. Rigid envelopes of asbestos board or sheet iron have also their uses, though care is required to prevent air circulating between electrode and sheath, which then forms a draft chimney and intensifies the damage.

In this connection Ch. Louis recommends that the electrode be protected by an agglomerate of magnesia or dolomite, 3 cm. to 5 cm. in thickness, inside a jacket of 1-mm. sheet iron. The agglomerate is heated for mixing and contains 6 to 7 per cent of pitch and 5 to 8 per cent of tar. Adherence on the electrode is increased by chipping its surface and painting it with tar. The sheath being held in place by an external mold, the agglomerate is packed tightly between it and the electrode. The mold is then withdrawn, and a joint is made at the top between sheath and electrode by a paste of silicate or refractory earth. It is not essential to rebake an electrode thus protected.

The Gin process is to embed the electrodes in a carbon agglomerate. With this end in view the electrodes are formed of several cores (say, eight or ten), and the agglomerate is a mixture of coke or ground electrode stumps with pitch or tar. The agglomerate forms simply a mechanical bond between the electrodes. It is not traversed by any considerable fraction of the current and is, therefore, at a much lower temperature than the cores and is less exposed to oxidation. Its protective action endures beyond the point in the furnace at which iron sheathing would be melted away.

It is evident that a protective coating of any sort carries its impurities into the manufactured product, and for this reason it is sometimes better to do without the coating and simply modify the shape of the electrodes.

The rate of electrode consumption referred to unit weight of product manufactured varies widely with the product concerned and with the type of furnace employed. For instance, in the manufacture of 25 per cent ferro-silicon the electrode consumption is about 3 mm. per hour, increasing to 4 mm. when a 58 per cent silicon alloy is made. Manganese-silicon alloys involve a mean consumption of 3 mm. and calcium carbide of 2 mm. per hour. All these figures refer to covered furnaces charged continuously in which consumption is always a minimum.

In aluminum manufacture the electrode acts not only as a current conductor but also as a comburent, and its consumption is generally proportional to the quantity of metal produced—say, 700 gm. per kg. (1500 lb. per ton) of metal produced.

In steel furnaces of direct-production type, with electrodes about 2 m. long, the consumption varies with the process. The following table shows the net weight of electrodes burned effectively in various works:

Furnace	Electrode Consumption per Ton of Steel Kg.	Lb.	Remarks
Stassano, Turin	7 to 10	15½ to 22	Charged cold
Girod, Urgine	11.4	25	......
Chapelet, Allevard	11.3	24.8	......
Heroult, LePraz	17.5	38.5	......
Lindenburg, Remscheid	2.68	5.9	Fluid charge

Allowing for stumps of utilization and starting directly from ore, the average net consumption of electrodes is now 4 kg. to 5 kg. (8¾ lb. to 11 lb.) per ton of steel. In some cases electrodes have lasted for 1200 working hours, corresponding to more than six weeks of continuous operation.

Electrode Terminals and Cooling Arrangements. The manner in which electrodes are supported while being left free for up and down adjustment at will and the manner in which connection is made to the electric supply mains play an important part in the maintenance and durability of electrodes. Bad fitting may cause the electrode to become red hot at places, and this in turn leads to breakage or excessive combustion. The damage is cumulative because the resistance of carbon decreases with increasing temperature; hence current passes by preference through the overheated parts, aggravating their state and exposing them to yet more rapid depreciation.

There are several methods available for the attachment of carriers to electrodes, but the two types at present in use are clamp connections and central connections. Cooling may be secured in all cases by a water basin near the connection or by a trough of water surrounding the electrode and provided, if necessary, with radiating ribs or wings.

Electrode Cooling.—Haakon Styri suggests a simple arrangement for cooling electric-furnace electrodes by water. The cooling water comes through the armored hose to a distributing box, fastened on the outside of the columns for the electrode holders. Only three pipes go out from the distributing box—one to each electrode—each of which is furnished with a regulating valve. Where the pipe passes the roof ring a piece of rubber hose is inserted for insulation and connected with a union to the pipe which goes to the cooling ring. The return pipe from the cooling ring is connected with a union to the rubber hose, which is sufficiently long to allow for total electrode movement and some surplus to prevent kink. This rubber hose is again, by means of a union, fastened to the pipe leading to the electrode holder, and the return pipe from this is, by means of union and rubber hose, connected to the downflow pipe, which is fastened to the electrode carriage. From this pipe the armored rubber hose leads to the common waste-water box.

Leads for Furnaces. In cases where the common distance between leads is relatively great, considerable can be gained by making the leads of two concentric tubes, says Arvid Lindström

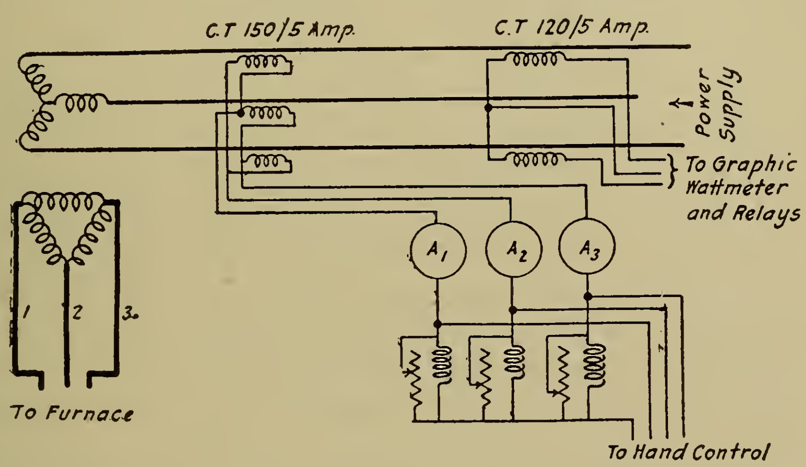


Fig. 81—Proper Connections for Balancing and Regulating Three-phase Currents in Steel Furnace

in the *Teknisk Tidskrift.* The inductance as well as the increase in the resistance will thus be a minimum. In those parts of the circuit, on the other hand, where each pole has a separate path the use of a single group of laminated bars for each lead would, in general, seem unsuitable. This is especially true where large cross-sections are involved. As near as possible to the place where the leads separate, each conductor should be divided into two groups, placed sufficiently far apart with respect to the length. With not too great a current, each of these groups may consist of a single bar whose thickness should not exceed 15 mm. to 20 mm. If the current is great, so that for practical reasons a total thickness of the bars for each group of more than 20 mm. would have to be used, tubes should be used instead of bars.

Otherwise the arrangements should be as stated previously. In general, a greater diameter of the tube (and consequently a less thickness of the walls) as well as a greater distance between the groups will give a better result in regard to the inductance as well as to the increased resistance.

HEAT TREATING BY ELECTRIC MEANS

The field of the resistance-type furnace is mainly in operations requiring temperature between 400 deg. and 1650 deg. Fahr. (200 deg. and 900 deg. C.) and includes such work as annealing and heat treatment of steel and other metals and melting of non-ferrous metals, especially those with a strong affinity for oxygen. Some data on Baily furnaces follow:

One furnace with a 20-in. by 12-ft. (50.8 cm. by 3.7 m.) hearth used for annealing brass and silverware blanks handles 1 ton (0.9 t.) of blanks per hour with an energy input of about 200 kw. A motor-driven pusher mechanism pushes pans carrying the blanks into the furnaces and discharges other pans on the other side into a quenching bath at the end of each annealing period. Another furnace of the same general type, but with its pusher mechanism automatically controlled by clock-actuated relays, is handling steel motor-car parts. Its hearth is 26 in. (66 cm.) wide by 12.5 ft. (3.8 m.) long. It is heating 800 lb. (282 kg.) of steel to 1650 deg. Fahr. per hour with an electrical input of 130 kw. A third size of this general type has a hearth 4 ft. (1.2 m.) wide by 20 ft. (6.1 m.) long. It is heating 1.5 tons (1.4 t.) of steel to 1650 deg. Fahr. per hour with an electrical rating of 360 kw. The largest size of this type in operation has a hearth 7 ft. (2.1 m.) wide and 20 ft. (6.1 m.) long and handles 3 tons (2.7 t.) of steel to 1650 deg. Fahr. per hour. It is rated at 660 kw. Equipments of this character, when automatically controlled by a contact-making pyrometer, reduce the human element to a minimum and lessen the chance for error in treatment. One man loads the pans. Drawbar knuckles and motor-car parts are among the products now being treated in these furnaces.

Another and somewhat similar type of furnace is known as the car type. With this type parts loaded on cars are pushed into the furnaces, treated and pushed out. Cast-steel parts for motor-car construction, locomotives and car axles, aluminum, copper, brass and gun castings and forgings are treated in these car-type furnaces. Among the sizes of this type now in operation are those with hearths 4 ft. (1.2 m.) wide and 10 ft. (3 m.) long, with a capacity of 0.5 tons (0.45 t.) per hour and a rating of 150 kw., and those larger sizes with 6-ft. (1.8-m.) by 18-ft. (5.5-m.) hearths with a capacity of 1 ton (0.9 t.) of steel per hour and a rating of 300 kw.

A new type of furnace that is just being put into operation for annealing steel and copper is the recuperative car type. It is arranged to accommodate two lines of cars passing through the furnace in opposite directions, so that the hot outgoing cars give up some of their heat to the cold cars on the way in. This furnace, which is 22 ft. (6.7 m.) wide and 19 ft. (5.8 m.) long, is rated at 600 kw. It will heat 150 tons (143 t.) of steel to 1500 deg. Fahr. or 350 tons (317 t.) of copper or brass to 1200 deg. Fahr. (649 deg. C.) in twenty-four hours. No covers are required to keep the metal from scaling.

Another new type of special furnace is one built for reduction of tungsten ores. It is also of the car type. The cars with their contents are, however, moved continuously through the heated furnace, which is gas-tight. After being fully heated the cars are pushed into a long discharge hood to cool slowly. The furnace is built in one size only. It is 10 ft. (3 m.) wide, 50 ft. (15.2 m.) long, and has a capacity equivalent to annealing 0.5 ton (0.45 t.) of steel to 1650 deg. Fahr. (900 deg. C.) in one hour. It is rated at 150 kw.

PYROMETER SYSTEM FOR ANNEALING FURNACES

An indicating and recording pyrometer system that is giving complete satisfaction to both the furnace operator and the metallurgist was installed some time ago by T. W. Poppe in connection with a battery of six annealing and hardening furnaces. Six indicating pyrometers with the auxiliary equipment are installed on the checkers' bench; the recording pyrometers are situated in the metallurgist's laboratory and signaling lamps are mounted over each furnace to notify the attendant when the temperatures of the furnace are high, low or correct. Three thermocouples are installed in each furnace so that the central and end temperatures can be observed, and so the operator can determine which fuel valve to operate to keep the temperature correct. To avoid the use of too many pyrometers and still not hinder the observation of temperatures, the thermocouples are connected in groups of six to three circular switches, which in turn are connected with double-pole, double-throw switches.

A small hole is provided in each furnace where the temperature is desired and the thermocouple centrally attached to a tripod the feet of which rest upon the top of the furnace. What might be called a stuffing box is provided to seal the space between the thermocouple and the furnace casing, the construction, (c) in the accompanying illustration, being such that the thermocouple can be raised or lowered by adjusting the tripod attachment. This arrangement also makes it easy to remove the thermocouples for renewal or inspection. To prevent the leads of the thermocouples carbonizing, owing to heat escaping through the holes in the top of the furnace, long enough thermocouples are used so that their upper ends can be bent at an angle of 90 deg., bringing the cold ends 1 ft. (0.3 m.) from the middle of the furnace, where the circuits run into conduits leading to the checker's bench and metallurgist's office.

All of the wires, which have asbestos insulation, are installed in iron conduit. The checker's bench being centrally situated, a 2-in. (5-cm.) conduit was installed from it to a pull box placed between the third and fourth furnaces. From this point to the second and fifth furnaces 1½-in. (3.8-cm.) conduit is used and reduced to 1 in. (2.54 cm.) where it extends to the first and sixth furnaces. From the main conduit ¾-in. (1.9-cm.) conduit extends above the furnaces to points over the thermocouples, where ¾-in. (1.9-cm.) conduit tees equipped with porcelain bushings are provided. One-and-one-half-inch (3.8-cm.) conduit is used between checker's bench and the metallurgist's laboratory.

ELECTRIC WELDING

Great economy has been effected in the Rock Island Railway system, says E. Wanamaker, by means of electric welding devices which perform a variety of services, such as cutting plates and holes, the welding together of sheets, welding of tubes to the back flue sheets and repairing holes in fire boxes of locomotives. The "metal electrode" method of welding is employed, using a soft steel wire or other metal as the negative. Direct-current energy at 20 volts is furnished by a number of portable motor-generator sets which are applicable to the considerable varieties of work. The detailed results of six months' operation, based on the expenditure of $40,000 for electrical welding outfits, show that 85.7 per cent of the cost of welding by older methods was saved by the new system and that the electrical system shows a saving of 28.5 per cent over the gas method. On the basis of results obtained thus far, Mr. Wanamaker calculates the rate of saving to be $200,000 per year. Of this, $136,000 is a direct saving in the performance of the work and $64,000 represents increased service of engines due to shorter time for repairs. By extending the use of the electric welding operation over the whole Rock Island system Mr. Wanamaker estimates a possible yearly saving of $1,000,000.

COMPARATIVE CHARACTERISTICS OF ARC WELDERS

The characteristics of the different types of direct-current welders are so well known because of their years of use that there is not much use in going into their characteristics except in a very general way. The direct-current machines are of two general classes—those which get their regulating properties from resistance and those which have the regulating properties inherent in the machine. Both are successful when properly designed and both are in use in large numbers. The machine which eliminates resistance is somewhat simpler as far as control is concerned and uses considerably less power. Where a multiplicity of operators is required the first cost of the apparatus is larger than with the resistance type. Which one is best suited to the work depends entirely on conditions, and for that reason both are used to a very considerable extent.

