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MAY, 1919

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(See article, page 373)

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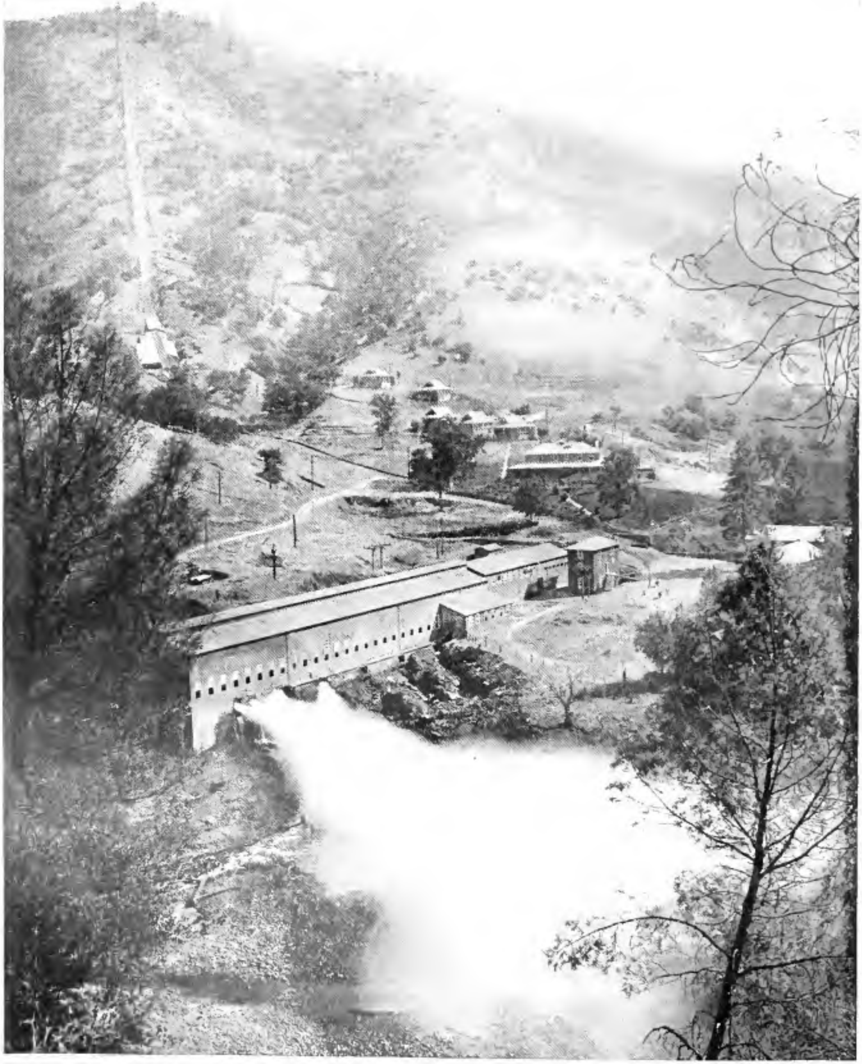

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GENERAL ELECTRIC REVIEW

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GENERAL ELECTRIC REVIEW

FUNDAMENTAL FACTORS OF ECONOMIC ACTIVITY

By David B. Rushmore

Engineer, Power and Mining Engineering Department, General Electric Company

Economics is the social science which treats of that portion of human activity which is concerned with earning a living. It is the social science of business. It deals with the necessities and luxuries of our daily life and naturally also with the commodities and services upon which this our well-being is dependent. The reason for industrial activity is therefore the effort to satisfy the so-called demands of the consumer.

The industrial expansion of the United States has been nothing short of marvelous. At the time when our independence was declared our activities were mainly those of an agricultural community, but it did not take very long before the vast extent of our undeveloped resources and the superior advantages for manufacturing became appreciated, and the United States has thus also gradually been transformed into a manufacturing nation, at the same time maintaining its place among the food producing countries. The principal activity of a large part of the entire world, in fact, is rapidly becoming industrial or manufacturing, and a large and increasing proportion of the wealth of the world that is being created comes from the manufacture of goods, which means the change in form and character of materials with the introduction of power and labor.

Many countries, such as Germany Belgium and England, import most of their foodstuffs, their population being chiefly engaged in manufacture. These countries do not raise enough food to support their population, but must rely on imports from food-raising countries, and in many instances, must get their necessary machinery, farm implements, etc, from a manufacturing country. The result of this interchange of commodities is what is known as trade, and is due to the efforts of men to realize the economics connected with a territorial division of raw material and labor, that is, to devote each particular country or area to those products for which it is best adapted, while securing from other localities, by means of exchange, their special products.

Food, clothing and shelter are the fundamental necessities of life, and these can be expanded into a very long list. The place where necessities stop and luxuries begin is rather indefinite, but there is every indication that with our increased social development many articles which formerly were chiefly considered as luxuries are now being looked upon as essential to the welfare of the people at large. That this transition will continue to increase is more evident now than ever, and the readjustment to these new conditions is one of the big problems in the industrial world today.

The supply of raw materials, such as are provided in kind and position by nature, is of fundamental importance in any industrial undertaking, and it is the recovery of these raw-materials and their transformation into finished products for ultimate consumption that makes up the activities of industry. In any tabulation and classification of industries, we would naturally start with raw materials in their natural positions and conditions, and proceed to the getting of these raw materials from the surface of the earth either by agriculture, mining, quarrying, lumbering, hunting or fishing. Often these raw materials must be stored for long periods to meet conditions of demand and supply, or they may have to be transported for long distances to localities which are more suitable for transforming them by one or more changes into the final shape for ultimate consumption. The processes by which such transformations are accomplished are, of course, widely different, depending on the nature of the products themselves as well as the conditions under which the work is being done.

Raw materials may be classified into three main classes, namely, mineral, vegetable and animal, the different subdivisions and principal individual materials being given in the following tabulation.

From the element raw material to the final finished product a long series of more or less intricate manufacturing processes are involved. The finished product of one process or industry becomes the raw material for the next. Energy is transformed at many points, both in changing the material and also in the local transportation, and it is this which has made the period since the beginning of the last century distinctly an age of power.

Electricity is the most convenient form in which to transmit and apply energy, and the electric motor is a means for transforming electrical to mechanical energy and produces motion and torque at various speeds and in different directions. Among the numerous advantages of electric drive of machinery in general may be mentioned the increased production which is obtained for a given equipment, besides a much improved product; a decreased power consumption and higher efficiency due to the possibility of centralizing the power supply, simplicity of transmission and distribution of the power, better location and control of the apparatus, resulting in greatly improved operating conditions and economy, etc.

While the more important manufacturing companies still generate their own power, there is now a strong tendency toward consolidation with a view of concentrating the power supply for all uses in a large territory from one system. The interconnection of transmission systems is also a step in the right direction as demonstrated in many places where several large systems are tied together, furnishing power to each other on an "interchange" contract basis. The advantages of this are obvious. The peak loads of the different systems may not coincide, the minimum stream flow of hydro-electric plants may occur at different times on the different water sheds, common reserve stations may be used, and in general the operation may be so improved that a most efficient and reliable service can be rendered to the customers of all the systems so tied together.

The labor item is one of the most important, if not the most important, in our present industrial activity, and the relation between work and pay must receive careful consideration. The cost of labor is constantly going up, the working hours are made shorter, and the effect which this has on the cost of the finished product and on the competition with other producers with cheaper labor conditions is obvious.

The success of an industry is also to a great extent founded upon invention, and the future activities of the world will to a large extent consist in discoveries and inventions and their introduction into improved means of manufacturing. The importance of such industrial research has been strikingly brought out during the war. The success and the results achieved are too numerous to tabulate; we need only mention the deadly poisonous gases, explosives, helium, artificial nitrogen products, synthetic dyes, etc.

These are only some of the fundamental factors entering into our industrial life, but reforms are constantly taking place in every field with a view of improving the rising standards of mankind.

Electric Drive for Steel Mill Main Rolls

By K. A. Pauly

Power and Mining Engineering Department, General Electric Company

Steel mill roll drives may briefly be divided into three classes, viz.: non-reversing single speed mills, non-reversing adjustable speed mills, and reversing mills. The requirements of the single speed mills are the simplest from the standpoint of the motor equipment; they may be driven by either direct-current shunt or compound motors, or by single-speed induction motors. For adjustable speed mills two speed slip ring induction motors have been used to a limited extent; but where reasonable efficiencies are demanded the so-called Scherbius system has been found to give the most satisfactory results and the widest range of speed. The motors driving reversing mills are subjected to extremely severe usage; they are required to carry tremendous overloads at all speeds in either direction of rotation and must be capable of rapid acceleration. Direct-current motors are used for these mills, with Ward Leonard system of speed control or a combination of Ward Leonard and motor field control. The satisfactory operation of any of these installations is dependent upon the control apparatus, and the design and construction of this equipment demands equally careful consideration, down to the minutest details, as do the motors themselves.—Editor.

It is safe to say that the resources of few, if any, of the industries of this country were more severely over-taxed during the war than those of the steel industry. The mills have been called upon to deliver their maximum output and in many cases under most exacting specifications. Extensive additions to existing mills as well as the building of entirely new works have been necessary to at all keep pace with the ever-increasing demands for increased tonnage. In this rapid growth electricity has played a very important part in every branch of the industry, but perhaps no where to so great an extent as in the rolling mills, and a review of some of the important new developments and installations may be of more than passing interest.

Because the main roll motors are usually housed in to protect them from the mill dust, it is frequently impossible to get good photographs so that the writer has used some pictures of earlier installations to illustrate the various types.

During 1916, 1917, and 1918 the General Electric Company sold approximately 150,000 h.p. (continuous capacity 40 deg. C. rise in motors for driving main rolls, which motors have a combined maximum momentary overload capacity of approximately 450,000 h.p.

Electrically-driven main rolls may be subdivided into three classes:

- First, 3-high and 2-high non-reversing single speed mills.
- Second, 3-high and 2-high non-reversing adjustable speed mills.
- Third, 2-high reversing mills.

This sub-division is a natural one which follows from the nature of a rolling mill load, and the inherent characteristics of the shunt direct-current motor and the induction motor. It is not the intention of the writer to discuss at length the engineering problems affecting the choice of a drive to meet any set of conditions, but a brief outline of the important considerations will assist the reader in understanding why a particular drive is used in one case and is entirely unsuited in another.

Rolling mills may be divided as suggested above into three classes from the standpoint of their electrification: first, single speed; second, adjustable speed mills which, although

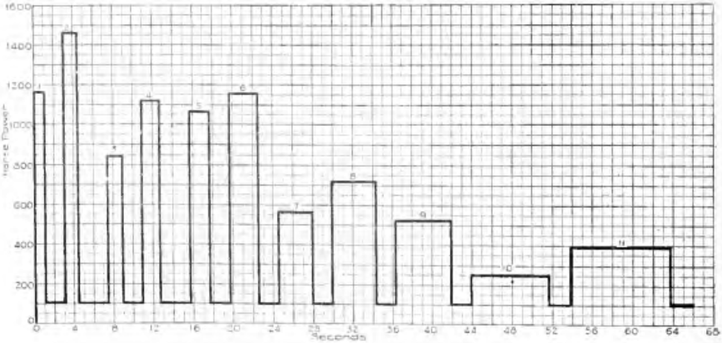

Fig. 1. Typical Load Cycle for Single Stand of Rolls

provision must be made for reversing them, are only reversed in an emergency; and third, those mills which are reversed after each pass. The first and second classes are commonly referred to as non-reversing and the third class as reversing mills.