Characteristics of Alternating-Current Arc Welder. The alternating-current arc welder, however, is of more recent development and its characteristics are not so well known. In discussing the claims made by the sellers of this type of apparatus, J. F. Lincoln points out that as is the case with all apparatus, this type of welder has some points which are very valuable and others which are not. A consideration of the facts in the case as applied to each job will generally decide for the buyer which type should be used. The claims made for the alternating-current machine are the following: (1) No moving parts; (2) no commutator with its consequent trouble; (3) possible portability by hand; (4) high efficiency, and (5) low cost.

The first two claims are borne out except for the fact that in order to reduce the size of the welder a fan is sometimes used for cooling. A machine suitable for delivering 150 amp. for welding weighs approximately 400 lb. (181 kg.); thus it is obvious that two men may carry it around to some extent, although if it is to be widely portable as is required in most places where portability is necessary at all, a truck must be used either for this type of welder or for any of the previous types of direct-current welders.

Since there is no less in resistance and since the transformation is done by a transformer, it is a fact that the efficiency is very high compared with that of any direct-current apparatus. However, for protective reasons, it is necessary to have very large leakages in the transformer, which results in an over-all efficiency considerably less than that of a standard constant-voltage transformer. The cost also is low.

Among operating characteristics of the alternating-current welder which are emphasized by the manufacturers is the short arc obtained, which gives less chance of burning the weld. However, arcs greater than ½ in. (1.2 cm.) in length have been established by the writer with a covered electrode, although it is a fact that with the bare electrode a short arc only can be maintained. Furthermore, the welds obtained were not so perfect as the manufacturers claim should be produced regularly with this type of apparatus.

Some of the difficulties, as seen by the users of these machines, follow: (1) Heat is equal at both electrodes; (2) alternating-current welders cannot be used for carbon electrode work; (3) power factor is low; (4) considerable skill is necessary to hold the arc at all with bare electrode; (5) speed of operation is relatively low; (6) the weld is liable to be poor when using bare electrodes because of the frequent breaking of the arc, and (7) the arc tends to sputter considerably, using more electrode than if this did not occur.

In discussing these points it is self-evident that the heat at each electrode must be the same. With the direct-current welder the heat at the point where the most heat is required can be secured by making that electrode positive. This is very essential where heavy plate is being welded.

The alternating-current arc is not suitable for carbon-electrode work because when the electrode is positive carbon is carried across the work, thus very greatly changing the characteristics of the weld.

A power factor of approximately 10 per cent is usually necessary to maintain the arc at all, and a power factor of 5 per cent gives considerably better operation. This means that for an outfit which would normally deliver 3 kw. to the arc transformer connections the power-house capacity and line capacity necessary to serve it must be 30 kw. at 10 per cent power factor.

The speed of operation is low because it is more difficult to hold the arc; it is practically impossible under normal operating conditions for any man to hold the alternating-current arc continuously during a ten-hour day.

Any arc welder is good or bad, depending upon the amount of oxide included in the metal. Each time that the arc is broken there is very apt to be a little pocket of oxide formed; consequently there is very great possibility that each time the alternating-current arc breaks a defect in the weld will be occasioned. Because of the difficulty of holding the arc the weld is less reliable.

Cost of Operation. The sputtering of the electrode is something that cannot be explained positively. It probably comes from very wide variation in heat being liberated at the arc during different parts of the cycle. The fact still remains that the arc sputters very considerably more with alternating current than with direct current.

Considering the cost of operation, there are three important items: (1) Cost of equipment; (2) cost of equipment supplying the power, and (3) cost of labor in doing the welding. All three of these can be determined with fair accuracy.

The first cost of a 150-amp. alternating-current welder is about $150 and that of a direct-current equipment about $1,000. The relative cost of generating and line equipment for the alternating-current welder is about $170 per kva., and for the direct-current set about $225 per kw., or $5,100 and $680 respectively for 3-kw. sets. The comparative labor costs are approximately 100 per cent for direct current and 125 per cent to 150 per cent for alternating current. Where power is purchased the cost of energy for the two types should be considered in place of the second item above. If the rate is not based on power factor or kva. input (compared with kw. input), the cost may be less for alternating-current equipment because of its higher efficiency. However, based on the making of a certain weld, this advantage for alternating-current apparatus would probably be offset. At any rate, many central stations are now penalizing for low power factor, so the cost of power will most likely be higher for alternating-current welders.

Comparative labor costs in one of the large shipbuilding plants have been ascertained. The best operator on alternating-current apparatus could do about two-thirds as much work as the best operator on direct current. With an operator of less skill the direct current could be operated in a fairly satisfactory way, but the alternating-current outfit could not be operated.

There are no doubt improvements which will be made over the present type of alternating-current welding apparatus both as regards operating characteristics and cost which will improve both. For instance, one of these is to use, instead of a transformer, a reactance with a variable magnetic circuit. This will improve the characteristics and at the same time reduce the cost.

DATA ON SPOT WELDING

To decide whether it is better to rivet or to spot-weld an article one must take into consideration the use of the article and must not base his decision on the cost of obtaining a desired strength. In light work spot welding can successfully replace riveting in 90 per cent of the cases. There are numerous conditions where it is impossible to use rivets because the stock will not permit the punching of the hole or because the rivet head is objectionable. Special spot-welding machines can be made to take care of the difficult shapes and thus reduce the cost of an article in the saving of the rivets and dies, maintenance of dies and labor in laying out and punching the stock.

An ideal condition for spot welding, says G. A. Hughes, electrical engineer of the Truscon Steel Company, Youngstown, Ohio, is where a smooth surface is desired and the material does not permit the countersinking of the rivet heads. But spot welding is not confined to the sheet-metal industry alone. Structural steel can be successfully welded. In fact, it is being used in shipbuilding to advantage. The question that arises is, "What is the greatest thickness of material that can be success-

TABLE XXX—DATA OBTAINED USING THREE 3/16-IN. PLATES

Volts	Amp.	Kw.	P.F.	Size of Spot, In.	Condition of Materials	Auto-Tap of Transformer	Time in Seconds
232	186	17.6	0.41	7/16	Free from rust	5	44
232	176	18.4	0.45	7/16	Free from rust	5	42
232	180	18.1	0.43	7/16	Free from rust	5	44
230	256	25.6	0.43	7/16	Free from rust	7	30
230	248	24.0	0.42	7/16	Free from rust	7	31

TABLE XXXI—DATA OBTAINED USING TWO 9/32-IN. PLATES

Volts	Amp.	Kw.	P.F.	Time in Seconds	Tap of Auto-Transformer	Condition of Material
218	208	26.4	0.57	24	7	Scale and rust were present
218	224	26.0	0.53	22	7	
218	224	26.4	0.53	24	7	
218	228	26.8	0.54	22	7	
218	216	26.0	0.55	22	7	
218	224	26.4	0.54	26	7	
218	220	25.5	0.53	25	7	
218	224	28.0	0.57	22	7	

TABLE XXXII—DATA WITH DIFFERENT MATERIAL

Volts	Amp.	Kw.	P.F.	Material Used	Time, Seconds	Tap of Auto-Transformer	Size of Spot In.
220	244	24	0.54	Two 3/16-in. mild-steel plates	15	7	3/8
220	260	20	0.35	Two 3/16-in. Vasco non-shrinkable steel plates	20	7	3/8

TABLE XXXIII—COMPARISON[1] OF SPOT-WELDED AND RIVETED JOINTS

Test No.	Size of Spot, In.	Condition of Sheets, and Contacts	Maximum Load, Lb.	Nature of Failure	Number of Spots
1	5/16	Free from scale, Contacts good	4,460	Welds pulled out	1
2	5/16	Free from scale, Contacts good	7,250	Welds pulled out	2
3	5/16	Free from scale, Contacts good	10,920	Welds pulled out	3
4	5/16	Scale on sheets, Contacts poor	4,400	Welds sheared	2
5	5/16	Rust and scale. Contacts good	8,100	Welds sheared	3
6	Two-1/4-in. rivets, holes drilled and rivets inserted with care		4,700	Rivets sheared	..
7	Two-1/4-in. rivets, holes drilled and rivets inserted with care		5,200	Rivets sheared	..

fully welded?" The thickness of material will depend entirely upon its size and shape, together with the rating of the welding machine. The writer has seen two pieces of ½-in. (1.27-cm.) material—a total thickness of 1 in. (2.54 cm.)—welded on a 30-kw. machine.

The data are intended to give an idea of (1) power consumption, (2) strength of the weld, and (3) speed at which welds can be made. All the tests on which the data are based were made on 30-kw., 220-volt, 60-cycle hand-operated machines made by the Federal Welding & Machine Company of Warren, Ohio. The machines were in service for two hours before the tests were

[1] All tests were on No. 14 gage sheets, steel 3 in. wide, single lap-joint, single-shear.

made. This was to allow for the heating of the machines. Each machine had an auto-transformer in the primary circuit of the welding transformer to control the welding circuit. Taps were provided on the auto-transformer to adjust the primary voltage in eight steps from 65 per cent to full-line voltage.

TABLE XXXIV—TENSION TESTS ON SPOT-WELDED JOINTS

Test No.:	1	2	3	4
Maximum load, lb.	3,700	3,740	6,470	6,195
Nature of failure	Weld pulled out	Weld pulled out	Weld pulled out	Weld pulled out
Number of spots	1	1	1	1
Kind of joint....	Lap Single shear	Lap Single shear	Butt Double shear	Butt Double shear

Test No.:	5	6	7	8
Maximum load, lb.	4,980	4,980	7,830	7,790
Nature of failure	Weld pulled out	Weld pulled out	Plate failed	Plate failed
Number of spots	2	2	2	2
Kind of joint....	Single shear Lap	Lap Single shear	Butt Double shear	Butt Double shear

In making the test recorded in Table XXX three plates of soft steel $\frac{3}{16}$ in. (4.8 mm.) thick were used, making a total thickness of $\frac{9}{16}$ in. (13.2 mm.). The first three welds were made with the auto-transformer on tap 5. The time of welding varied from forty-two to forty-four seconds and the power demanded from 17 kw. to 18.4 kw. The fourth and fifth welds were made with the auto-transformer on tap 7. The time of welding was thirty to thirty-one seconds and the power demanded 24 kw. to 25.6 kw. All of the welds were satisfactory. (Note the power factor.) An attempt was made to weld on tap 8, but this was unsuccessful as the material next to the copper contacts would become hotter than the center plate and would be forced out from under the contacts and thus burn the material at point of weld.

An attempt was made to determine the proper pressure for the contacts while welding, since the presence of the scale and rust caused considerable arcing and burning of the material under the contacts, forcing the molten metal out and thus leaving a bad weld, although it would have the appearance of a perfect one. Upon cutting into the weld, however, it would have the appearance of a honeycomb. To avoid this trouble it was decided first to burn the rust and scale off. This was accomplished by forcing the welding contacts firmly on the material and then turning the power on the welder for a moment. This method removed the scale and assured a good contact between the welding points and the material. Then the power was turned on and the material brought up to a welding heat without arcing. This saved the cleaning of the stock and added about 50 per cent to the life of the welding points.

To determine the kilowatt-hours consumed in a day's run an integrating watt-hour meter was installed. Some conclusions made from these readings are given:

Material tested—No. 16 gage sheets, 3 in. wide; wields ⅜-in. spots.

1480	welds of two pieces No. 18 gage sheet steel.
1050	welds of four pieces No. 16 gage and one piece 3/16-in. plate.
2530	welds total in ten hours. Energy consumed, 42 kw.-hr.
680	welds of two pieces No. 18 gage sheet steel.
1350	welds of four pieces No. 16 gage and one piece 3/16-in. plate.
545	welds of one piece of No. 18 gage and one piece of ⅛-in. mild steel.
2575	welds total in ten hours. Energy consumed, 35 kw.-hr.

The number of welds made in a ten-hour period was not large owing to the nature of the material, it requiring three men to handle the work and one man to operate the machine. The result of tension tests on spot welding are given in Table XXXIV. Table XXXIII compares the use of ¼-in. rivets and spot welding.

WELDS AS A SUBSTITUTE FOR RIVETS

Electric welding as a substitute for riveting is being tested by the government at four shipbuilding yards, and so far the work is proving highly satisfactory, says the *Marine Review*. According to recent data, the process will increase the strength of the joint at least 25 per cent and decrease the time to get out a hull nearly 50 per cent. Eminent marine engineers claim that there will be a saving in labor of 60 to 70 per cent. The machine employed is the Wilson welder. At present the plates are being lap-welded, the plates being overlapped at least 2 in. (5.1 cm.), sometimes more, and each edge welded down. In the future it is the intention to butt-weld the plates, in which case they will be beveled so that when placed edge to edge V-shaped grooves will be formed, into which the welding metal will flow, leaving a welt over the top of the V. The reverse side, the one exposed to the sea, will be left perfectly smooth. By this method considerable steel will be saved which otherwise is wasted by overlapping, and at the same time the weight of the ship will be reduced. Plates 3½ in. (8.9 cm.) in thickness have been welded, this being the maximum thickness used on the particular jobs where observations are being made. The advisability of casting entire steel sections and then welding them together is also under consideration. While electric welding will eliminate the use of rivets to a large extent, there is at present a certain amount of riveting to be done in attaching the plates to the frames. It is estimated that thirty welders can do the work of 125 riveters. The Wilson welding outfit operates on what is known as the arc principle and consists of a motor-generator set, the generator of which is wound for 35 volts. The welding metal serves as one electrode, while the ship plates constitute the other electrode.

ELECTRIC HEATING VERSUS OTHER METHODS

P. H. Mitchell compares the relative amounts of heat which can be produced for one cent with various fuels and electricity at different prices as follows:

	B.t.u.
Anthracite at $8 per ton	18,000
Anthracite at $10 per ton	14,300
Bituminous coal at $3.50 per ton	48,000
Bituminous coal at $7 per ton	24,000
Peat at $4 per ton	21,000
Fuel oil at 7 cents per gal	15,500
Fuel oil at 14 cents per gal	7,750
Electricity at 1 cent per kw.-hr	3,413
Electricity at 0.8 cent per kw.-hr	4,240

From this he concludes that electric heating is feasible at $12 per horsepower, but that it is not yet an economic possibility, due to high cost and lack of available power. Electric power rates would have to be one-quarter of the present rates for electric heating to compete with heating by anthracite coal. Many millions of horsepower would be required to meet even present requirements.

CHAPTER VI

METERS AND MEASUREMENTS AS APPLIED TO INDUSTRIES

USES OF THE GRAPHIC METER

It is always wise before undertaking to motor drive equipment to find out what the real conditions are rather than to rely upon assumptions. In the early days of motor applications the besetting sin of everyday practice was installation of motors considerably too large for the job. This fault was generally an unhappy inheritance from steam-engine practice, in which it was a custom to install an engine as large as would probably be needed and then a couple of sizes larger still for good measure. When the electric motor came along there was a very strong tendency on the one hand to order, and on the other to sell, a machine of about the same rated output as the previous engine without further investigation. The penalty paid for this indiscretion was high first cost, low efficiency, and in the case of alternating-current motors abominably low power factors. Later people began to make experimental tests of the power actually required, and then reform began. By means of the graphic meter it is easy to find out exactly not only the output which may be required but also the distribution of that output through the day's work, often economically more important than the actual work required. In these days, when charges for electrical energy are commonly based on demand as well as energy required, the nature of that demand is of large economic importance, and this is precisely what the graphic meter provides ready to hand. It shows not only how much energy is required but hour by hour the probable range of variations. Indeed, it goes further and gives an exceedingly good line on the general activities of the shop, sometimes with results important to the cost of production.

There are two general varieties of graphic meters, each of them important in its own sphere and considerably used. The familiar dial instruments are extremely convenient for rough determinations of demand in terms of time, and from their simplicity they can be very handily used in keeping records over a considerable period. While not attempting accurately to register the quick variations which sometimes appear, for many uses they are quite sufficient. The curve-drawing instruments working on a continuous roll capable of a variety of speeds and giving results in rectangular co-ordinates which can readily be graphically integrated meet another class of requirements—those which require a close measurement of power involving quick variations. Cases of this sort arise in connection with some machine tools having a cycle of operations in which the input is necessarily very variable from time to time. Such graphical instruments often give extremely valuable hints for improvements in design and management. Their place is to fill the gaps necessarily left by the simpler and rougher recorders whenever close analysis becomes necessary. Both classes of recorders have their necessary uses, and both should be employed much more frequently than they are, even at the present time when their value has already become well established.

As an example of what can be done with graphic meters the following case will be cited:

Speeding Production by Using Graphic Meters. In its plant at San Francisco, Cal., the National Paper Products Company has spent considerable money to install circuits and graphic metering equipment to check the operations of its machines and men. The machines, which are of the type required to fabricate paper in rolls into paper products such as paper cans, crimped paper novelties and the like, are driven mostly through direct connection by fifty-three motors ranging from 0.5 hp. to 10 hp. in size. Every motor is arranged for connection to the checking circuits. The design of the checking system is such that its control is centralized in the office of the general manager of the plant. No one except this officer of the company knows what combinations of switches will check the different machines, but all of the employees are aware that some machine and its operator are continually under scrutiny.

The need for such a system has been well explained by A. L. Bobrick, the general manager. He said: "The principal object in installing this equipment was to get an absolute record of the running time of our machines and to check up the report sheets turned in by the operators every day. In the paper-converting business there is a great deal of time lost in making changes on the machines, and our big problem is to keep all of our machines running to full capacity at all times, as our profits depend upon the tonnage we can convert per day.

"Every morning at 10 o'clock I have production reports on my desk, showing just what each machine has done for the last twenty-four hours, this report being up to 8 A. M. of that morn-

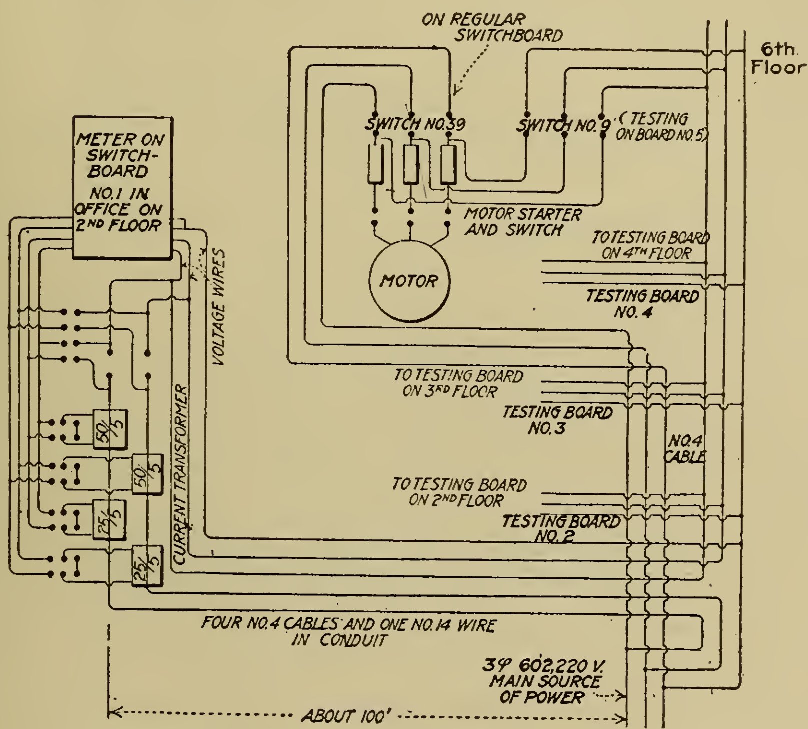


FIG. 82—SOME FEATURES OF PYROMETER INSTALLATIONS

ing. Our meter is always on some machine in the building. I usually take reports of about four machines during the twenty-four hours, and these reports are compared with the production report of the particular machine. If there is any discrepancy, either a mistake of the operator or falsification of the report, it shows up.

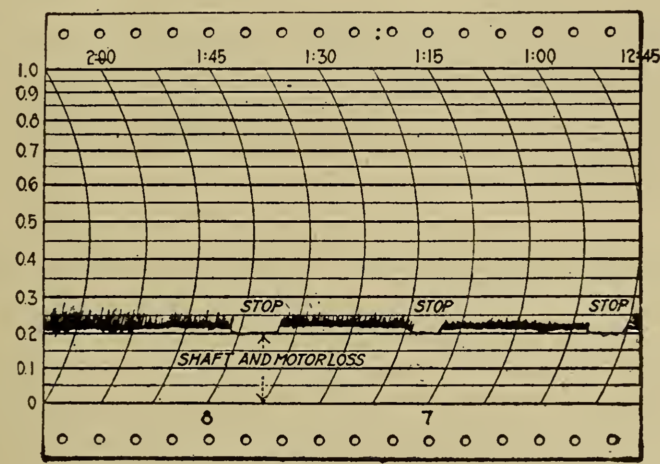
"Since most of the operations in the paper-converting industry are cutting and since the machine uses more power during the cut, it is very easy to obtain a clear record showing distinctly each operation."

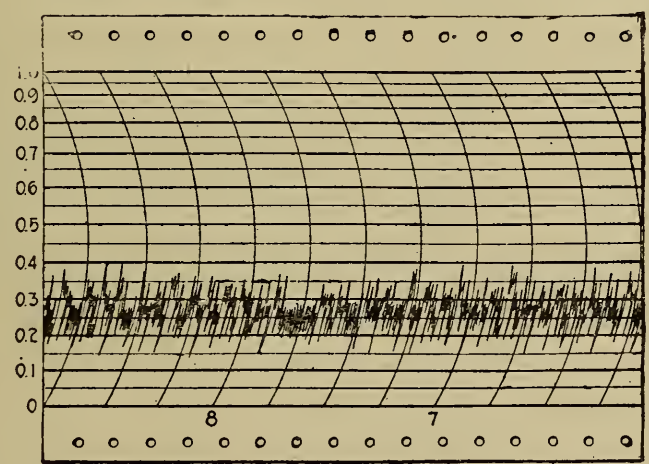
The electric features of the system are of especial interest. The apparatus consists of an Esterline 220-volt, 5-amp. polyphase graphic wattmeter with switchboard and circuit arrangements to connect it easily to any motor or group of motors in the plant. This meter, together with two 50/5-amp. current transformers, three 30-amp., single-throw, four-pole, non-fused switches, one single-throw, two-pole, non-fused switch and two 30-amp. fuse clips with two 5-amp. fuses, is mounted on a panel in the executive office. On this panel clips are also provided under two of the switches for short-circuiting the secondary windings of the instrument transformers when they are not in use.

When the plant was originally wired for motor drive, distribution panels were installed on each floor with a knife switch in each motor circuit. Alongside each of these panels an additional panel, also equipped with knife switches of the same size, was installed to carry the checking system equipment.

The checking system circuits are laid out so that by manipulation of the switches on the office switchboard and on the panelboards on each floor any motor can be taken off its regular supply circuit and transferred to a circuit running through the metering equipment in the office without interrupting the flow of energy to the motor. The method by which this is accomplished can be easily understood by reference to the wiring diagram (Fig. 82), which shows complete connections between the source of power and one motor. This diagram also indicates where similar taps are made for motors on other floors. To keep secret the switching arrangement the knife switches on the panels in the factory are numbered and the number combinations are known only to the general manager. These switches are opened and closed only on his orders. The effect of opening and closing them is to connect certain motors through the office and disconnect the regular supply.

In actual operation there are two or three methods of using this equipment. First, the meter may be switched on a certain machine and the chart arranged to feed at the rate of 6 in. (15.2 cm.) per hour. This method can be used to check a production record for the machine. Such a chart as that shown in Fig. 83 will then be produced. It clearly indicates the machine stops made by the operator on the 64-in. (162.6-cm.) corrugator, which in this instance was under observation. If a more detailed study of a man's ability to run a machine to its limit is desired, the meter can be set to run at 6 in. (15.2 cm.) per minute. This produces a record like that in Fig. 84 and shows every individual





Figs. 83 and 84—Graphic-meter Chart from Motor Driving Large Corrugator, and Type of Record Used to Study and Compare Speeds of Operators

In making the first record the chart speed was 6 in. per hour; with the second it was 6 in. per minute. The chart in Fig. 84 was obtained on a crimping machine for 4⅞-in. paper cans. The input (in kw.) to the 0.5-hp., 220-volt, three-phase, 60-cycle motor driving the machine can be obtained for any instant by multiplying the ordinate by 2. Every deflection means one can crimped.

operation. In this case the record was taken on a 0.5-hp., 220-volt, three-phase, 60-cycle motor driving a crimping machine making 4⅝-in. (14.4-cm.) paper cans. Every peak on the chart means one can crimped. The closely grouped and lesser fluctuations show idle time. A third method of operation is to connect through the meter the motors of two or more machines of different horsepower ratings and different characteristics. With this plan a record will be produced which can be interpreted by one with a prior knowledge of the characteristics of the machines. Mr. Bobrick has been able to take intelligible records on four machines at once by this method This, however, is a possibility that developed after the system was installed, as it was originally intended to give only the records of one machine at a time.

A SIMPLE METHOD OF FINDING MOTOR LOAD

Although motors in a properly equipped factory are supposed to operate at or near full rating most of the time, the assumptions on which the motor ratings were based may be in error or the load may have changed, so that it is advisable to test the power required by motors from time to time. If this is not done, the motors may operate at less than rated load unnoticed and the power factor (if they are induction motors) and efficiency will suffer thereby. While arrangements for connecting in portable ammeters are preferable, the power required can be easily checked, points out Willard S. Wilder of the meter and testing department, Milwaukee Electric Railway & Light Company, by observing the number of disk revolutions in the watt-hour meter connected with the motor circuit. Of course, if other motors or apparatus are served from the meter, they must be disconnected while the test is being made.

For most General Electric, Duncan, Sangamo and Fort Wayne meters the watt-hour constant will be found painted on the edge of the disk. On the Columbia meters the constant is on the name plate, while on the Westinghouse meters the constant cannot be found on the outside of the meter. By the use of the accompanying table the watt-hour constant can be determined for any meter, after obtaining from the name plate on the meter the make, type and capacity in amperes of the meter.

Since the watt-hour constant is the number of watt-hours consumed during one revolution of the meter, all that is necessary to do in order to compute the power (watts) demanded is to count the number of revolutions of the disk during one minute and multiply by sixty times the watt-hour constant.

As an example, take a Westinghouse type OA meter, 110 volts, 10 amp. rating. From the table the watt-hour constant is found to be 2/3. Then, operating the apparatus that it is desired to test, taking care that no other electrical device is drawing energy

TABLE XXXV—TESTING CONSTANTS FOR 110-VOLT, 60-CYCLE STANDARD WATT-HOUR METERS[1]

Make of Meter	Type of Meter	Capacity in Amperes							
		3	5	10	15	20	25	40	50
General Electric	J; J-1; JN; FN; D-1; DN	1/5	0.5	0.5	1.0	..	1.0	..	2
General Electric[2]	I; I-8; I-14	1/5	0.3	0.6	1.0	..	1.5	..	3
General Electric[3]	C; C-5; C-6; C-9; J-2; D-2	1/8	0.2	0.4	0.6	..	1.0	..	2
Westinghouse[3]	A; round	..	1/6	1/3	..	2/3	..	4/3	..
Westinghouse[3]	B; C; OA; D; C	..	1/6	2/3	1	4/3	5/3	8/3	10/3
Fort Wayne[4]	K; K_1 K_2 K_3 (above serial No. 345,000)		0.25	0.5	0.75	1	1.25	2	2.5
Sangamo	F		1/2	2/3	..	4/3	..	8/3	..
Sangamo	D		2/3	2/3	..	4/3	..	8/3	..
Columbia[3]	All		5/18	5/9	5/6	..	25/18	..	25/9
Duncan	No. 150,000)		0.25	0.5	1	..	1	..	2

[1] For 220-volt meters double the constant.
[2] For polyphase meters double the constant.
[3] For three-wire and polyphase meters double the constant.
[4] For three-wire meters double the constant; for polyphase meters multiply the constant by four, except type K_3 polyphase meters, for which the constant is doubled.

at the same time, the number of revolutions of the meter disk for one minute on are counted. Suppose this came out thirty revolutions. Then the power demanded would be $30 \times 60 \times 2/3 = 1200$ watts.