Mills belonging to the first or second class may consist of a single three-high stand of rolls, as in a plate mill, or a group of two-high or three-high stands or both, as in a merchant or rod mill, and driven by one motor. Mills of the third class consist of a single two-high stand of horizontal rolls, as in the reversing blooming mill, or of a combination of two horizontal and two vertical rolls as in the universal mills, each pair of rolls being driven by a separate reversing motor, or both by the same motor.

The curves showing the work done by a single stand of rolls are similar for all three classes, differing only in that the rolls for the even and odd passes run in opposite direction in the reversing mill. Fig. 1 shows a typical load cycle for a single stand. For those mills which consist of several stands of rolls with steel simultaneously in more than one stand, the load curve is a combination of several overlapping passes, each of which resembles those of Fig. 1, but which combined produce a resultant curve of which Fig. 2 is typical.

Single Speed Mills

Obviously single speed mills, class one, may be driven either by direct-current shunt or compound motors or by single-speed induction motors; but since power is distributed as alternating current, induction motors are universally adopted as the motive power for these mills. Because of the magnitude and short duration of the loads, advantage is usually taken of flywheels to assist the motors in carrying the peaks, in which case special provisions are made in the control for automatically inserting resistance in the rotor circuit of the motor when the load exceeds a predetermined amount, thus causing it to slow down and allow the flywheel to carry its part of the load. Incidentally the flywheel performs another very important function by considerably reducing the mechanical shocks which would otherwise be transmitted back from the mill to the motor,

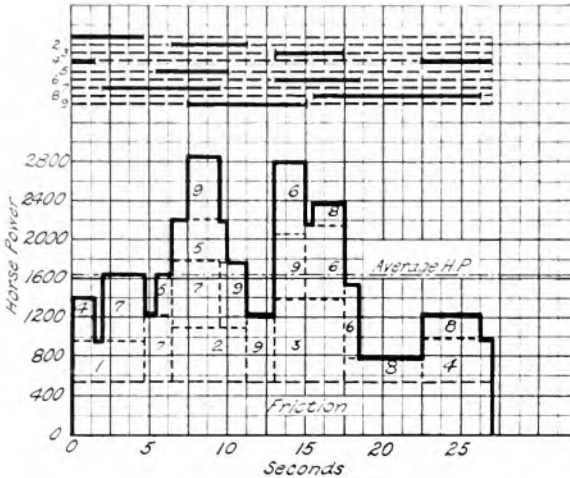

Fig. 2. Typical Load Cycle for Multiple Stand Rolling Mill with Steel Simultaneously in More Than One Stand

and thereby materially increases the life of the windings.

Adjustable Speed Mills

While shunt or compound wound direct-current motors may be used to drive adjustable speed mills, the speed-torque characteristics of the simple slip ring induction motor are such as to make it entirely unsuited for driving these mills. Two-speed slip ring induction motors have been used and probably will continue to be used to a limited extent where the output of the mill, either as to variety or quantity of product, is such that a compromise in speeds is preferable to the greater first cost of obtaining adjustable speed control over the whole range.

In rheostatic control of slip ring induction motors resistance is inserted in the rotor circuit by connecting it across the slip rings. A voltage, the magnitude of which depends upon the current and resistance, is necessary to force the rotor current through the resistance and the induction motor slows down to such a speed that the voltage at its slip rings is just sufficient to produce the current required by the load on the motor. Obviously, as the current varies with the load, and therefore the slip ring voltage necessary to force the current through the resistance, the speed of the induction motor varies with the load for any given setting of the controller with this system of control. It is this characteristic which eliminates the induction motor from consideration for driving mills of the second class. But this is not the only harmful characteristic of the induction motor: the slip energy, which is all converted to heat in the resistance, is wasted and would greatly lower the efficiency of the induction motor were there no other more important defects in its characteristics.

Fig. 3. 3500-h.p., 92-r.p.m., 2200-volt, 60 cycle, Single-speed Main-roll Motor Driving a Continuous Mill

Fig. 4. 4000-h.p., 83.3-r.p.m., 6600-volt, 25 cycle, Single-speed Main-roll Motor Driving 110 in. Shear Plate Mill

It is apparent that if we are to obtain the desired speed characteristics at reasonable efficiencies with the induction motor driving adjustable speed rolls, we must oppose the voltage at its slip rings by a voltage which is substantially independent of the current or load and conserve the slip energy which, with rheostatic control, is dissipated as heat in the resistor. Two systems of control, commonly referred to as the Scherbius system and the rotary converter system, both of which meet these requirements, have been developed and in operation for several years in connection with main roll motors. Of these, the so-called Scherbius system has been most generally applied. In it a polyphase commutator motor with shunt field excitation, which will be referred to as the regulating motor, is connected across the slip rings of the induction motor to be controlled, its counter electromotive force opposing the voltage across the slip rings. Obviously, by varying the excitation of the regulating motor, the slip ring voltage opposing its counter electromotive force must increase, and to bring this about the main motor must slow down. Because of the shunt excitation of the regulating motor, its counter electromotive force and therefore the speed of the roll motor remains practically constant through the entire range of loads for any given setting of the controller.

If now we can conserve the energy delivered to the regulating motor we will have met both the objections to the rheostatic control. This may be done either by mounting the regulating motor on the main roll shaft with the induction motor or by driving a generator by it and returning the slip energy, less the losses in the motor-generator, to the power supply system. In their operating characteristics these two methods are alike, but because of its lower first cost the latter method has been universally used. With this system, the speed control may be obtained all below synchronism (single range control), or part above and part below synchronism (double range control). The double range control is cheaper and more efficient than the single range system, and although there are a number of single range installations they were all made prior to the development of the double range system.

In the rotary converter system, which is similar to the Scherbius system in principle, a rotary converter is connected on its a-c. side to the slip rings of the induction motor, thus converting the slip energy to direct current which, as in the Scherbius system, may be used either to drive the roll shaft through a d-c. motor or returned to the power supply system through an inverted motor-generator. There are many obstacles in the way of, as well as very little to be gained in first cost by the development of this system for double range control, which fact accounts for all of these installations being of the single range type. The very natural question which always arises when alternative methods for accomplishing any result are available is which of the two is the better? The answer in this case is the usual one: either may be, depending upon the special conditions affecting any given installation.

Fig. 5 1500-h.p., 450-r.p.m., 2200-volt, 30 cycle, Single-speed Main-roll Motor Driving Skelp Mill

Fig. 6. 4000-h.p., 82-r.p.m., 6600-volt, 60 cycle, Single-speed Main-roll Motor Driving 110-in. Plate Mill

As previously stated, the Scherbius system, because of its many advantages over its competitor, is more generally used. Briefly these advantages are:

Higher efficiency.

Lower first cost except in special cases.

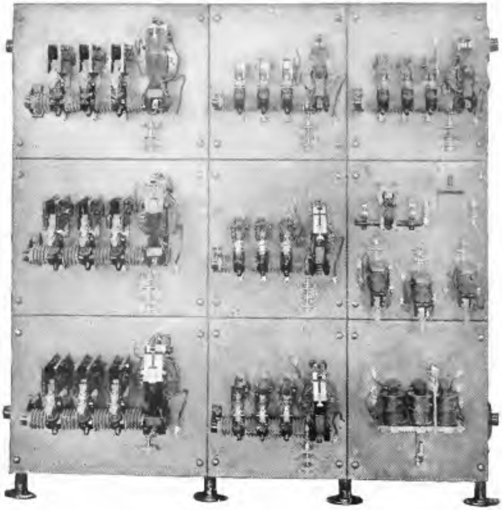

Fig. 7. Automatic Control for Single-speed Main-roll Induction Motor

Power factor correction obtained with no added complication and with little or no increase in first cost. Because of the difficulty of operating synchronous converters at leading power factor, power factor correction cannot be obtained with the rotary system.

Greater stability when main roll motor is running near synchronous speed.

Overload capacity of main roll motor the same (150 per cent overload) at or near synchronous speed as at other speeds. This high overload capacity at these speeds has not yet been obtained with the rotary system as developed commercially.

The synchronous speed of the main roll motor is between the maximum and minimum speeds. This permits of running the main motor alone at the intermediate speed and saving all the losses in and the wear and tear on the regulating set at this speed, which is frequently the speed at which a large part of the product is rolled. This intermediate speed will also be found advantageous during repairs on the regulating set. With the rotary system the main roll motor without regulation runs

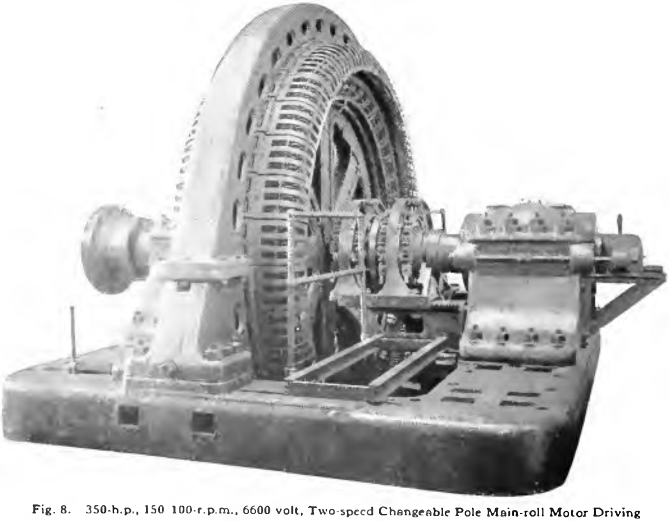

Fig. 8. 350-h.p., 150 100-r.p.m., 6600 volt, Two-speed Changeable Pole Main-roll Motor Driving 12-in. Finishing Mill

at maximum speed, which will be too high for rolling any of the products of the mill except the very lightest sections when the regulating converter is shut down, if the supply system is 25 cycles.

The maximum frequency at which it is advisable to operate Scherbius regulating motors is approximately 20 cycles. This limitation, with the single range system, would have proved a serious disadvantage where the frequency of the power supply is 60 cycles, but with the double range system, which is now universally used, 20 cycles is seldom approached in meeting the mill speed requirements.

The fitness for the work and the thorough reliability of the Scherbius system of control have been demonstrated by years of very successful operation under the most extreme speed and load conditions.