A table could be prepared in which sixty times the watt-hour constant would be given, but this might not be convenient to use when it was desired to count the revolutions for less or more than one minute. If the timing period is other than one minute, the multiplying factor is watt-hour constant ÷ period in hours.

METHOD OF TESTING METERS AT TWO POWER FACTORS

A meter-testing panel has been developed by Joseph N. M'Clurg, foreman of the meter department of the Scranton

Electric Company, which may be helpful in testing single or polyphase meters of 0.5-amp. to 100-amp. ratings at 110, 220 and 440 volts. It is represented in Fig. 85.

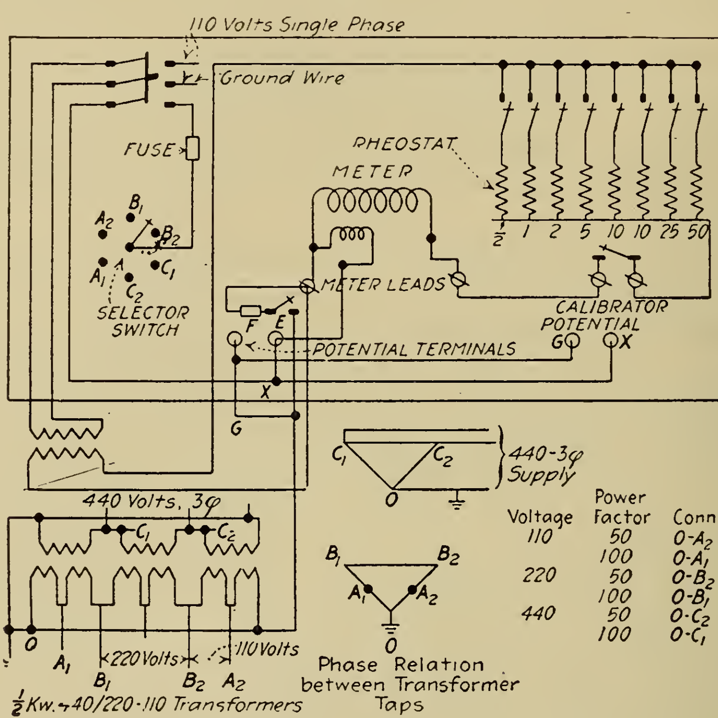


Fig. 85—Wiring Diagram and Phase Relation Between Transformer Taps

The load consists of old direct-current arc-lamp resistance coils connected with an old 5-kw., 2200/110-volt transformer operated at reduced voltage to obtain 20 volts on the secondary. The selector switch gives 110-220-440 volts, 50 and 100 per cent power factor. The connections for giving different voltages and power factors are indicated in the accompanying diagram. Switch *E* is closed when testing single-phase meters, one potential lead being fastened to the line terminal of the series coil in the meter. This switch is opened if the potential coil is not joined with the current coil. It has individual terminals.

From the vector diagrams at the bottom of the illustration it may be seen that if the load current is in phase with vector OC_1, OA_1 or OB_1, 100 per cent power factor will be obtained by connecting selector switch with contact A_1, B_1 or C_1, the voltages being 110, 220 and 440 volts respectively. When connected with

A_2, B_2 or C_2, however, the voltage is 60 deg. out of phase with the current, so 50 per cent power factor will be obtained.

TESTING THE LOADS ON DISTRIBUTION TRANSFORMERS

A transformer testing outfit that consists of a split-type current transformer with two windings connected to a low reading ammeter with a 48-ft. (14.6-m.) duplex stage cord is used by the Portland Railway, Light & Power Company of Portland, Ore. Two scales, one for each winding, were calibrated with standard instruments. The low scale has a range of from 5 amp. to 40 amp. and the high scale from 45 amp. to 150 amp. A two-point dial switch mounted on the side of the current transformer is used for changing scales. The contact bar on this switch touches one button before leaving the other, so that in changing from one scale to the other the circuit is not opened.

All testing is done on the secondary side of the transformers, generally in the outside legs only, and in each direction from the transformer. In this way the total load on the transformer is obtained. The conditions of balance between the two sides of the line are shown and also how near the transformer is to its center of load.

In using this outfit it is, of course, necessary to test at a time when the peak load is on.

In addition to testing transformers, this outfit is frequently used to test motors and also to test the current in 2400-volt circuits to determine how the current in the three phases was balanced up and to determine the load on a branch circuit. This scheme was suggested by W. C. Heston and R. E. Thatcher.

CHAPTER VII

HANDLING MATERIAL IN INDUSTRIAL PLANTS WITH ELECTRIC TRACTORS

For handling materials in industrial plants the electric industrial tractor has unique advantages. It is handled with extreme ease even by comparatively inexperienced men. It is economical in service, quick in operation and entirely free from the fire dangers which tend to discourage the use of gasoline trucks in and about buildings. The truck for this purpose is developed in the form of a tractor which picks up loaded trailers and transfers them from cars to storage or vice versa, thereby dispensing with a very large amount of manual labor and a corresponding amount of expense. It should be noted in this connection that electric power is one of the few things which has not advanced materially in price, while war conditions have greatly enhanced the wages of even the most inexperienced workers. Most of the work around industrial plants has customarily been done by hand trucks, slowly and at large expense. The tractors, handling loads up to about 25 tons, do the large amount of actual haulage necessary with far greater rapidity and at a much lower cost, requiring a reduced number of men for the actual work of transferring the goods from the tractor back to the cars in half an hour the tractor can do the same haulage that would require six men for three hours, while itself requiring the services of only two men, leaving the rest of the gang free to speed up the actual work of loading.

The following information by F. C. Meyers, formerly with the Society for Electrical Development, relates to some specific cases:

Table XXXVI shows some statistics on electric industrial-truck freight moving taken from one of the most representative steam railroads operating east of the Missippi. There are shown the saving in time and the reduced amount of labor required—both of which spell money, the money that railroads need and are begging for. Other data show some typical instances of economy in labor and time in freight handling of various commodities.

TABLE XXVI—PERFORMANCE OF TRACTORS

DAY OPERATION (TWO TRACTORS), ELEVEN GANGS, FORTY TRUCKERS	
Total amount of tonnage handled, lb.	1,624,733
Average tonnage per gang, lb.	147,703
Average truckers per gang	3.6
Average number of pounds per trucker	41,029
NIGHT OPERATION (FOUR TRACTORS), FIVE GANGS, THIRTEEN TRUCKERS	
Total amount of tonnage handled, lb.	643,058
Average tonnage per gang, lb.	128,611
Average truckers per gang	2.6
Average number of pounds per trucker	49,466

The figures show that in the day operation with eleven gangs, assisted by two tractors indiscriminately helping, the average tonnage per trucker was 41,029 lb. (about 18,600 kg.), or 20.5 tons per day. In the night operation, which was made a full tractor operation with four tractors doing all the work for five gangs and a man less per gang than in the daylight, the average tonnage per trucker was 49,466 (about 22,400 kg.), or 24.7 tons per night. From these figures it will be observed that for this day's work full tractor operation shows an increased tonnage per man of 4.2 tons over that of mixed hand and tractor operation.

The tractor in one-half hour does the work of six laborers in three hours, or in the ratio of thirty-six to one. In minor operations, such as towing large machinery on a six-wheel truck, dragging heavy cable chains into and from cars, pulling in shore gangplanks and moving large crates of 5000 lb. to 10,000 lb. (2267 km. to 4535 km.) each, the tractor did the work of twelve men. Two men were required for rollers.

The labor saving is shown by the comparative figures on labor requirements to move miscellaneous freight given in Table XXXVII.

In one instance with hand trucks on a short haul a load of 49,881 lb. (about 22,600 kg.) required twenty-four men two hours. With a truck and trailer 73,097 lb. (about 33,110 kg.) required but ten men two and one-quarter hours. On a 200-ft. (60.9-m.) longer haul 106,700 lb. (about 48,200 kg.) used the services of twenty-four men ninety-three hours with hand trucks, while with a truck and trailer 173,353 lb. (about 78,500 kg.) took only ten men sixty-two hours. With one tractor 48,876 lb. (about 22,150 kg.) can be hauled 600 ft. (182.8 m.) in twenty-five minutes, but a hand truck requires one and one-half to two hours.

In the case of freight packed up on various piers on trailers waiting for tractor, the tractor does in one-half hour what otherwise required two laborers three hours each. Only two men, a chauffeur and a conductor, are required with electric transportation.

At one place of 10,000 population this railroad is using one tractor with two men to move barrels weighing 260 lb. (118 kg.) each 450 ft. (137.1 m.) from a barge to cars up the ramps. The tractor moves thirty barrels in three minutes, where formerly one man with assistance up the ramps moved one barrel in six minutes on a hand truck.

At another point the road formerly employed 132 truckers. Now it is doing this work with tractors and trailers with seventy-three men and is handling 500 tons a month more freight than formerly.

On July 16 at one transfer point there were employed 165 men; on July 17 tractors and trailers were installed and the number of men was reduced to 117, while the freight was handled more expeditiously than formerly. Since this date the tonnage has increased approximately 500 tons, and the number of men has not been increased.

The following data were taken from installations which have proved the industrial truck to be both a time-saving and labor-saving device:

In the handling of lumber 12 in. by 12 in. and 14 ft. to 20 ft. long (0.3 m. by 0.3 m. by 4.2 m. to 6 m.) fifty pieces were carried on each load, a total round-trip distance of 600 ft. (182.8 m.) with two trucks. Two round trips were made and required four men and took thirty minutes' time. This amounted to a total of 2000 ft. (609 m.) of board lumber, weighing about 3500 lb. to 4000 lb. (1578 kg. to 1814 kg.) per 1000 ft. Four men's time at thirty minutes, at the rate of 30 cents an hour, would be 60 cents. The charge for running this machine a full working day of ten hours is $1.25, or 6 cents for half an hour. This, added to labor cost, would be a cost of 66 cents to move 2000 board feet a total distance of 600 ft.

In another operation where lumber was handled, the size of which was 12 in. by 16 in. by 11 ft. (0.3 m. by 0.4 m. by 3.3 m.) long and the total weight 600 lb. (272.1 kg.), six pieces were carried on each load, making a total weight of 3600 lb. (1632 kg.). In one hour, two trucks and eight men moved ninety-six pieces of lumber, a total weight of 29 tons, a round-trip distance of 800 ft. (243.8 m.). The recapitulations of this show that 29 tons of lumber, or 16,900 board feet (5151 m.), were moved a distance of 12,800 ft. (3901 m.) by eight men and two industrial trucks in one hour. The labor, at the rate of 30 cents, amounted to $2.40. Wear and tear, depreciation and charge for running truck, at the rate of $1.25 for a ten-hour day, would amount to 25 cents for two hours, which, added to the above cost, would amount to $2.65. This is at the rate of 9 cents per ton.

TABLE XXXVII—COMPARATIVE LABOR SAVING, TRAILERS OVER HAND TRUCKS

	Lb.	Trailers	Hand Trucks, Men
40 boxes oranges	3200	3	10
102 half chests tea	7680	5	25
12 casks tobacco	2520	3	12
63 chests tea	4390	4	17
85 pig tins	8075	2	21
146 barrels groceries	3400	4	29
66 boxes oranges	5280	3	17

In the handling of miscellaneous freight three electric trucks and ten men moved 53 tons a round-trip distance of 450 ft. (137.1 m.) and required five and one-half hours' time. This, at the rate of 30 cents an hour, amounts to $16.50, and, added to charges against the truck of 28 cents, amounts to $16.78, or at the rate of 32 cents a ton.

In the same operation the following was the cost of handling miscellaneous freight by hand trucks. Thirty-three tons were carried by six men with hand trucks, four men being required to load and unload, a total distance of 375 ft. (114.3 m.) in five and one-half hours' time, and this, at the rate of 30 cents an hour, amounted to $16.50 to move thirty-three tons, or a total of 50 cents per ton, showing a saving of 16 cents a ton in the use of electric trucks, which covered one and a fifth times the distance of the hand trucks.

In the handling of coffee in bags, the weight of each bag being 240 lb. (108.8 kg.), a total of 118 tons was carried on two electric trucks, which made ninety-eight trips, each 200 ft. (60.9 m.) long, and required the service of fourteen men for five hours. This, at the rate of 30 cents per hour, amounted to $21, or allowing $1.20 for wear and tear and depreciation of trucks, to $22.20 to move 118 tons, or at the rate of 18 cents a ton.

TABLE XXXVIII—COMPARISON OF LABOR REQUIREMENTS, TIME OF OPERATION AND LOAD WITH HAND TRUCKS AND WITH TRACTORS AND FOUR-WHEEL TRUCKS

	Hand Trucks, Aug. 14, 1917	Tractors Aug. 21, 1917
Trucks in line 4 p. m.	30	19
Trucks in line 4.30 p. m.	22	22
All backed up	6.19 p. m.	5.15 p. m.
All unloaded	6.30 p. m.	5.40 p. m.
Total number of packages handled	3875	5350

Coffee in 135-lb. (61.2-kg.) bags for distances up to 160 ft. (48.7 m.) is being handled in one place by electric trucks for 6 cents a ton. Rags in 500-lb. (226.7-kg.) bales cost up to 18 cents a ton with hand trucking. Sixty-four 800-lb. (362.8-kg.) barrels of plumbago were moved 60 ft. (18.2 m.) in twenty-five minutes for 5.3 cents per ton with electric trucks, while sixty-three 800-lb. barrels of plumbago were moved the same distance in two hours, costing 14 cents a ton, by hand trucking. Four men were required to guide and push the hand trucks up an incline.

One hundred and fifty 300-lb. (136-kg.) boxes of rubber were moved 75 ft. (22.8 m.) in fifty minutes for 8¼ cents per ton. By hand trucks the cost was 18 cents per ton at an Eastern terminal.

CHAPTER VIII

OUTDOOR SUBSTATIONS

THE MODERN OUTDOOR SUBSTATION

When the outdoor substation first appeared as a new and distinct type of construction a great many objections were raised against it by engineers and operators. Some thought that outdoor apparatus would not work satisfactorily under conditions of cold weather and snow; others held that it was not advisable to expose apparatus to the sun, and again others objected for the reason that apparatus placed outdoors would not receive so much attention from operators as it does when housed. All these and other objections have now been practically overcome, says M. M. Samuels, and many of the objectors have been so convinced of the advantages of placing high-tension apparatus outdoors that they would now strongly object to housing it. Thus the outdoor station, although of very recent creation, has come to be generally accepted as a matter of course. Most high-tension apparatus, regardless of whether it is for indoor or outdoor service, is now being built to stand up under outdoor conditions. Outdoor transformers, outdoor oil circuit breakers, outdoor metering apparatus and outdoor lightning arresters are now standard with all manufacturers of high-tension equipment and are as reliable in operation as any indoor apparatus was, and perhaps even more so.

Transformers.—Many improvements in outdoor transformers have been made within the last year or two. Terminal troubles have practically been eliminated, all high-tension transformers now having their terminals on top of the case instead of on the side. Furthermore, no more difficulty is being experienced in laying out the proper connections to their terminals. The necessity of climbing ladders or mounting platforms for the purpose of reading transformer temperatures and the danger connected therewith have been done away with, since modern transformers are equipped with electrical temperature indicators, which can be mounted so that the reading can be done from the ground, or where a switchboard is available in a nearby building the temperature indicator can be placed on this switchboard. Some difficulty is still being experienced when it is necessary to read the oil gage, since no indirect method for this reading has yet been developed and the gage must be mounted at a considerable height near the top of the transformer tank.

Large transformers of the older type were water-cooled, requiring elaborate piping and pumping installations, cooling ponds or cooling towers. This was always a source of worry to operators as well as to station designers, since outdoor piping and water pumping were very difficult to design properly, and since in the winter time great difficulty was usually experienced in maintaining the equipment in good operating condition. Modern transformers are therefore being designed for self-cooling. Most of the units are of the radiator type, this construction having given satisfaction even for large transformers of very high voltage.

The Oil Circuit Breaker.—Oil circuit breakers of high rupturing capacity and designed for voltages of 150,000 have withstood the severe operating conditions obtained out of doors and may be considered thoroughly reliable. However, with ever-increasing voltages the oil circuit breaker is increasing enormously in size, and it will probably reach its limit soon, when it will become necessary to develop entirely new methods of switching and of breaking the circuit. It is likely that when line voltages go up to 250,000 and higher the present type of oil circuit breaker will have to be of such large proportions and will require such enormous quantities of oil that its use will be impossible.

Lightning Arresters.—The lightning arrester has also been greatly improved within recent months. Many new devices have been introduced to prevent the burning out of charging resistances and the blowing up of tanks. The oxide-film arrester which was placed on the market recently promises to overcome many of the objections to the older types of arresters, but it has not been in operation long enough to make it possible to give accurate figures as to its operation, particularly for very high voltages and outdoor use.

Choke Coils.—The improvements made recently on choke coils are practically all of a mechanical rather than electrical nature. Good choke coils have been developed which maintain their shape under operating conditions. and the flimsy coils of the past, in which the windings often came in contact with each other and even melted together, are gradually disappearing. However, there does not seem to be any agreement among manufacturers as yet on the proper dimensioning of choke coils, such as diameters, shapes of conductors, number of turns and amount of reactance. Since engineers asking bids on choke coils, as a rule, do not specify their requirements except as to current and voltage rating, competition tends to make manufacturers reduce the copper to a minimum, which, of course, does not result in reliable coils. This subject should be thoroughly considered by the standardization committees of the A. I. E. E., the N. E. L. A. and other societies interested, and an understanding should be reached as to what constitutes a standard choke coil for a given voltage, a given current and a given frequency. At present no distinction is being made between choke coils of various frequencies.

Air-Break Switches.—A great many types of air-break switches, disconnecting switches, busbar supports, etc., have been developed for outdoor use and have been tried out and found satisfactory under all kinds of weather conditions, even though this line of apparatus still offers and will continue to offer for some time to come a large field for new inventions and developments.

There are two distinct types of air-break switches and mechanically operated disconnecting switches on the market at present. In the first type the motion of the blade is affected by an insulator which pivots around its own axis. The insulator being exposed to torsion at every operation, its top, to which the blade is attached, or its pin very often breaks and causes considerable operating trouble. In the other type the motion of the blade is affected by an insulator which rocks around a shaft at right angles to the center line of the pin. With this type the porcelain is always exposed to a bending moment and breaks even more often than with the pivot type. Neither of these types, although both give excellent results in many cases, can be considered as final. New apparatus will have to be developed based upon sounder mechanical principles and operating experience. Ice and sleet trouble on air-break switches, although partly overcome, should still be the subject of thorough study by switch designers and inventors if a perfect air-break switch is to be developed. The hoods which are generally used as sleet protectors do not always serve their purpose; they very often act as accumulators of ice and snow rather than shields. New methods will have to be devised to protect the switch contacts.

Bus Supports.—Various types of bus supports are now obtainable, suitable for outdoor substations and arranged to accommodate copper pipe of various sizes, both for horizontal conductors and for vertical conductors. While the post-type or pillar-type supports are both too heavy and too expensive for the purpose, petticoat insulators with suitable cap and pin design are satisfactory for solid (non-flexible) buses in outdoor stations. For vertical conductors it is advisable to mount the insulator at 45 deg. to the horizontal to prevent rain water from accumulating on the inside of the petticoats. This can be accomplished by the use of properly designed angular pins and angular caps. The part of the support which is to be attached to the steelwork, be it the pin or the cap, should not have more than two bolt holes, so that it can be accommodated on a single steel member. If three or four more mounting bolts are used, it is necessary to provide two steel members for each support. Either the cap or the pin or both should be adjustable so that the support can be mounted either on a steel member which runs parallel to the conductor or at right angles to same. It is very essential to have this adjustment since it is generally necessary to order bus support before the station steel design is finished and is not possible to tell in advance exactly how each member will be arranged.

Status of Station Design. In spite of the wonderful improvements made within the last year or two on outdoor apparatus, most of the designs of the outdoor stations themselves are still open to a great deal of criticism. Most designers of outdoor stations still persist in using the old primitive method of setting four heavy steel towers, one in each corner of the station, and of connecting these towers in both directions by heavy steel trusses and span wires. Many times when it is necessary to make a connection between pieces of apparatus a span extending from one support to another is installed even when the apparatus to be joined is close together. This, of course, requires very heavy steel work and an endless amount of floor space. In addition to this, strain disconnecting switches or other types of hook-operated disconnecting switches are installed at great heights, and it is necessary to build high platforms to make it possible to operate these switches even when using the clumsy switch hook of 12-ft. or 15-ft. (3.7-m. to 4.6-m.) length. Under present conditions, when every economy is of extreme value and when the waste of steel must be considered a crime, more consideration should be given this subject by designers of outdoor substations.

It is obvious that when strain insulators are used and a strain span is installed for every bus, connection or tap the steel work will have to be very heavy (strong enough to take care of all the pulls to which it is subjected), whereas if a solid bus is used the steel work may be comparatively light, since it has only to carry the weight of buses, connections and insulators. The tendency in outdoor substation design must therefore be to eliminate strain spans and substitute solid bus work.

It must, of course, be admitted that, whereas it is a comparatively easy matter to design a station of the strain-span type, the design of a solid bus station requires a great deal of skill and designing ability. But when the results are considered it is well worth while to apply the best designing skill to developing outdoor stations which will occupy the minimum of space and will require the minimum of steel.

In addition to the economy in steel, the solid-bus type of station has a great many more advantages as regards safety and continuity of operation. For instance, in the strain-span station any injury to even one disk insulator may cause a wire to drop across the buses, short-circuiting them and thus putting the whole station out of service. This is not likely to happen to a solid bus.

In order to reduce the number of insulators in the solid bus station to a minimum, tubing should be used for conductors in preference to wire or bar. Insulators spaced about 10 ft. (3 m.) apart on $\frac{1}{2}$-in. (13-mm.) pipe bus will generally give a good appearance, whereas when a wire or a bar is used as a conductor supports will generally have to be installed every 4 ft. or 5 ft. (1.2 m. or 1.5 m.).

In addition to the above-named advantages of the solid bus station the possibility of extension must be considered. A strain-type station is generally dead-ended, and a great deal of difficulty is experienced when it becomes necessary to add feeders or transformer circuits, whereas the solid-bus station can be designed as a unit type, so that any number of circuits can be added at any time and it is not necessary to make the initial installation of steel work and concrete heavy enough to take care of future requirements.

The general requirements to be met in the design of outdoor substations are: (1) simplicity, (2) safety, (3) a minimum of steel, (4) a minimum of space, (5) flexibility and interchangeability of circuits, and (6) possibility of extension without disturbing old circuits. All connections should be made by clamp fittings, so that apparatus can be disconnected, removed or replaced without keeping the circuit or the bus out of service for an excessive period of time. Soldered or welded joints should therefore be avoided as much as possible. When running a pipe connection from a transformer or a switch to a bus care should be taken to allow for expansion and contraction, otherwise the bus may be pulled off its supports or the insulators broken. One right-angle turn in each connection will generally be sufficient for the purpose, and it is never necessary to provide unsightly loops.

The 45,000-volt station shown in Fig. 86 is a good illustration of the unit-type idea. This station shows that with skillful designing the unit idea can be applied even when strain insulators are used. Strain insulators had to be used in this case because they were readily available, whereas solid bus supports could not be obtained within the time allowed. It will be noted that with this type of design the lines can run into the station from any direction.

The lightning-arrester horn gaps are placed at the very top of the structure, and the lines go directly to the gaps and thence to the electrolytic tanks without any loops or semi-loops in the discharge circuit. This arrangement should be adhered to wherever possible, since a direct path from the line to the arrester is always the best.

Provision is made on the low-tension side of the transformers for phasing out. Three bars are installed the full length of the three transformers which make up a bank, and connection bars are provided from each transformer to these buses, so that whenever it is necessary to interchange a phase it can be done by simply interchanging the connection bars, which are attached to the buses by means of clamps. This arrangement is preferable

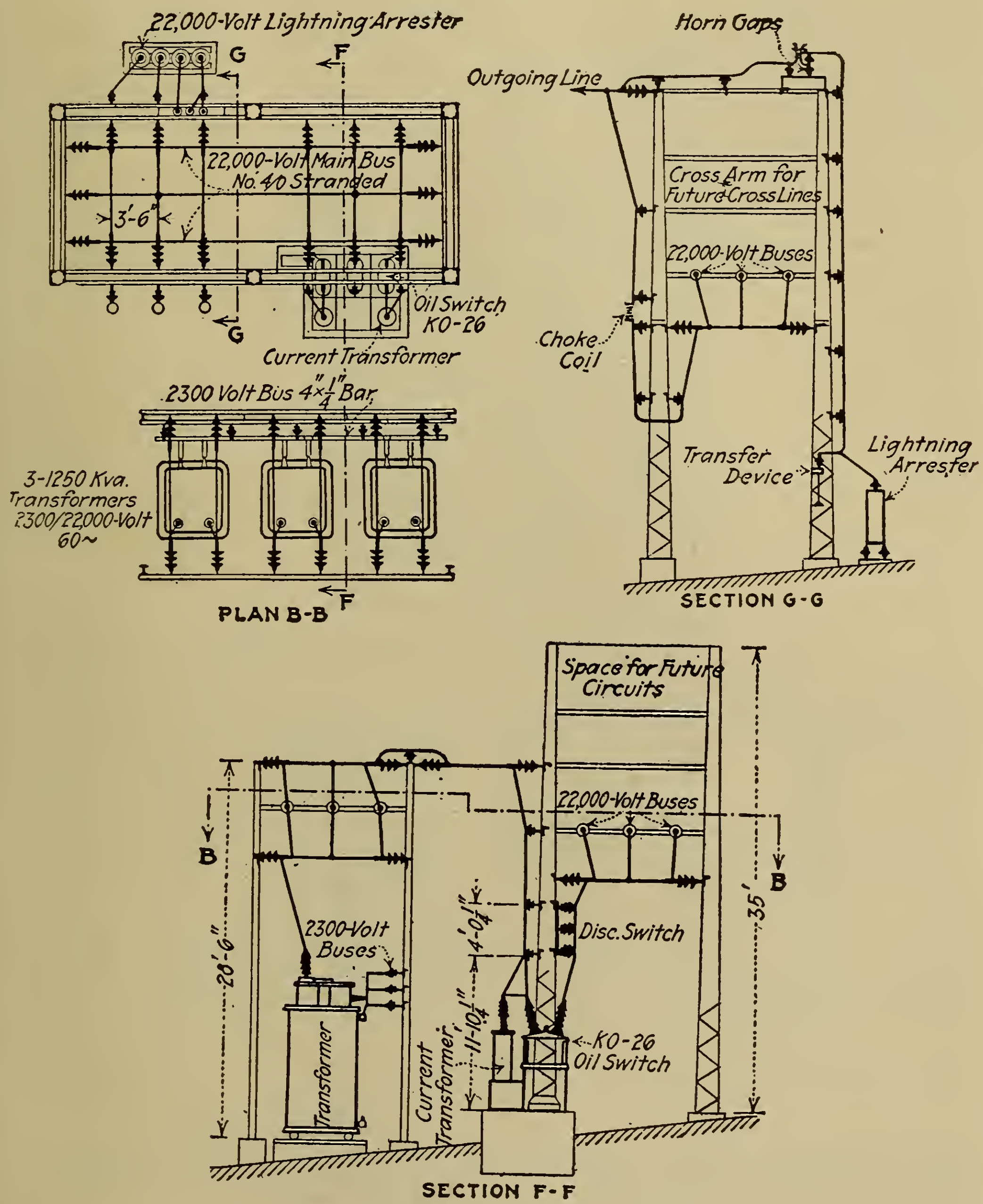


Fig. 86—45,000-volt Unit-type Substation

to the phasing out of the high-tension side of the transformers. The low-tension circuits connect with underground cables through a set of potheads mounted on one of the steel columns.