Fig. 9. 1400/950-h.p., 600/405-r.p.m., 2200-volt, Adjustable Speed Main-roll Motor with Rotary Converter Speed Control Driving 21-in. Structural Mill Showing Direct-connected Direct-current Motor

Reversing Mills

It is safe to say that of all the applications of electric motors, none is subjected to more severe conditions than are those driving the third class, or reversing mills. These motors are frequently subjected to overloads several times their continuous capacity. They must carry these overloads throughout the full range of speeds, from rest to maximum speed in either direction, and when driving the mill or operating as a generator in braking.

Fig. 10. 325-kw. Synchronous Converter Used to Control 1400-h.p. 21-in. Structural Mill Motor

In breaking down large ingots the draft is large for the first passes and the piece so short as to require less than one revolution of the rolls to complete the pass after the steel enters. Unless the speed of the rolls is kept down as the ingot is entered, the rolls will not bite it, and the delivery speed must be low to prevent throwing the steel onto the tables in such a way as to interfere with its quick manipulation. Further, the pass is so short that no appreciable gain can be made by running the mill at high speed. As the steel lengthens out and the section and drafts are reduced the entering and delivery speeds are increased and considerable time saved by rolling at high speeds during the pass.

A motor to meet these conditions must have the following characteristics:

Its speed must be adjustable over the full range from rest to maximum speed in either direction of rotation, and when adjusted for any speed this speed must be practically independent of the load.

It must be capable of carrying extreme overloads at all speeds during acceleration, driving the mill at full speed or

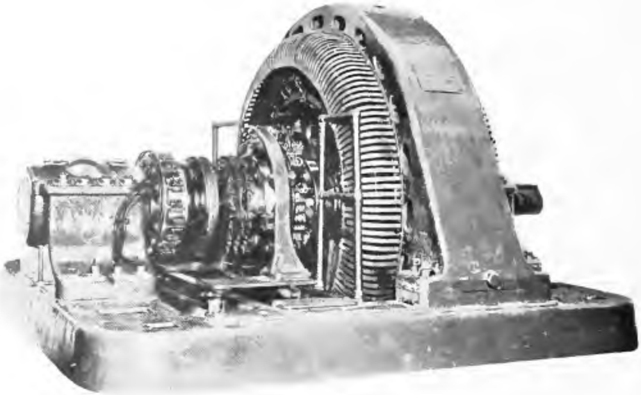

Fig. 11. 1200-h.p., 360-r.p.m., 2300-volt, Adjustable Speed Bar Mill Motor with Double Range Scherbius Control Between 450-r.p.m. and 270-r.p.m.

during regenerative braking in slowing down the mill at the end of the pass.

The inertia of its revolving parts must be kept low to permit of rapid acceleration and reversal. This is necessary as the greater part of the time consumed in breaking down an ingot is taken between passes, making it extremely important not to add the least amount to this time by the use of motors which are slow in accelerating.

These conditions can be met by direct-current motors controlled by the Ward Leonard system throughout the full speed range, or by this system through the lower range with motor field control for the upper range, the latter being universally adopted because of its effect on the design of the generator supplying the power. The percentage of the total speed range obtained through generator voltage control, Ward Leonard system, and by motor field control depends of course upon the mill requirements, but in general the Ward Leonard range is about one third the total range.

The problem of obtaining the maximum rate of automatic acceleration and retardation and at the same time providing complete

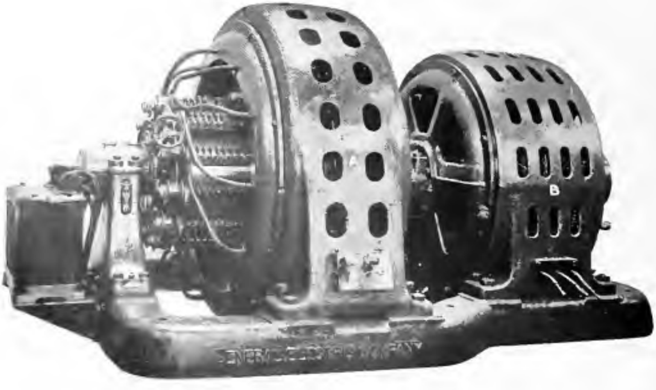

Fig. 12. 450-kv-a. Double Range Scherbius Speed Regulating Set.

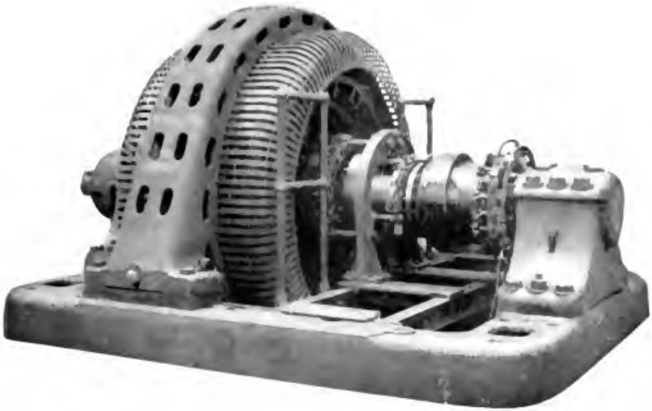

Fig. 13. 600-h.p., 500-r.p.m., 3000-volt, Adjustable Speed Motor with Double Range Scherbius Control Between 550-r.p.m., and 370-r.p.m. Driving 8-in. Merchant Mill

adjustable speed control throughout the complete speed range is a nice one, involving not only a study of the load conditions but a very careful study of the magnetic characteristics of both the motor and its generator. The best results can be obtained by the use of a motor-driven controller which is operated from a small "follow up" master controller controlled by the mill operator.

Fig. 14. Motor Room Showing Adjustable Speed Rod Mill Roughing and Finishing Motors with Scherbius Speed Regulating Sets

A flywheel motor-generator is always used for supplying power to the roll motors, the flywheel serving to iron out the peaks from the load, which are extremely high and of very short duration, and which would otherwise be reflected back to the power system.

Experience has shown that the varying requirements of reversing mills can best be met by the standardization of a small number of generator and motor units, combining one or more of these standard units into sets, depending upon conditions, to drive a mill. Different methods have been employed by different manufacturers in rating these units and combinations of them where more than one unit has been necessary to drive a mill, but the logical and only safe way from the purchasers' standpoint is to insist on their being given a rating based on their continuous capacity. The "every ingot" maximum capacity, that is, the maximum load which the equipment will carry at as frequent intervals as once during the rolling of each ingot, and the maximum emergency capacity must be stated, but they should not be included in the rating.

The General Electric Company has developed two standard reversing mill motor units and two standard generator units having the following continuous and momentary capacities:

Main Roll Motors

2500 h.p., 50/120 r.p.m., with 8500 h.p. maximum momentary capacity at 45 r.p.m.

3500 h.p., 150/175 r.p.m. with 8500 h.p. maximum momentary capacity at 150 r.p.m.

Generators

2000 kw. at 375 r.p.m. or 360 r.p.m.
2800 kw. at 375 r.p.m. or 360 r.p.m.

Equipments consisting of one and two motor units and of one, two and three generator units have been installed.

Fig. 15. Transformer Master Controller and Contactor Panel for Controlling Speed with Double Range Scherbius Equipment

Growth in the steel industry has followed along lines similar to those of other industrial developments. The small mill capable of rolling a wide variety of shapes has given way to the large mills designed for a limited variety of output. To the mill man this has meant increased production and lower cost, but to the electrical engineer it has meant simplification of the drive and increased load factor at the station. Single speed motors can be used where under the old condition reversing or adjustable speed motors were necessary, or the range of speeds has been reduced where even under the new condition adjustable speed motors are required, as is frequently the case for the finishing end of a mill, the roughing or intermediate stands of which are driven by single speed motors. We are, therefore, not surprised to find that more adjustable speed than reversing motors have been used, and that more single speed motors than all others combined have been installed.

The severity of steel mill service, to which reference has already been made, cannot be too strongly emphasized. The purchaser cannot safely neglect to thoroughly investigate the mechanical design as well as the electrical characteristics of the equipment which he is purchasing.

The load comes on abruptly, producing enormous strains in all parts of the machine but more especially in the shaft and rotor spider and windings. It is not satisfactory to simply make the shaft stronger than any part of the mill—it must be of such section

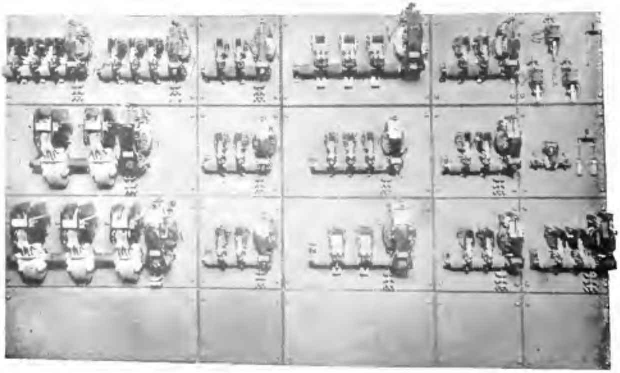

Fig. 16. Secondary Control Panel for Main Motor with Double Range Scherbius Speed Regulating Set

that it will withstand the breaking of a spindle without straining the shaft beyond the elastic limit. The rotor spider should be of steel except for the very small units.

The grinding of the gears between the upper and lower rolls produces vibrations which are transmitted back to the windings which, unless the windings are rigidly supported and thoroughly insulated, may materially shorten their life.

When the piece enters the rolls severe side thrusts are produced in the mill and transmitted to the motor if direct connected, which thrusts must be taken up in a thrust collar or bearing. Occasionally extreme side thrusts are produced by an accident in the mill and provision for taking these without injury to the motor should always be made. Where the motor drives from one end only, the protection against side thrusts is readily provided by the use of the so-called "mechanical fuse," or breakable end thrust device familiar to all steel mill electrical engineers. The pedestals which must ultimately take up this side thrust must be massive and low.

Tonnage and more tonnage is the aim of all the rollers, in many cases their pay being affected by the output of their mill, and this spurs them on to take advantage of every ounce of torque in the motor, and the motor which has been shaded in capacity is doomed to discredit if not disaster. A small saving in first cost may handicap a whole mill throughout its life.

The mill air is filled with an abrasive and often conducting dust which, unless kept out of the motor windings, will shorten the life of the insulation. Trouble from this source can almost always be avoided by properly housing the motors, which is now the general practice in those plants which pretend to take reasonable care of any of their equipment. In housing in space for the free circulation of air should be provided all around the motor, and clean, cool air supplied from an external source unless the room is sufficiently large to provide the radiating surface necessary to keep the temperature of the air around the motor reasonably low. But little trouble has been experienced from this cause where motors have been housed in, but the fact that all the losses in a motor are converted into heat must not be lost sight of and provision made for taking care of this

Fig. 17. Motor Room Showing 2500-h.p. Direct-current Reversing Mill Motor and 2000-kw., 2-Unit Flywheel Motor Generator for 36-in. Blooming Mill

Fig. 18. 2500-h.p., 40/120-r.p.m., 500-volt, Reversing Mill Motor Driving 36-in. Blooming Mill

heat if the motor is to operate within safe temperature limits.