Bar connections are provided between the potheads and the low-tension transformer delta buses.

Fig. 87 shows a 45,000-volt station which is similar in type

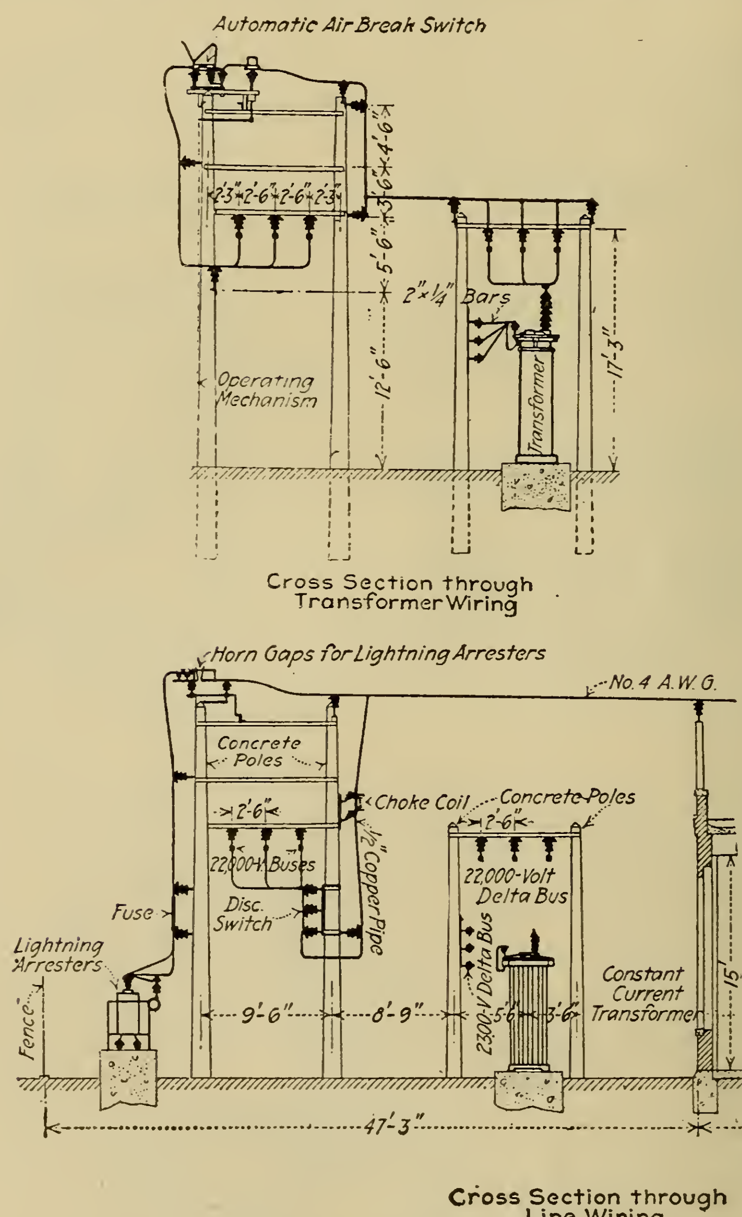


Fig. 87—45,000-volt Substation Employing Pin Insulators, thus Permitting Use of Concrete Poles

to the one above, with the exception that it is a solid-bus station The use of a solid bus made it possible to use concrete poles instead of steel, thus not only reducing the cost but making it possible to complete the work in a much shorter time than would be possible with steel poles on account of the long delivery on steel. If strain buses were used, concrete poles would, of course, be out of the question. There are other interesting features in this station. It is a combination indoor and outdoor station. The 2300-volt switching and the instrument switchboard are housed, whereas the transformers and the high-tension switches are outdoors. The line is equipped with an automatic air-break

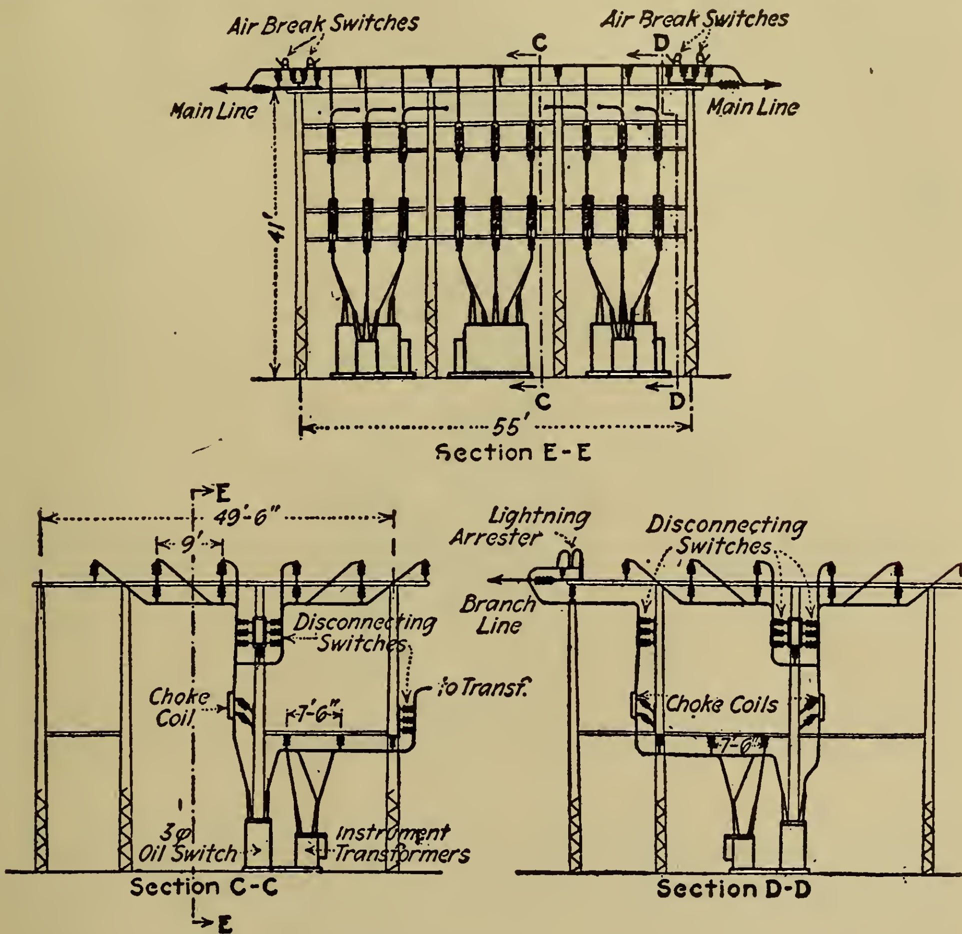


Fig. 88—Outdoor Station Equipped With Oil Circuit Breakers and Metering Equipment (See Fig. 89)

switch which was considered sufficient for the present load. However, as may be seen in the cross-section, provision has been made for the installation of oil circuit breakers to replace the automatic air-break switches as the load on the line increases.

Two sizes of concrete poles are used in this structure. The larger ones, used to support the line equipment, are 33 ft. (10 m.)

long and have 18-in. (45-cm.) square butts and 8-in. (20-cm.) square tops. The smaller poles used for the transformer wiring are 23 ft. (7 m.) long and have 15-in. (38-cm.) butts and 8-in. (20-cm.) tops.

The 33-ft. poles have ¾-in. (19-mm.) reinforcing bars in each corner extending the entire length of the pole. Besides these there are two rods symmetrically placed in each of two opposite faces. These additional rods extend from the base 17 ft. (5 m.) up the pole. The rods are tied together about every 2 ft. (60 cm.). To permit attaching the steel cross members used in the station 1¼-in. (32-mm.) standard steel pipe is cast in the poles through which to run the clamping bolts. The 23-ft. poles are similarly reinforced in the corners but lack the additional reinforcing.

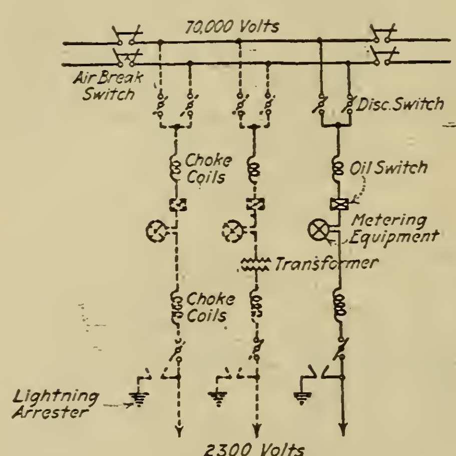
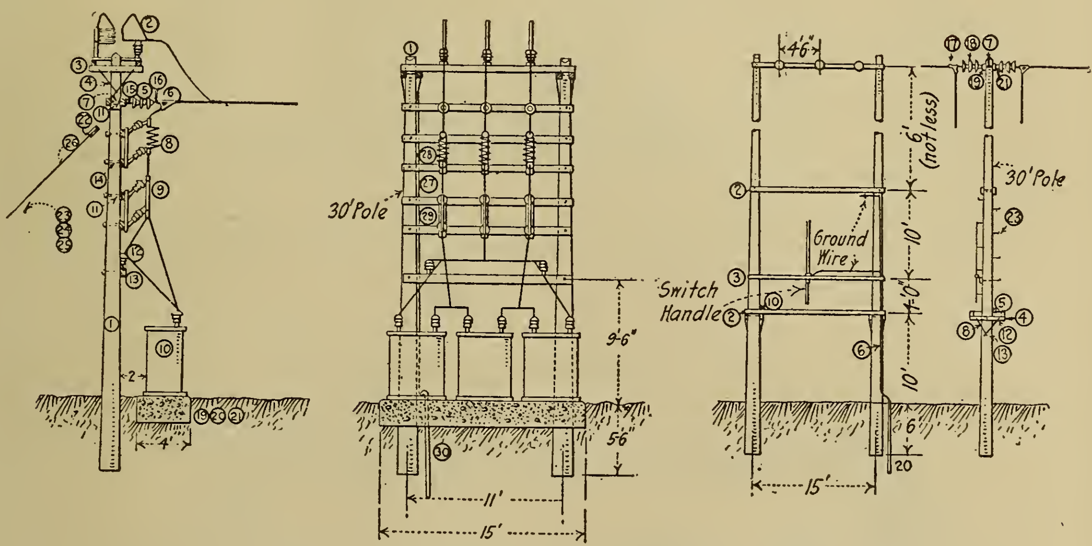


Fig. 89—Schematic Diagram of Connections for Stations Shown in Fig. 88

The argument is often heard that whereas in stations of comparatively low voltages a solid bus may be satisfactory, this construction is not advisable with stations which must operate at very high voltage, because a greater distance must be maintained between conductors and because of the extensive use of pole-top switches. This is not at all true, since solid-bus stations have been designed, built and maintained for 75,000 volts and even higher.

A station in which pole-top air-break switches, vertically mounted disconnected switches, oil circuit breakers and outdoor metering equipment are used is shown in Fig. 88. High-tension metering equipments are now standard apparatus and operate satisfactorily. They generally consist of an oil tank in which are contained two current transformers and two potential transformers, requiring a total of only three high-tension terminals, whereas if each current and potential transformer had its individual tank a total of six high-tension terminals would be required. The meter itself is generally placed in a steel compartment on the side of the metering equipment. If a building is nearby, the meters may be installed inside by simply running the secondary instrument leads from the instrument transformers to the metering equipment in an underground conduit or overhead on a messenger suspension.



FIGS. 90 AND 91—TWO-POLE TRANSFORMER STATION AND TWO-POLE SECTIONALIZING STATION

Outdoor substations should be well lighted for the purpose of inspection and repair by night. Floodlighting, has been found to be not only preferable to other forms of illumination but the only satisfactory method, and it is now in common use.

All of the stations described above which may be considered models of modern outdoor stations were designed and installed by the J. G. White Engineering Corporation of New York.