Frequent inspection of the equipment should be made and the windings thoroughly cleaned if there is any tendency for dirt to accumulate. Occasionally varnishing the windings, as is done in many plants, will materially increase their life.

It is a wonderful sight to see the progress of the steel in the mill as it is changed from a crude ingot into a rail or a structural shape by a few passes between the rolls, and to realize the tremendous forces required, and then go back into the motor house and see the motor "plugging" along, giving no outward indication of the enormous work which it is doing. So impressive is this exhibition of power that, unless the observer is a specialist, he may leave the motor house without ever realizing that it contains anything but the motor, and at best he will not give the control more than a passing glance.

Nevertheless the success or failure of these giants of power is often tied up in this control tucked off in one corner of the room, and too great importance cannot be attached to the problems involved in the design of its elements or to the design of the control as a whole. It is no exaggeration to say that the complete success which has attended the application of motors to mills is due as much to the careful consideration which has been given to the minutest details of the control as to the design of the motors themselves.

The control for the single speed motors without flywheels, which provides only for starting, stopping, and reversing, is comparatively simple but increases in complication with the use of flywheels, as the duty of forcing the flywheel to help out the motor during the peak loads falls on the control. Several methods, all of which involve the automatic insertion of resistance in the main motor rotor circuit, have been developed. As we pass from the simple single speed mills to the adjustable speed and reversing mills the combinations of control devices required to accomplish the desired result and protect the motor from abuse appear to become complicated because of the number of elements involved, but their simplicity will be revealed by a careful analysis of the circuits. Their thorough reliability has been demonstrated by years of entirely successful operation.

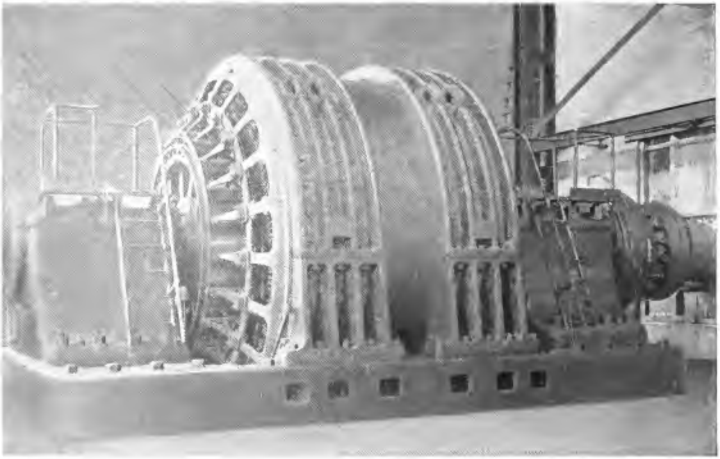

Fig. 19. 5000-h.p., 50/120-r.p.m., 600-volt, Direct Current Reversing Mill Unit Driving Blooming Mill

In the design of control every attention must be given to the question of repairs. The number and variety of elements must be reduced to a minimum and the parts which require renewals made accessible. Safety of the operator is of paramount importance. Apart from humanitarian considerations, the safety of an installation has an important bearing on the cost of production and money judiciously expended for safety appliances will bring large returns on the investment

Safety, accessibility, flexibility and thorough reliability are the conspicuous features in the design of the removable truck safety-first switchboard units which are of especial interest to all steel mill operators, especially where several motors are controlled from one board. Extensions can readily be made or the units moved to other locations to meet changed conditions. All live parts are enclosed. A spare removable unit can be used to reduce to a minimum the time lost for inspection and repairs. When removing the truck the busbars need not be killed or small wiring disturbed. Oil switches, busbars, and all live parts are in compartments which reduce fire hazard.

The stationary member carries the current and potential busses with their disconnecting switch studs. Barriers are used between the current studs to prevent accidental contact by any one who enters the compartment. The side walls are provided with hand holes, permitting the busbars and buswires to be continued from one unit to the next. Access to the rear of a compartment can be had by means of a hinged sheet steel door provided with padlock.

The portable truck, which is mounted on wheels, carries a sheet steel panel on which is mounted the usual switches and instruments. The truck is centered by rails upon which it rolls.

Control boards ranging from single panel units to 17 panels are now in use in rolling mills and in many other plants where the question of safety is given careful consideration

Having outlined a few of the fundamental considerations which affect the application of motors to steel mill main rolls, it may be of interest to refer briefly to a few of the larger and more important of the recent installations which are typical of modern practice.

Fig. 20. Motor Room Showing 5000-h.p., Reversing Mill Motor and 4000-kw., 3-Unit Flywheel Motor Generator Set for Driving Reversing Blooming Mill

It is difficult to determine which among many installations is most important, as after all, importance is largely determined by the point of view of the observer and it is quite possible that to another looking from a different angle the relative position of those which I have chosen with respect to other installations may appear entirely different, for in considering these installations the writer has tried to view them only from the standpoint of the motors driving the mills. It is also difficult to know where to end such a list as the writer has undertaken to prepare, and if he has omitted reference to any installa-

TABLE I

Initial Installation of Adjustable Speed Main Roll Induction Motors with Double Range Scherbius Control, MacDonald Bar Mills Carnegie Steel Company

No. of Units	Cont. Cap. H.p. at Max. Speed	Frequency	Syn Speed R.p.m.	Range of Speed Control R.p.m.	Driven Mill
1	3000	25	250	200 to 300	12 in. Continuous Hoop Mill
1	3000	25	250	225 to 275	10 in. Continuous Bar Mill
1	2200	25	250	225 to 275	14 in. Continuous Bar Mill
1	2200	25	250	275 to 300	18 in. Continuous Band Mill
1	1800	25	375	300 to 450	10 in. Continuous Hoop Mill
1	1650	25	375	337 to 413	10 in. Continuous Bar Mill
2	1200	25	375	300 to 450	8 in. Continuous Hoop Mill
1	1100	25	375	337 to 413	8 in. Continuous Bar Mill

TABLE II

List of Main Roll Motors at Fairfield Works, Tennesse Coal & Iron Railroad Company

No. of Units	Cont. Cap. H.p. at Max. Speed	Frequency	Syn. Speed R.p.m.	Range of Speed Control R.p.m.	Driven Mill
1	5600	D.C.		0 to 120	44 in. Reversing Blooming Mill
1	4000	60	82	None	36 in. by 110 in. Plate Mill
1	3000	60	144	130 to 155	24 in. Structural Finishing Mill
1	2500	60	82	None	28 in. Structural Roughing Mill

TABLE III

Motor Installation at the Lackawanna Steel Plant

No. of Units	Cont. Cap. H.p. at Max. Speed	Frequency	Syn. Speed R.p.m.	Range of Speed Control R.p.m.	Driven Mill
1	7000	D.C.		0 to 150	Finishing End of Rail Mill
1	1200	25	214	150 to 300	4 Stands 12 in. Roughing Rolls 2 Stands 10 in. Finishing Rolls
1	700	25	300	200 to 400	Finishing Stands
1	700	25	300	200 to 400	Finishing Stands
1	600	25	500	400 to 600	7½-in. and 8½-in. Finishing Stands

TABLE IV

Main Roll Motors at the Trumbull Steel Plant

No. of Units	Cont. Cap. H.p. at Max. Speed	Frequency	Syn. Speed R.p.m.	Range of Speed Control R.p.m.	Driven Mill
1	5000	D.C.		0 to 120	36 in Reversing Blooming Mill
1	3500	60	92	None	Continuous Mill
1	3500	60	92	None	Continuous Mill
1	1500	60	360	270 to 450	Hot Strip Mill
1	1200	60	360	270 to 450	Hot Strip Mill
1	1200	60	360	270 to 450	Hot Strip Mill
1	1200	60	360	270 to 450	Hot Strip Mill

TABLE V

Individual Installation Main Roll Motors, Maryland Works of Bethlehem Steel Company

No. of Units	Cont. Cap. H.p. at Max. Speed	Frequency	Syn. Speed R.p.m.	Range of Speed Control R.p.m.	Driven Mill
1	5000	D.C.		0 to 120	40 in. Reversing Blooming Mill
1	4000	25	83.3	None	36 in. by 110 in. Shear Plate Mill
1	4000	25	83.3	None	24 in. Billet Mill
1	3250	25	94	None	18 in. Sheet Bar Mill

tion which warrants mention this omission has been entirely unintentional.

The installation of adjustable speed main roll induction motors with double range Scherbius control at the MacDonald Bar Mills of the Carnegie Steel Company at Youngstown, Ohio, is the largest in the world, there being nine units having a combined continuous capacity of 17,000 h.p. The initial installation, which is only a part of the ultimate equipment, is given in Table I.

The main roll drives at the new Fairfield Works of the Tennessee Coal, Iron & R.R. Company are of especial interest because of the 44 in. reversing blooming mill, which is the largest electrically driven mill of this type in America when considered from the standpoint of maximum torque delivered at the rolls, which torque corresponds to approximately 22,000 h.p. at 50 r.p.m. The mill is driven by a two-unit standard reversing motor set which receives power from a 6000-kw. flywheel motor generator, the direct current end consisting of three standard 2000 kw. generating units. This plant also contains two of the largest slow speed, single speed, 60-cycle mill motors and the largest 60-cycle adjustable speed mill motor with double range Scherbius control. (Table II.)

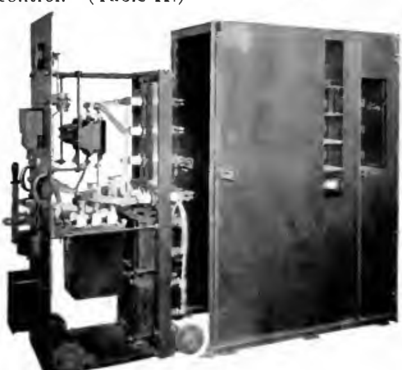

Fig. 21. Removable Truck Safety First Switchboard Unit with Truck Pulled Out

At the Lackawanna steel plant, in addition to four adjustable speed drives with double range control, we have the largest electrically driven reversing mill in the world, considered from the standpoint of the continuous capacity of the driving motors, which is

Fig. 22. Control for Reversing Blooming Mill Motor

7000 h.p. This installation comprises the equipment listed in Table III.

The Trumbull steel plant stands with the leaders in point of number and capacity of electrified main rolls, this installation consisting of seven units having a combined continuous capacity of 17,100 h.p. Of particular interest is their continuous hot strip mill, driven entirely by adjustable speed induction motors with double range Scherbius control, which is reputed to be the fastest mill of its kind. The 36-in. reversing blooming mill has also given an excellent account of itself. Table IV gives a summary of the mills and their drives.

Almost immediately after the Bethlehem Steel Company had taken over the Maryland Steel Works, which is now known as the Maryland Works of the Bethlehem Steel Company, extensions of the plant were begun on a very large scale. New mills are being added, all of which are to be electrically driven, and while this installation does not now stand at the head of the list in point of number and capacity of units, it is second to none in point of future possibilities. Our main roll drives included in this first development are listed in Table V.

One installation, although not in the least conspicuous, either as to the capacity or number of motors, is extremely interesting because of the record time in which it was installed, the uninterrupted operation of the mill from the start, and its tonnage record. I refer to the 110 in. "Liberty" plate mill driven by a 4000-h.p., 83.3-r.p.m. single-speed induction motor which was installed complete at the Homestead Works of the Carnegie Steel Company in six months from the day orders were issued to start work and which has rolled over 20,000 tons of ship plates in a single month.

Fig. 24. Removable Truck Safety First Switchboard

The application of motors to tire rolling mills is of interest because of the novelty of the mills and of their special power requirements. The tire blank, which is simply a disk with a hole pierced at the center, is placed in the mill, which is either stationary or turning at a slow speed. The forming rolls are then brought to bear on the piece and the mill speeded up as the blank is gradually rolled out into a tire. The range of speed control is the same as that for a reversing mill. but the cycle differs from that of the reversing mill in that it consists in but one pass and the mill is not reversed during the pass. Two very interesting installations have been made in which the rolls are driven by direct-current motors controlled on the Ward Leonard system, each taking power from a flywheel motor-generator similar to that used for reversing mills.

The motor driven intensifier for the large hydraulic bloom shear which is now being installed by the Tennessee Coal & Iron R.R. Co. is one of the most important new developments in the application of motors to the mill. While it is in no sense a main roll drive, the cycle of duty so closely resembles that of a reversing mill that standard reversing mill equipment is used to drive it, which is perhaps sufficient reason for referring to it in this paper.

The hydraulic intensifier can be considered simply as a reducing gear between the motor and the shear, the travel of the piston in the intensifier corresponding both in direction and distance with that of the shear. The motor, which drives the piston of the intensifier through a rack and pinion, must reverse with each stroke of the shear and vary in speed with the speed of the shear as larger and smaller sections are cut.

This same method is applicable to the operation of hydraulic presses, and the successful operation of the Tennessee Coal, Iron & R.R. bloom shear will open up a very extensive and interesting field for the application of standard reversing mill equipments which will compare very favorably in size with those required by some of our largest reversing mills.

Fig. 23. Removable Truck Safety First Switchboard Unit with Truck in Position

Direct-current Mill-type Motors for Steel Mill Auxiliary Drives

By J. D. Wright

Power and Mining Engineering Department, General Electric Company

As pointed out by the author, the continuous operation of a mill is as dependent upon certain auxiliary drives as it is upon the main drive itself. Therefore, since "the chain is no stronger than its weakest link" and these motors are subjected to a particularly arduous duty, the greatest care must be exercised in their design and manufacture. The motors are built in both the enclosed-frame and open-frame type and in a variety of sizes ranging from 3 to 275 h.p. This article compares the details of construction of the enclosed-frame and open-frame type motors, and furnishes very complete information concerning ratings, bearings, brushes, and poles of the various sizes of motors.—Editor

It has become the custom to designate by the term "auxiliary drives" such drives as are applied to ingot buggies, screw downs, mill tables, manipulator fingers and side guards, tilting tables, chain conveyors, etc. The necessity of uninterrupted operation of any and all of these auxiliaries is no less urgent than that of the main drive. A failure occurring in any one of these drives stops the operation of the entire mill just as effectively as does the failure of the main drive itself. The duty of the motor which is applied to these drives is frequently very severe, especially on front and rear mill tables and screw downs where the motor is started, stopped or reversed as often as 15 times per minute.

To meet this exceptionally heavy duty the General Electric Company developed, some years ago, a complete line of direct-current mill type motors. These motors are of very heavy and rugged construction and have been successfully applied to all heavy duty drives in steel mills and to other locations where the operating conditions partook, more or less, of the nature of mill service.

Nomenclature

MD—Enclosed frame, direct current

MDS—Open frame, direct current

Forms A and AA—without countershaft brackets.

Forms B and BB—with countershaft brackets.

These motors will carry loads varying instantaneously between free running and 100 per cent overload with black commutation, and will carry without serious sparking much greater overloads.

Owing to the heat resisting character of the insulation these motors can operate for considerable periods of time at temperatures of 150 deg. C. without serious deterioration.

Frames

MD Motors (Figs. 1, 2, 3, 4, and 19). These motors are built totally enclosed in horizontally split steel frames, the two halves of which are held together by four large corner bolts. In the sizes in which commutating poles are used the poles located near the split are held entirely in the lower half, the frame being offset in a simple manner to provide for this. Four heavy feet are pro-

RATINGS

ENCLOSED FRAME (MD) MOTORS

Frame	Mill 60 Min.	Speed Full Load		Crane 30 Min.	Speed Full Load	
	H.P.	230 Volts	550 Volts	H.P.	230 Volts	550 Volts
101	3	1175	1350	5	825	925
102	7	1025	1250	10	800	1000
103	12	875	1050	16	725	875
104	20	725	850	30	575	650
104½	30	625	700	45	500	550
105	40	550	575	50	475	525
106	60	550	600	80	475	525
107	80	525	550	105	460	500
108	100	500	530	140	425	460
109	150	435	475	200	385	425

OPEN FRAME (MDS) MOTORS

Frame	Continuous	Speed Full Load		60 Min.	Speed Full Load	
	H.P.	230 Volts	550 Volts	H.P.	230 Volts	550 Volts
102	6	1150	1375	9	875	1075
103	10	1000	1175	15	750	900
104	20	725	850	27.5	625	675
105	30	600	650	40	550	575
106	50	575	650	63	525	[illegible]
107	70	550	600	87	500	[illegible]
108	90	500	550	115	450	500
109	135	460	500	170	400	450
109½	175	475	525	230	425	475
110	200	425	450	275	370	400

vided, each foot being drilled for one foundation bolt. Wrought iron bails cast in the upper half of the frame provide a convenient means of handling the motor.

All sizes up to and including frame 107 are provided with hinges to facilitate handling the upper half.

Fig. 1. MD-102, 7-h.p., 1025-r.p.m., 230-volt, Series-wound, Mill-type Motor

One large opening in the frame is provided directly over the commutator, giving ready access to commutator and brushes. Other frame openings are provided for inspection of the armature and field coil connections, and all openings have malleable iron covers fitted and held in place by locking levers or bolts.

On all sizes except frame 110, pads are provided on the lower half of the frame for mounting a gear case at either end, and also for mounting a solenoid brake at either end.

MDS Motors (Figs. 5 and 6). The construction of the MDS motor differs from that of the MD motor in that the upper half is entirely open. The lower half is very similar to that of the MD motor but with several large cored openings, the material in the frame being distributed to give maximum ventilation without sacrificing mechanical strength.

The foundation drilling, length of shaft, shaft extensions, height of shaft above feet, gear centers, and in fact all essential dimensions are alike in the two lines of motors. The complete MDS motors are therefore interchangeable in the same foundations with the corresponding MD motors.

The only difference in construction between the MD and MDS motors are those which are obvious from the illustrations of the two types of machines, these differences consisting in the use of separate bearing caps and magnet yoke instead of a single box type upper half of frame, as is the case with the MD motors.

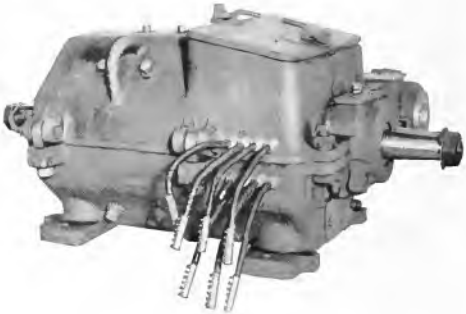

Fig. 2. MD-104½, 30-h.p., 600-r.p.m., 230-volt, Series-wound, Mill-type Motor

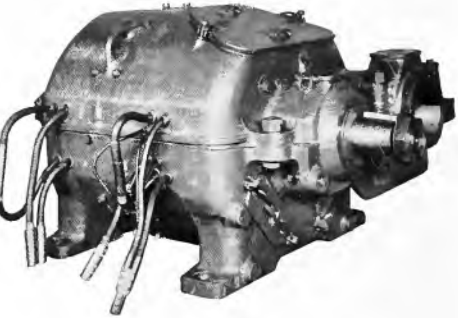

Fig. 3. MD-109, 150-h.p., 435-r.p.m., 230-volt, Compound-wound, Mill-type Motor

Fig. 4. MD-105, 40-h.p., 550-r.p.m., 230-volt, Series-wound, Mill-type Motor, with Upper Half Raised

Armature Bearings

MD Motors. Armature bearing housings form part of the frame castings. The bearing linings are cast steel babbitted. Oil ring lubrication is standard. The two halves of the bearing linings are together and a lifting bail is cast in the upper half. This construction provides an easy means of handling the armature.

This bearing construction, in which the two halves of the lining are bolted together, serves the further purpose of protecting the oil rings against breakage in case of carelessness in removing the armature from the frame.

A system of oil grooves in the bearings and oil deflectors on the shaft are used whereby seepage of oil from either end of the bearings is prevented.

The bearing linings are prevented from rotating by wings on the lower half which bear against machined surfaces on the upper half of the bearing housing (on the upper half of the frame). The armature end thrust is transmitted directly to the frame through a shoulder in the bearing lining. This construction therefore dispenses entirely with the necessity for dowels.

Armature bearing linings may be easily removed from the frame without disconnecting the armature shaft from the machine to which it is connected.

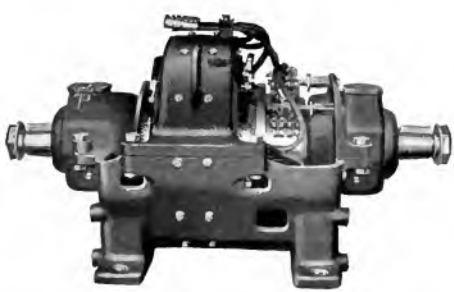

Fig. 5. MDS-109, 135-h.p., 460-r.p.m., 230-volt, Series-wound, Mill-type Motor

Hinged, dust proof, spring closed covers are provided on all bearing caps.

MDS Motors. Because the upper half of the MDS motor frame is open, separate armature bearing caps are of course necessary. Each bearing cap is securely held to the lower half of the frame by two dowel pins and two through bolts. Each cap is

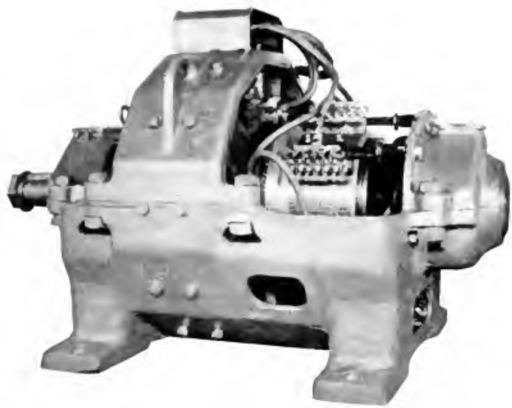

Fig. 6. MDS-110, 200-h.p., 230-volt, Series-wound, Mill-type Motor

provided with a hinged, dust proof, spring closed cover.