COST OF OUTDOOR SUBSTATIONS

Data on the cost of outdoor substations are given here that apply to the types of construction shown in Figs. 90–92. The

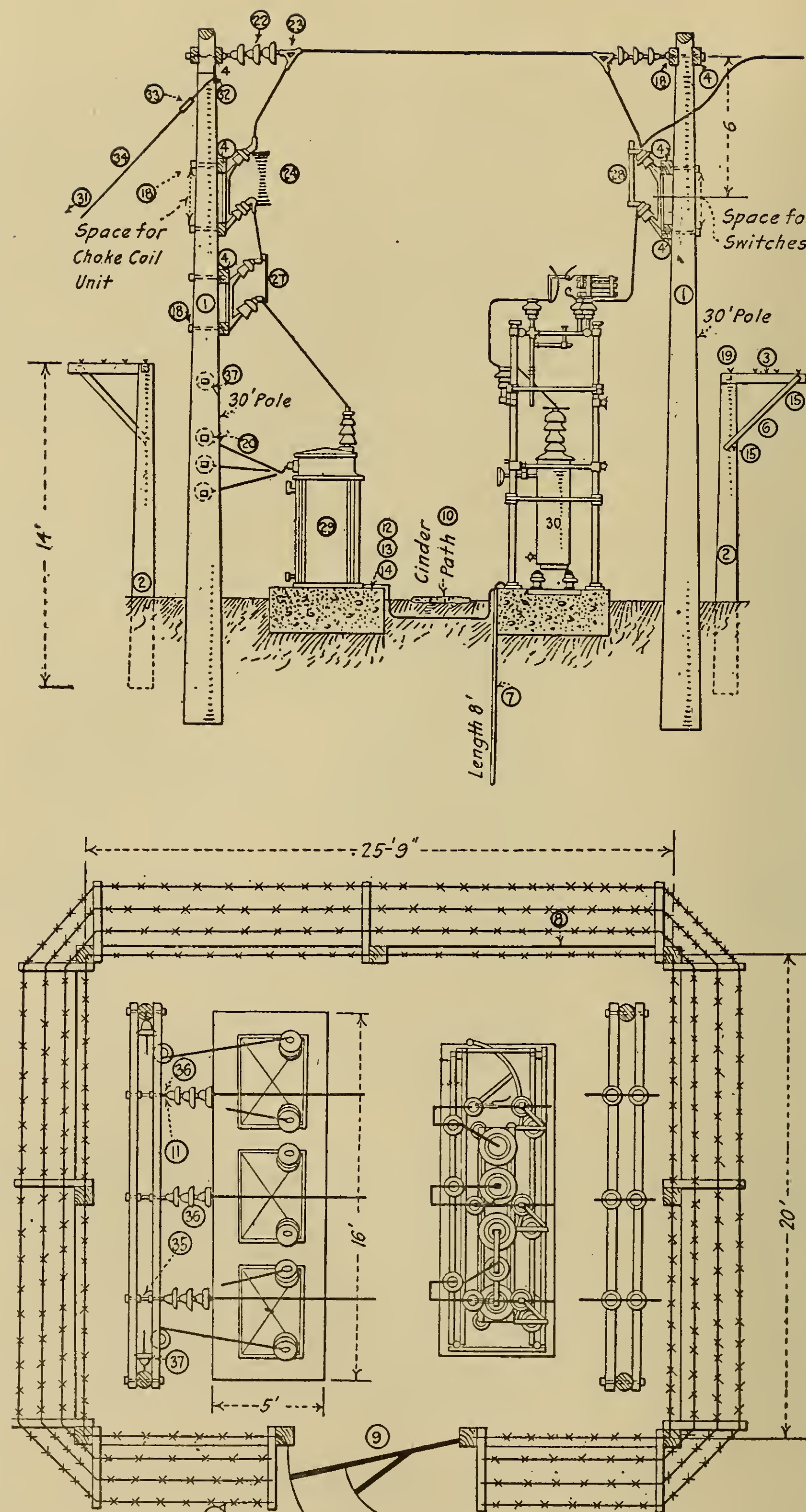


Fig. 92—Elevation and Plan of Four-pole Substation

information was obtained from the Southern Illinois Light & Power Company of Hillsboro, Ill.

The cost of a two-pole station of this type without transformers and without the switch structure, which is built separately as shown in Fig. 90, is $773. An itemized statement of this expense is given in Table XXXIX below.

TABLE XXXIX—ITEMIZED COST OF TWO-POLE SUBSTATION

Material	$424
Labor	100
Superintendence	10
Interest and miscellaneous contingencies	40
Freight and drayage	100
Ten per cent overhead	63
Five per cent engineering and purchasing charges	36
Total	$773

TABLE XL—ITEMIZED COST OF FOUR-POLE SUBSTATION

Material	$1,219
Labor	110
Superintendence	75
Interest and miscellaneous contingencies	50
Freight and drayage	100
Ten per cent overhead	156
Five per cent engineering and purchasing charges	78
Total	$1,788

The four-pole type of station is used where the load and the character of the service required demand the use of electrolytic lightning arresters. The company has built this type of station in sizes ranging from 150 kw. to 500 kw., but there is no reason why the same design could not be employed for even larger stations. The installations which have been made to date serve towns, but stations of the same design could be used to serve such isolated industrial loads as coal mines if housing space were not available. The drawing and the bill of material give an adequate description of the station. It may be pointed out that the company at first used four-pin cross-arms in building the barbed-wire fence support because the arms were standard line equipment. It has been found cheaper, however, to employ 4-in. by 4-in. (10.16-cm. by 10.16-cm.) timbers. Square posts were selected for sightliness Building a small gate within the larger one makes for convenience under ordinary operating conditions and also at times when equipment must be moved in or out. The same special dead-end fittings are used on this structure as on the two-pole type. The cost of this station without transformers and without the separate high-tension switching structure is $1,788. The costs are itemized in Table XL.

TABLE XLI—BILL OF MATERIALS—FOUR-POLE STATION

Item		Quantity
	POLE STRUCTURE	
1	30-ft. poles	4
4	4-in. by 6-in. hard pine	10
17	2¼-in. by 2¼-in. by 5⁄16-in. square washer	76
18	¾-in. by 18-in. galvanized bolts	16
20	¾-in. by 14-in. eye-bolts	6
31	⅝-in. by 8-ft. anchor rods	2
32	Shim plates	4
33	Three-bolt clamp	4
34	⅜-in. guy cable, ft.	75
	FOUNDATIONS, ETC.	
12	Portland cement, bag	44
13	Sand, cu. yd.	4½
14	Screened gravel, cu. yd.	11
10	Cinders, cu. yd.	2
	FENCE	
2	14-ft. square posts	9
3	4-in. by 4-in., 3½-ft. yard post	13
5	Barbed wire, ft.	400
6	26-in. cross-arm brace	13
8	Galvanized square-mesh fencing	96
9	Gate	1
15	½-in. by 4-in. lag bolts	13
16	⅜-in. by 4½-in. carriage bolts	13
19	¾-in. by 14-in. galvanized bolts	13
21	Staples	5
	APPARATUS AND ACCESSORIES	
22	Ohio Brass strain disks	27
23	Ohio Brass dead-end clamps	6
24	Delta-Star type choke coil	3
27	Delta-Star fuse mount No. 8131	3
28	Delta-Star disk switch, type G	3
29	Westinghouse 200-kva., 33,000-volt to 2300-volt transformer	3
30	General Electric electrolytic arrester, type I	1
7	¾-in. by 8-in. galvanized pipe	3
11	Angle-iron hanger	3
35	⅝-in. by 18-in. space bolts	4
36	Ohio Brass insulation hooks	3
37	2300-volt strain insulator	6
38	S. C., No. 51	9

Placed outside both of these types of station about one span distant is a two-pole high-tension switch structure. The detached location for this structure was chosen to afford plenty of clearance for working on the station dead. The bill of material for this structure without apparatus is given in Table XLIII. The apparatus used in addition to that itemized list consists of a Burke disconnecting switch with separate cast pins. This latter feature is an improvement which makes it possible to change insulators without taking the switch down. It also does away with handling small parts which linemen are apt to drop

TABLE XLII—COST OF SWITCH STRUCTURE

Item	Quantity
Material	$224
Labor	50
Superintendence	5
Interest and miscellaneous contingencies	15
Freight and drayage	25
Ten per cent overhead	31
Five per cent engineering and purchasing charges	18
Total	$368

BILL OF MATERIALS—TWO-POLE SWITCH STRUCTURE

Item		Quantity
1	Straight cedar poles	2
2	4-in. by 6-in. by 16-ft. hard pine (long-leaf)	6
3	4-in. by 4-in. by 16-ft. hard pine (long-leaf)	1
4	Standard two-pin cross-arms	4
5	2-in. by 4-in. by 4-ft. hard pine	25
6	1-in. half-round single groove molding, ft.	12
7	¾-in. by 20-in. spacing bolts	3
8	26-in. standard cross-arm brace	8
9	¾-in. by 18-in. galvanized bolts	8
10	¾-in. by 12-in. galvanized bolts	8
11	2¼-in. by 2¼-in. by 3/16-in. square washers	56
12	⅜-in. by 4½-in. carriage bolts	8
13	½-in. by 4-in. lag screws	4
14	20-d wire nails, lb.	4
15	1-in. pipe straps	4
16	8-d wire nails, lb.	1/6
17	Ohio Brass dead-end clamp No. 6233	6
18	Ohio Brass strain disk No. 11,535	18
19	Dead-end angles	3
20	¾-in. by 9-ft. galvanized-iron pipe	1
21	Ohio Brass hooks	6
22	No. 2 B. & S. gage copper wire, ft.	50
23	Galvanized pole steps	11

and lose. The cost of this structure, including the switch, amounts to $368. The cost is itemized in Table XLII.

TABLE XLIII—BILL OF MATERIALS—TWO-POLE STRUCTURE

Item		Quantity
1	Straight cedar poles	2
2	Schweitzer & Conrad or Burke sphere-gap arrester	3
3	Standard 4-ft. cross-arm	4
4	26-in. cross-arm braces	8
5	Victor insulator No. 2335A or Ohio Brass No. 4535	9
6	Ohio Brass clamps No. 6233	3
7	¾-in. by 18-in. spacing bolts	3
8	Delta-Star type G choke coil	3
9	Delta-Star type G fuse mount	3
10	Transformers	3
11	4-in. by 6-in. by 12-ft. hard pine	9
12	Thomas insulator No. 3058 or Locke No. 3512	2
13	Electric Service Supplies Co. iron pin No. 163	2
14	¾-in. by 18-in. galvanized bolts	4
15	Locke or Ohio Brass attachments	3
16	Locke or Ohio Brass attachments	3
17	⅜-in. by 4½-in. carriage bolts	8
18	½-in. by 4-in. lag bolts	4
19	Portland cement, bag	27
20	Sand, cu. yd.	2
21	Screened gravel	5
22	Three-bolt guy clamp	4
23	Guy thimbles	4
24	6-in. anchor rods	2
25	3-in. by 3-in. anchor washers	2
26	⅜-in. galvanized guy cable, ft.	75
27	Ground molding, ft.	24
28	1-in. pipe straps	12
29	Upper ground cable, ft.	40
30	¾-in. by 8-ft. ground pipe	1
31	No. 2 B. & S. gage solid copper wire, ft.	60
32	½-in. by 7-in. machine bolts	18
33	2¼-in. by 2¼-in. square washers	42
34	Schweitzer & Conrad No. 51A	3
35	Washers placed under each through-bolt head and nut.	

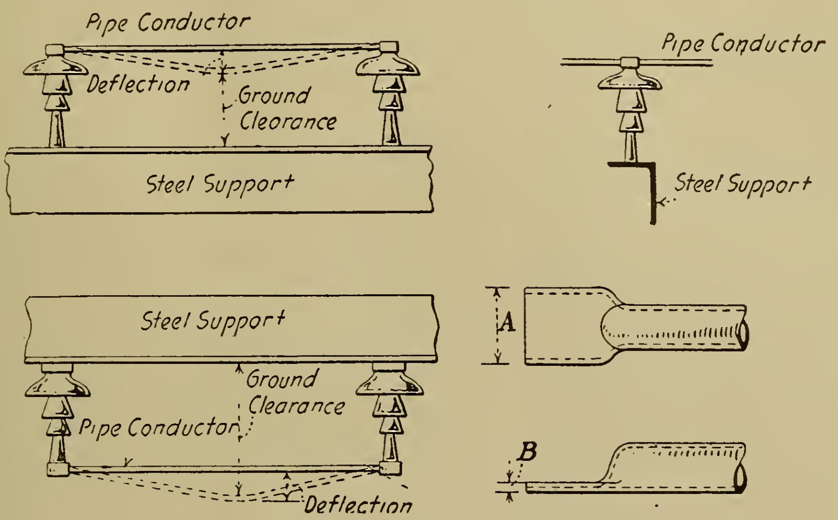
The stations of these types which the company has built are proving satisfactory. Practically the only important change in the first design consisted of employing strain-type insulators on the poles near the lightning arresters (Fig. 92) instead of the pin-type insulators which were first selected.

The outdoor substations described here were designed under the direction of W. F. Corl, general superintendent of the Southern Illinois Light & Power Company.

THE UTILIZATION OF PIPE FOR OUTDOOR BUS WORK

Copper, brass and iron pipe is now being used extensively in high-tension parts of outdoor substations for buses and connections, the great advantage of being able to support it on rigid insulators instead of by strain insulators being generally recognized, says M. M. Samuels.