Countershaft Brackets and Bearings

MD and MDS Motors (Figs. 7, 8, and 9). Countershaft bearings, when provided, are carried by brackets cast with the lower half of the frame. The mechanical construction of these brackets is such that they are very strong and rigid. In sizes above frame 104½ each bearing cap is securely held to the bracket by four through bolts and is lined up by a tongue and groove. Hinged, dust proof, spring closed covers are provided on all bearing caps.

The standard countershaft bearing linings are babbitted, although for countershaft diameters larger than can be obtained in this manner, special bronze linings can be furnished. Countershaft bearings are arranged for waste lubrication.

The bearing linings are prevented from rotating by a dowel pin located in the bearing cap, which engages with a hole in the upper half of the lining. The back shaft end thrust is transmitted through the gear hub to the outside end of the bearing linings.

Table I gives the dimensions of armature and countershaft bearing linings for the MD and MDS motors.

Gears and Gear Cases

Pinions are made of the highest grade of hammered steel and gears of cast steel, either split or solid.

Entirely special frames using standard electrical parts have been developed in some sizes for very large gear ratios.

Gear cases are of malleable iron, are interchangeable between the two ends of the motor, and are supported by bolting to pads on the countershaft bracket and the lower half of the frame.

Shafts

The armature shafts are unusually heavy. They can be removed and replaced without disturbing the connections from the armature to the commutator. The standard armatures have tapered shaft extensions at both ends.

Armatures

The armature construction is exceptionally heavy, with a view of protection not only against the shocks and stresses incurred in service, but also to protect against careless handling of the armatures when removed from the frame (Figs. 10, 11, 12, 13, 14, 17, and 18.)

The finished armature is carefully balanced in accordance with the most improved practice, although on account of the heavy construction and low peripheral speed this is a refinement not really necessary for satisfactory operation. It has been shown by tests that in repairing one of these armatures no particular attention need be given to the question of balance.

In view of the importance in many instances of extremely rapid acceleration the armatures have been made small in diameter, so that the peripheral velocities are very low as compared with direct current motors of ordinary design. As a result, the power required to accelerate an MD or MDS motor to full speed in a given time is only one third to one fourth of that required for direct current motors of the ordinary types and corresponding horse power.

Fig. 7. MD-108, 100-h.p., 500-r.p.m., 230-volt, Compound-wound, Mill-type Motor

Fig. 8. MD-104½, 30-h.p., 600-r.p.m., 230-volt, Series-wound, Mill-type Motor

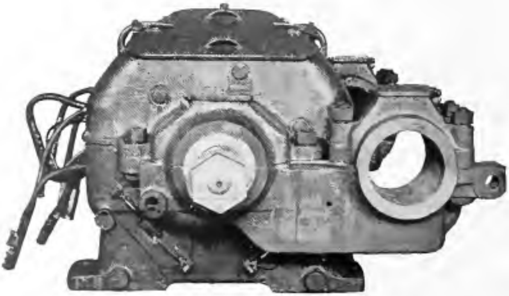

Fig. 9. MD-109, 150-h.p., 435-r.p.m., 230-volt, Compound-wound, Mill-type Motor

The armature punchings are keyed to a heavy steel spider and assembled between end flanges under heavy hydraulic pressure. Ventilating ducts in the punchings are

TABLE 1

Frame	Armature Bearings		Countershaft		Bearings
	Bore In.	Lgth. In.	Bore Std. In.	Bore Max. In.	Lgth. In.
MD-101	$1\frac{3}{4}$	$4\frac{3}{8}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$7\frac{23}{32}$
MD-102	$2\frac{1}{4}$	$5\frac{7}{16}$	$2\frac{1}{4}$	$3\frac{1}{4}$	$9\frac{5}{32}$
MDS-102	$2\frac{1}{4}$	$5\frac{5}{8}$	...	...	...
MD-103	$2\frac{1}{2}$	$5\frac{13}{16}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$9\frac{17}{32}$
MDS-103	$2\frac{1}{2}$	$6\frac{1}{8}$	...	...	...
MD-104	3	$7\frac{1}{16}$	3	4	$10\frac{13}{32}$
MDS-104	3	$7\frac{1}{4}$	...	...	...
MD-104½	3	$7\frac{1}{16}$	3	4	$10\frac{13}{32}$
MD and MDS-105	3	6	$3\frac{1}{2}$	5	$7\frac{1}{2}$
MD and MDS-106	4	8	$4\frac{1}{2}$	6	9
MD and MDS-107	$4\frac{1}{2}$	9	5	$6\frac{3}{4}$	$10\frac{3}{8}$
MD and MDS-108	5	10	6	$7\frac{1}{2}$	$11\frac{1}{4}$
MD and MDS-109	6	12	7	$8\frac{1}{2}$	$12\frac{3}{4}$
MDS-109½	6	12	7	$8\frac{1}{2}$	$12\frac{3}{4}$
MDS-110	$6\frac{1}{2}$	13	$7\frac{1}{4}$	$8\frac{3}{4}$	14

provided by I-beam shaped welded space blocks (Fig. 13). On sizes up to and including frame 101½ the front or commutator end flange is cast integral with the spider. On larger sizes the front flange is held in place by a shoulder on the spider. On the MD-105 motor and larger sizes the rear flange is pressed onto an extension of the spider and bolted to the spider by cap bolts (Fig. 12). On frames 101 to 101½ inclusive the rear armature flanges are held in place by lengthwise keys and rings shrunk into position on the armature sleeve behind the flange. The armatures of the 101 to 101½ frames are wound with formed coils of asbestos-covered wire. At the slot portion the coils are wrapped with sheet mica which is moulded to size. The ends of the coils are wrapped with mica tape and an outside wrapping of asbestos tape.

Fig. 10. Complete Armature of MD-103, 12-h.p., Mill Type Motor

Fig. 11. Complete Armature of MD-105, 40 h.p., 550-r.p.m., 230-volt, Mill-type Motor

Fig. 12. Armature Core of MD-106, 60-h.p., 550-r.p.m., 230-volt, Mill-type Motor

Fig. 13. Armature Core of MD-106, 60-h.p., 550-r.p.m., 230-volt, Mill-type Motor

In the frame 105, 230-volt motor and larger sizes the armature is bar wound with one turn per coil. The bars are continuous at the rear end, eliminating the soldered clips which are used at this point on the ordinary

Fig. 14. Details of Binding Band and Clamp on MD and MDS Armatures

lines of motors. The armature bars are insulated throughout with mica and specially treated tape, and the whole is then moulded to size over the slot portion.

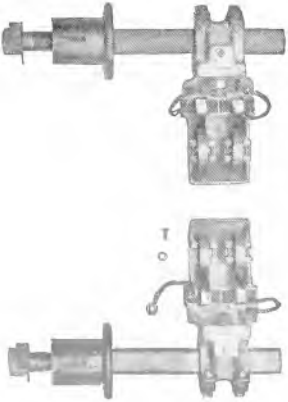

Fig. 15. Brush-holders and Brush-holder Studs for MD-103 Mill Type Motor

In all cases the end windings are protected against injury at the front end by the solid commutator ears, and at the rear end by the armature flange which is bell shaped and of the same diameter as the core. The rear end windings are further protected from dirt and steel dust by a covering of asbestos webbing held in place by the flange and rear armature binding band (Figs. 10 and 11).

In banding the armatures neither solder nor wire is used. Over the core surface the winding is held in place by metal wedges, and over the end surfaces by solid metal bands (Fig. 14).

One very important feature of the MD and MDS armatures is the fact that in all sizes a two-circuit "series drum" winding is used (sometimes known as a "wave winding"). This method permits the use of a less number of brush-holders than corresponds with the number of poles, without, however, requiring any cross-connections between commutator segments. This series winding also gives perfect electrical and magnetic balance, and in cases where more than two studs are used gives perfect distribution of current between the studs. No equalizers or cross-connections of any description are used with the armatures.

Commutator

The commutator bars are made of hard drawn copper with large ears which form part of the bars. The armature conductors extend

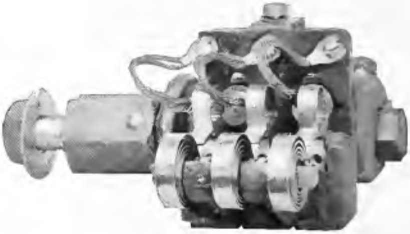

Fig. 16. Brush-holder and Brush-holder Studs for MD and MDS-106, Mill Type Motors

straight into the ears without the use of separable leads, thereby simplifying the construction and reducing the number of soldered joints. Commutator connections are soldered with hard solder.

The commutator construction is in accordance with best practice throughout, using bed insulation and one-piece cones of clear mica.

The commutator shell is mounted on the armature spider so that the shaft may be removed without disturbing the connections from the winding to the commutator.

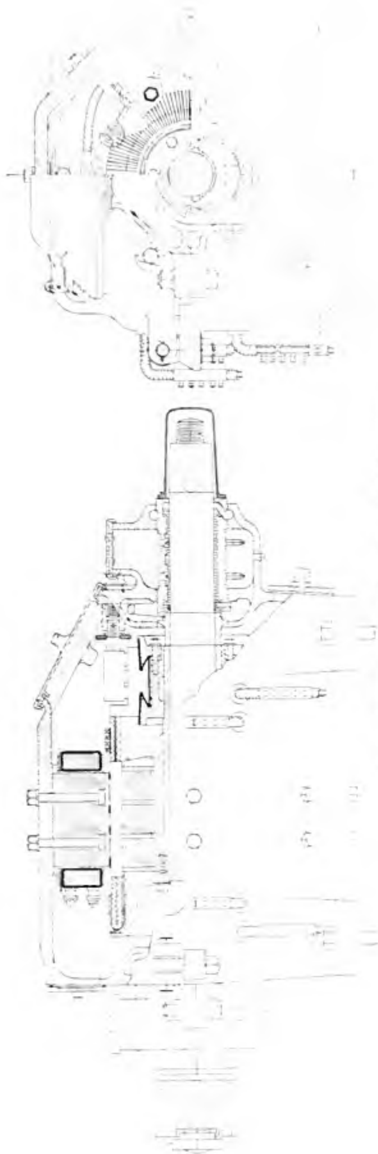

Fig. 17. Cross Section Assembly of Type MD Mill Motors

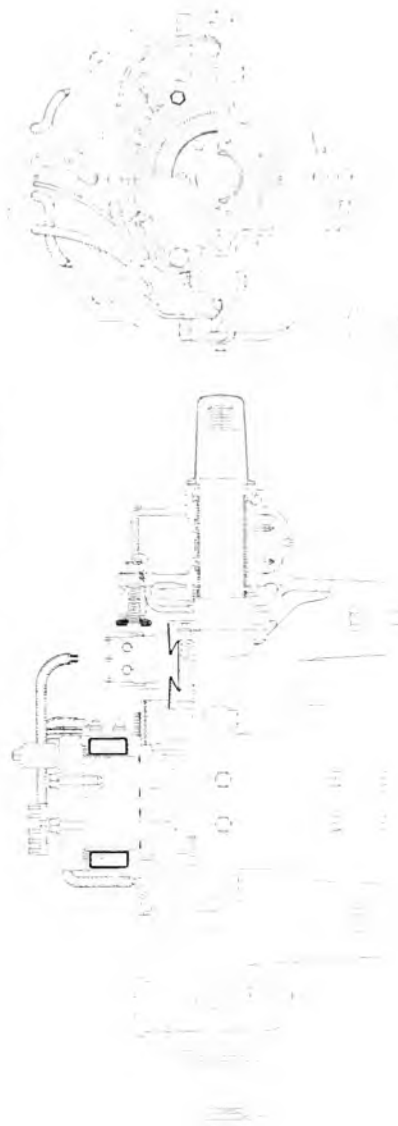

Fig. 18. Cross Section Assembly of Type MDS Mill Motors

Brush-holders and Brushes

The following tabulation shows the number of brush-holder studs and number and size of brushes per stud in the MD and MDS motors. (Figs. 15 and 16).

Brush-holder studs are of steel, insulated in the smaller sizes with mica wrapping over which is moulded a seamless fiber tube, and in the larger sizes by mica wrapping held in place by a special insulation and moulded down to size. The ends of the studs are covered by insulating plugs which are moulded solidly into the outer covering. The brush-holder box is brass and is finished for a close fit of the brushes, so that the current can be carried satisfactorily if the pig tails are removed. It is recommended, however, that brushes with pig tails be used in order to reduce the losses at this point. Heavy coiled phosphor bronze clock springs are used, which are non-adjustable and arranged to maintain practically uniform pressure over their entire working range.

Poles

The following tabulation shows the number of main and commutating poles in the MD and MDS motors:

Frame	Main Poles		Commutating Poles	
	230 V.	550 V.	230 V.	550 V.
MD-101	4	4	.	1
MD and MDS-102	4	4	.	1
MD and MDS-103	4	4	.	1
MD and MDS-104	4	4	.	2
MD-104½	4	4	2	2
MD and MDS-105	4	4	4	4
MD and MDS-106	4	4	4	4
MD and MDS-107	4	4	4	4
MD and MDS-108	4	4	4	4
MD and MDS-109	6	6	6	6
MDS-109½	6	6	6	6
MDS-110	6	6	6	6

Pole Pieces

The main pole pieces, Figs. 17 and 18, are built up of steel punchings strongly riveted together and extending through the entire depth of the coil. They are held in place in some cases by cap bolts passing through the frame, and in other cases by bolts with square heads embedded in the pole pieces and nuts on the outside of the magnet frame. Commutating pole pieces are held in place by cap bolts.

Frame	Number Brush-Holder Studs	Number of Brushes per Stud		Size of Brush			
				230 V.		550 V.	
		230 V.	550 V.	Width In.	Thickness In.	Width In.	Thickness In.
MD-101	2	2	2	¾	7/16	¾	5/16
MD and MDS-102	2	2	2	1	⅜	1¼	5/16
MD and MDS-103	2	2	2	1¼	½	1	⅜
MD and MDS-104	2	2	2	1½	⅝	1¼	7/16
MD-104½	2	3	2	1⅛	¾	1¼	½
MD and MDS-105	2	3	2	1¼	⅝	1¼	½
MD and MDS-106	2	3	2	1¼	⅞	1¼	⅝
MD and MDS-107	2	4	4	1¼	1	1¼	½
MD and MDS-108	2	5	5	1¼	1	1¼	½
MD and MDS-109	4	4	4	1¼	1	1¼	½
MDS-109½	4	6	4	1¼	1	1¼	⅝
MDS-110	4	7	4	1¼	1⅛	1¼	¾

In frames below the 109 only two brush-holder studs are used, both located in the upper half of the frame. The 109 motor and larger (which are six-pole machines) require four studs, three of which are in the upper half.

However, as all the 109½ and 110 motors and most of the 109 motors are built in the MDS open frames, and as the one stud in the lower half is located close to the split, this stud is practically as accessible as the upper studs. In the MD-109 enclosed motor a large handhole is so located in the lower half as to give the maximum possible accessibility to this stud.

Field Coils

The MD and MDS motors may be equipped with series fields or with either of two standard compound wound fields, one giving a no-load speed 50 per cent above full load speed and the other a no-load speed 100 per cent above full load speed. The shunt winding is designed so that line voltage may be impressed continuously without serious overheating.

For the five smallest sizes the main series field coils are wound with asbestos covered wire. For the larger sizes the main series fields and the commutating fields are strip wound with sheet asbestos between turns.

The shunt windings or the shunt portions of compound windings consist of asbestos insulated wire on all sizes except those that use small size wire. The latter is enameled and single cotton covered. In all compound wound coils the series winding is taped separately before the shunt turns are wound on. The entire coil in every case is finally covered with sheet mica and a heavy wrapping of non-elastic webbing.

All main and commutating coils are duplicates and can be put on the pole pieces either side up without any chance of confusion in the connections. To connect the coils properly it is not necessary to refer to any prints or to any tags on the coils, but merely to connect alternate coils oppositely in an entirely obvious manner.

Connections

Connections from parts in one half of the motor to parts in the other half are all made outside the motor. In order to take the motor apart it is therefore unnecessary to disconnect any leads inside the motor. Outside connections between the two halves of the motor are made by sleeve connections.

APPLICATIONS

The large majority of applications of mill type motors will always be in and about steel plants. But, although developed primarily for operating reversing auxiliary machinery in steel plants, mill type motors have been applied to many other classes of work, in some case under widely different conditions. In considering whether or not to use mill type motors it should be borne in mind that the most distinctive features of the mill type motors are unnecessary in general applications in which the ordinary types of motor have given and are continuing to give satisfaction. Where the ordinary standard motors have not stood up to the work it is advisable to consider the mill type motors with a view of determining whether the advantages offered by the mill type motors have any bearing on the particular case at hand. The advantages to be gained by the use of mill type motors hinge in general upon the following characteristics:

- Heavy mechanical design throughout.
- Large foundation area (i.e., distance between foundation bolts).
- Heavy self-contained countershaft brackets.
- Ease of replacing parts.
- Ease of making extensive repairs.
- Small stored energy in armature.
- Superior commutation.
- Heat resisting insulation.
- Totally enclosed features.

In addition to cranes and reversing auxiliary machinery in steel plants, the principal classes of electric drive to which mill type motors should be applied or can be applied with advantage are as follows:

- Ore and coal bridges and unloaders.
- Charging machines of all types; for example, for gas works.
- Coke pushers, levelers, etc.
- Heavy duty fabricating shop and erecting shop cranes.
- High grade factory cranes.
- Electric shovels.
- Dipper dredges.
- Capstans, gates, valves, etc., on canal locks.
- Draw and lift bridges.
- Small heavy duty hoists; for example, for construction purposes.

Fig. 19 MD-105, 40-h.p., 550-r.p.m., 230-volt, Series-wound, Mill-type Motor

Progress in the Electrification of Mine Hoists

By R. S. Sage

Power and Mining Engineering Department, General Electric Company

The history of the electrification of mine hoists is interestingly narrated in the following article which traces the subject from its modest beginning in the early days to its practically universal application of today. The requirements of a mine hoist are described and the advantages of electric drive are explained. The latter pages of the article are devoted to a description of the various parts of the modern highly developed mine-hoist equipment.—Editor.

As the natural occurrence of mineral deposits is usually such as to require their elevation from various depths underground to the surface, some means of accomplishing this transfer constitutes an important requisite in connection with the operation of almost all mines. In many cases, particularly with coal, it is possible for the material to be brought out through a tunnel driven either on a horizontal or on such a slight incline as to permit the use of cars drawn by mules or electric locomotives. For the most part, however, both with coal and ores, it is necessary to bring the material to the surface by hoisting, either through a vertical shaft or on inclines too steep for the employment of locomotives.

There are therefore so-called "main" hoists for bringing the material to the surface (or as is occasionally the case in metal mines, to lift the material to the main tunnel out of which it is brought in cars), and in many cases auxiliary hoists, generally referred to as "man and supply" or "chippy" hoists, chiefly used in handling men and the materials used underground. Underground small-powered hoists are often used for hauling cars up steep inclines from one level to another, and less frequently the main hoist itself is installed underground.

Until comparatively recent years the steam engine was used almost exclusively for operating these various mine hoists, compressed air, however, also being used to a considerable extent, the most notable example of the latter being the group still in operation at the Anaconda Copper Company's mines at Butte, Montana. It was many years after electricity had come into general use in the railway field and elsewhere before the use of electric motors for driving "main" hoists began to receive serious consideration in this country, although considerable development had been done along this line in foreign countries, especially in Germany and in the gold fields of South Africa. Electrification naturally began with the smaller hoists used in underground work, it being early found convenient and advantageous to operate these with electric motors from the direct current mine circuit supplying lights, pumps, and later electric locomotives, thereby eliminating long steam and air pipe lines. The practice, however, did not extend rapidly beyond these small equipments for many reasons.

Mine operators as a rule, were more or less unfamiliar with electric power except in the small quantities supplied by the usual direct-current circuit for the purposes previously mentioned.

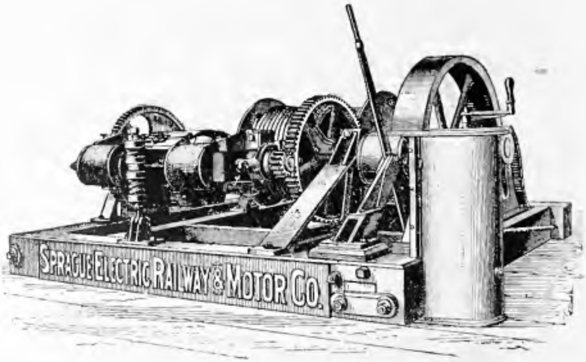

Fig 1. (Reproduction from Wood-cut in Electrical World.) The First Electric-driven Mine Hoist in This Country and Perhaps in the World, Driven by a 10-h.p., 440-volt, Railway Type Motor, Installed at Aspen, Colorado, July, 1888.

Central station power did not reach many mining localities, and where available often could not be had in sufficient quantity at attractive rates or with assurance of reasonable continuity of service. On the other hand, the highly fluctuating character of the mine hoist load was not such as to appeal to the moderate capacity central station.

There was also a certain amount of prejudice to the electric drive on the part of the users of steam engine driven hoists, due to a feeling of unreliability resulting probably from a knowledge of certain instances of power failure. And further, an idea was prevalent among coal mine operators that as the coal burned under their steam boilers came from their own mines, the cost of fuel for this purpose was little or nothing and therefore was not taken into account in estimates of the cost of steam power; whereas, actually, coal which could be used for this purpose had a considerable market value. The exceedingly low all-day efficiency with which the average steam hoist operated and the enormous waste of coal in supplying power to this and other mining operations was generally unappreciated until made the subject of special investigation and a comparison made with results by electrification.