No strict rules can be made as to how far apart pipe-bus supports should be. The exact spacing of insulators must be determined in each individual case. For instance, where a conductor runs parallel to a steel member, as in Fig. 93, with the steel



FIGS. 93 TO 96—GROUND CLEARANCE WITH BUSBARS STRUNG ABOVE, BELOW AND ACROSS STEEL SUPPORT—FORM OF TERMINAL

TABLE XLIV—DIMENSIONS OF FLATTENED COPPER OR BRASS PIPE FOR TERMINAL

	Size of Pipe in Inches										
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3
Standard iron-pipe size:											
A	0.57	0.76	0.96	1.20	1.52	1.86	2.44	2.82	3.56	4.32	5.28
B	0.12	0.17	0.18	0.22	0.23	0.24	0.29	0.30	0.31	0.38	0.44
Extra heavy iron-pipe size:											
A	0.54	0.72	0.91	1.15	1.48	1.85	2.39	2.76	3.49	4.20	5.16
B	0.20	0.25	0.25	0.30	0.31	0.35	0.39	0.41	0.44	0.56	0.61

member underneath the conductor, a large sag will considerably decrease the ground clearance. Therefore insulators must be

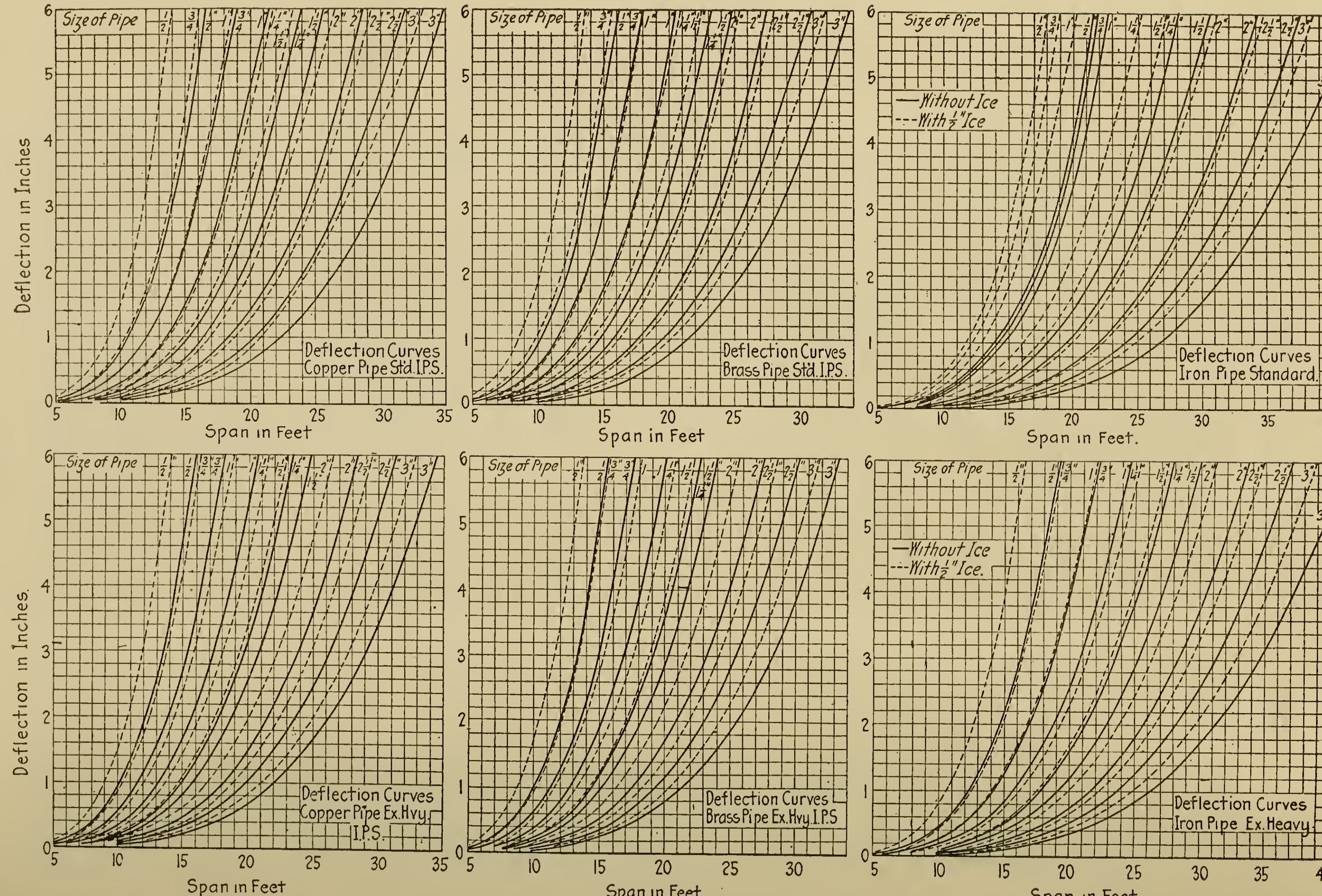


FIG. 97—DEFLECTION OF COPPER, BRASS AND IRON PIPE USED AS BUSBARS WITH AND WITHOUT ICE LOAD

spaced so that even with a maximum sag under ice conditions there will still be enough clearance between the conductor and the steel. But even for an individual case like this no rule can be made as to the minimum spacing of insulators, since the ground clearance at maximum sag will depend upon the insulator's height.

When the conductor is suspended underneath the insulator with the steel above the conductor, as in Fig. 94, or when the conductor runs at right angles to the insulator, as in Fig. 95, a greater sag and consequently a greater distance between supports is permissible. In this connection it may be mentioned that the majority of standard insulator pins on the market at present are too short to allow for the required ground clearance when used as in Fig. 93, since most standard pins are designed for cross-arm use as in Fig. 95. Caution should be used therefore when deciding upon the type of pin for a high-tension bus support.

The curves in Fig. 97 give the deflection of the various kinds of pipe for different spacings of insulators, both without ice load and with ice load. They may be used readily for determining the required spacing of insulators after a certain kind of pipe has been decided upon or to determine the size of pipe to be used when the distance between supports is fixed through other determinations. The deflections given are for two end supports and are therefore maximum. For a continuous pipe with more than two supports the deflections will be considerably less than those given.

The simplest method of connecting a pipe connector to a terminal is to flatten the pipe, drill a hole through it, and use the pipe conductor itself as a terminal lug.

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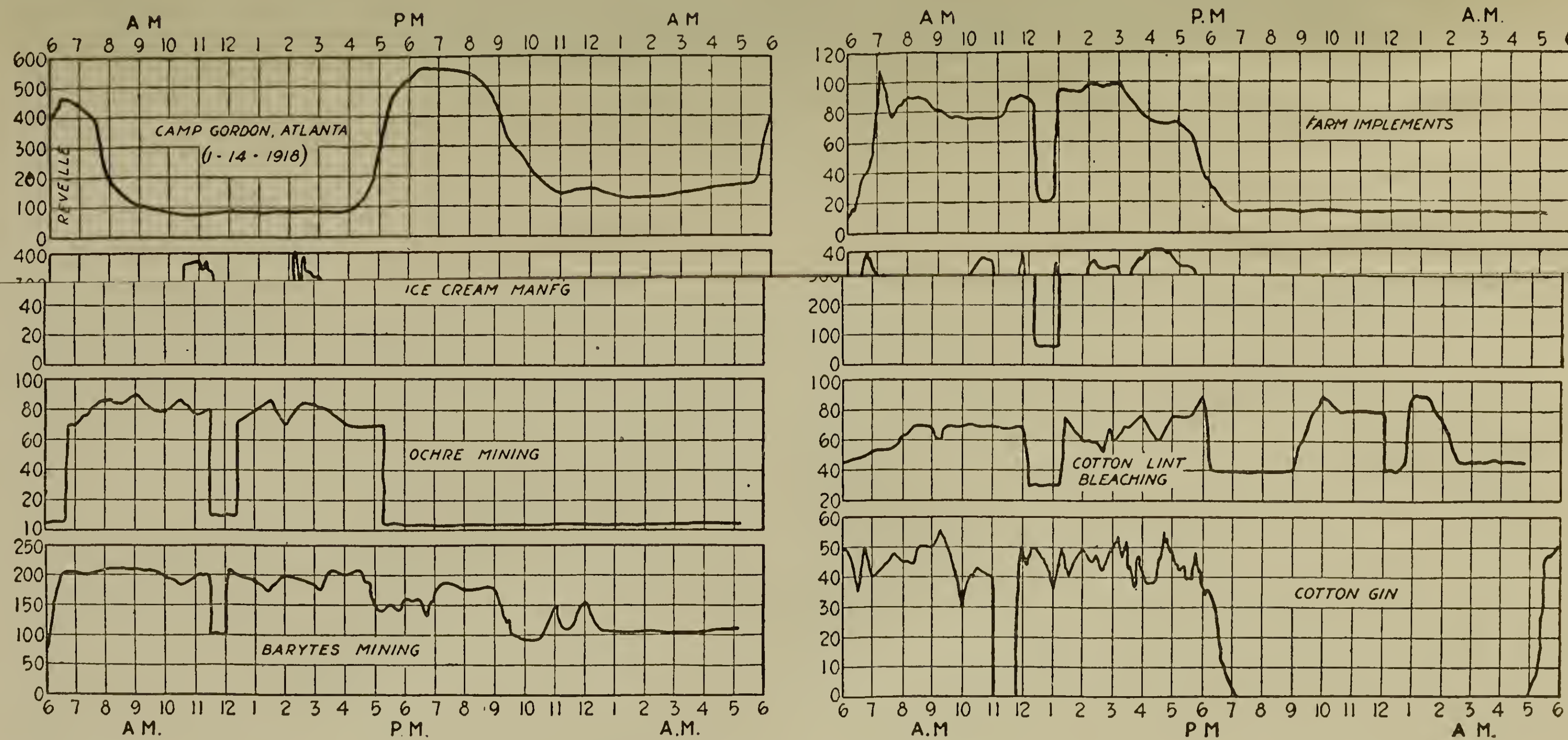
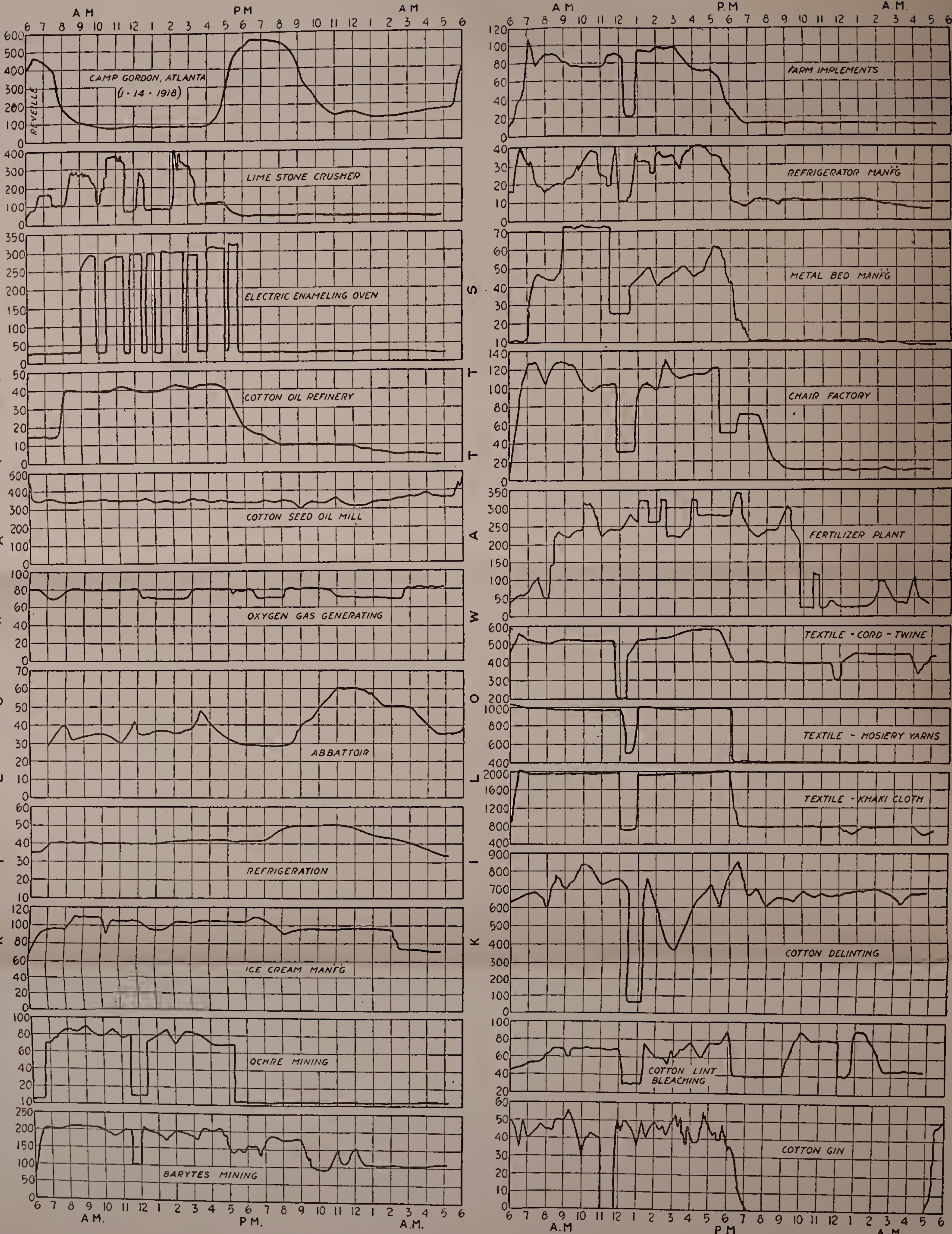


REPREESENTATIVE DAILY LOAD CURVES

The peculiar features of each class of load are here brought out in comparison with other loads and tend to show the effect of peak building and load diversity on any system. Most of the loads, of course, drop off in the eveñing. Certain of the loads have a very high load factor; for instance, the cottonseed mill, the oxygen-gas generator, ice-cream manufacturing and refrigeration. Others, like the cotton gin, have a poor load factor. The similarity of the load curves in the textile industry, though for different operations—cord and twine making, hosiery yarn spinning, khaki cloth manufacture—is noticeable. 2



Representative Daily Load Curves

The peculiar features of each class of load are here brought out in comparison with other loads and tend to show the effect of peak building and load diversity on any system. Most of the loads, of course, drop off in the evening. Certain of the loads have a very high load factor; for instance, the cottonseed mill, the oxygen-gas generator, ice-cream manufacturing and refrigeration. Others, like the cotton gin, have a poor load factor. The similarity of the load curves in the textile industry, though for different operations—cord and twine making, hosiery yarn spinning, khaki cloth manufacture—is noticeable.