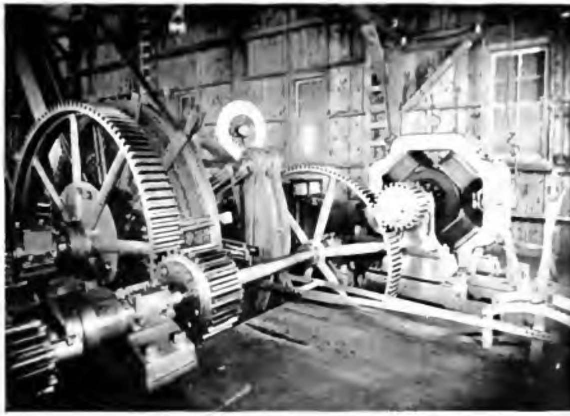

Fig. 2. Largest Electric Hoist in the World in 1895, Driven by a 100 kw., 650-r.p.m. 500-volt Railway Type Generator. Free Silver Shaft, Aspen, Colorado

Fig. 3. First Motion Steam Hoist Converted to Electric Drive, Driven by 900 h.p. Geared Induction Motor. Bantjes Shaft, South Africa

It was therefore necessary that many existing conditions and ideas had to undergo a change before hoist electrification became general, headway to this end being slow until the last few years. Much was accomplished by engineering reports of operating conditions at various mining properties which showed in the majority of cases indisputable advantages and economies to be secured by general electrification. As an instance: actual tests of a typical large coal mine hoist indicated that 50 lb. of coal was burned per horse power hour of work done on the coal hoisted. With electric power, produced in even a moderate capacity station, not more than one tenth this amount of coal would be burned for the same unit of work.

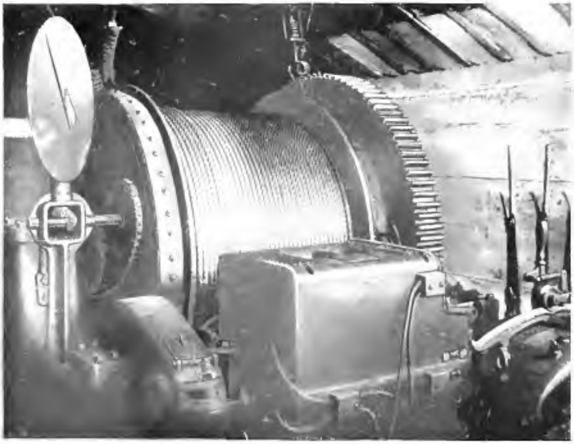

Fig. 4. View of the First Electrically-driven Mine Hoist Used in the Anthracite Coal Fields, Consisting of G-E 2000 Motor and Single-drum Hoist; Installed at Maltby Colliery, Lehigh Valley Coal Co. in 1896, and Still in Regular Operation

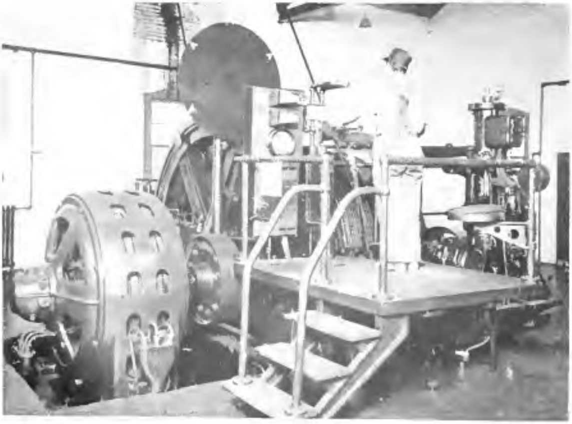

Fig. 5. Typical Modern Coal Hoist Driven by 300-h.p. Geared Induction Motor with Magnetic Control. Pittsburgh Coal Co., Cowden, Pa.

As more economical methods of electric power generation and distribution became known and the necessary apparatus became more highly developed, quite a number of companies carrying on extensive mining operations installed their own hydro-electric or steam-electric plants and instituted motor drive for all their operations, including hoisting. At the same time electric power became more accessible to other mining localities as the number of central generating stations increased and others were enlarged and their service extended. With such service available, there existed few instances in which electrification could not be shown justifiable from an operating cost standpoint alone. Meanwhile many hoist electrifications had been made abroad with great success, proving the many claims of superiority for the electric over the steam hoist, among which were greater safety, reliability, simplicity, and economy. An indication of the possibilities in economy accruing from electrification in mining properties is the statement recently made in connection with an investigation of the matter, that, through complete electrification of the anthracite coal fields the amount of coal used in the production of an annual tonnage of approximately 90,000,000 tons can be reduced from approximately 10,000,000 to less than 2,000,000 tons.

Growth of Electrification

Probably the first instance of the application of the electric motor to driving a hoist for mining purposes was the outfit (illustrated in the reproduction of wood-cut in Fig. 1) put into operation in July, 1888, at the Aspen Mining & Smelting Co., Aspen, Colorado. The manager of the company at that time was persuaded to install 1000 feet underground a single-drum, flat-friction hoist driven through a single reduction of gearing by a 10-h.p., 440-volt railway type motor, the complete outfit being built by the Sprague Electric Railway & Motor Co. This equipment, which replaced a steam operated hoist, was used for pulling cars into the tunnel and proved such a success that two similar hoists were installed soon after. This equipment continued in operation for many years with the original motor, which has since been replaced by a G-E 800 motor.

Fig. 6. Largest Induction Motor Driven Hoist in America. 1800-h.p., 360-r.p.m., 2200-volt Motor Geared to 12-ft. Diameter Hoist Drum, Controlled by Liquid Rheostat Shown in Left Back-Ground. Hoist Originally Driven by First Motion Corliss Steam Engine. Tennessee Coal, Iron & R. R. Co., Muscoda, Ala.

Fig. 7. The Largest Electric Hoist in the World, Driven by Two 2000-h.p., 53.5 Direct-connected D-c. Motors, Crown Mines, Ltd., South Africa

In 1895 there was installed at the Free Silver Shaft, also at Aspen, an electrically operated hoist (Fig. 2) of comparatively large capacity, driven through gearing by a 100-kw. railway type generator. This hoist, at that time the largest electrically operated hoist in the world, was designed by Mr. D. W. Brunton, Mining Engineer, and supplied by the Roaring Fork Electric Light & Power Co., a pioneer in hydro-electric power generation. An auxiliary motor of 60 h.p. was arranged for throwing in on a second pinion to assist the main motor when necessary to lift the heavy water bailer; little use, however, has been made of this arrangement.

In the anthracite coal fields the first motor drive for hoist work was installed in 1896 on a 1200-ft. slope at the Maltby Colliery of the Lehigh Valley Coal Co. at West Wyoming, Pa. The hoist, built by the Lidgerwood Manufacturing Company, is driven by a G-E 2000 (approximately 100 h.p.), 500-volt railway type motor and controlled by an R-15 controller, and is in regular operation at the present time, the entire outfit having been in continuous service during the 22 years since its installation. A view of this installation is given in Fig. 4.

From these small beginnings the electric hoist has become today the prevailing type.

many steam plants having been converted to motor drive (an example is shown in Fig. 3) with very great advantage, and fully 85 per cent of all new installations are electric motor driven. The General Electric Company alone has equipped many hundreds of mine hoists of various types in this and foreign countries. Considering only those driven by motors having a continuous rating of 250 h.p. or larger, there are 240 installations aggregating 121,000 horse power. A typical coal mine installation is illustrated in Fig. 5. Of these all but 35 are driven by geared induction motors, the largest being of 1800-h.p. continuous capacity, developing during starting approximately 2700 h.p. This equipment, (Fig. 6) the largest of this type in this country, is installed at the Tennessee Coal, Iron & R.R. Co. at Muscoda, Ala., having replaced a first motion Corliss engine for operating a single drum slope hoist. This installation, which is supplied with power by the Southern Power Company, affords an interesting example of the ability of the modern central power station to handle widely fluctuating loads of this character.

The direct-current equipments, which make up the remainder of this number, include two of 4000-h.p. continuous rated capacity, the largest in the world (Fig. 7), which are installed at the Crown Mines, Ltd., and the New Modderfontein Gold Mining Co., both in South Africa.

An electrification of unusual magnitude, indicating the extent to which electric drive for mine hoists has been carried out, is that of the Cleveland Cliffs Iron Mining Co., Ishpeming, Mich. This company, which was among the earliest to adopt electric power in mining operations, produces its own power in both hydro electric and steam plants, and has installed some 29 electric hoists, totalling over 11,000 h.p. rated capacity. Of these hoists, 26 are driven by geared induction motors, 16 of which, identical in every way as to electric equipment, are of 400-h.p. capacity at 360 r.p.m., 2200 volts. These installations have been made from time to time as new shafts were opened up, the hoists being used with complete success for handling ore and men, and during sinking operations.

There are many similar examples of extensive hoist electrification in both the metal and coal mining fields, and the number is continually being augmented as circumstances permit. An installation view of one of the 875-h.p. induction motor equipments at the Oliver Iron Mining Company is shown in Fig. 8.

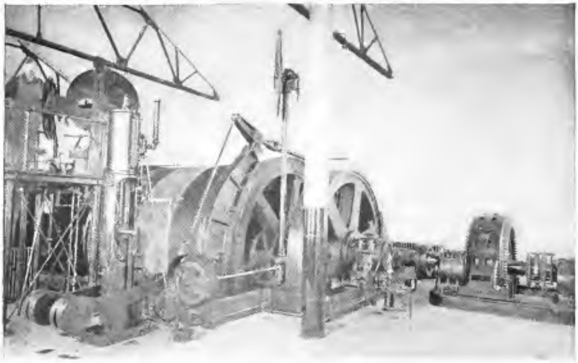

Fig. 8. Mine Hoist Driven by 875-h.p., 360-r.p.m., 2200-volt Induction Motor Controlled by Liquid Rheostat, Oliver Iron Mining Company, Ironwood, Michigan

Electrical Equipment

The General Electric Company has taken a prominent part in electrification in this field, as is evidenced by the large number of equipments which it has supplied, and the broad experience gained has lead to many improvements in the design of the apparatus constituting the complete equipments. This experience, backed by a thorough understanding of the various elements upon which the successful operation of the electric hoist depends, insures in every specific case the application of apparatus of the proper type and capacity required to meet the conditions of operation. In general, every case constitutes a problem in itself, necessitating for its solution not only a complete knowledge of the duty to be performed, but all other conditions affecting the design of apparatus and system to be employed. In the following paragraphs there are indicated some of the more important details which have required special attention and the improvements in equipment which have been made in the development of this application of electric drive to its present successful condition, with illustrations of late types of apparatus used in this service.

Hoist Motors

With induction motors, so widely used for this service, the principal requisite in addition to adequate torque and capacity, good performance characteristics, and rugged construction, is low slip-ring voltage in order to prevent flash-over at the rings in case the motor is reversed at full speed. Under this condition, which is apt to occur frequently in this service, double standstill voltage is developed between the collectors, and should a short-circuit occur the motor would be incapable of developing appreciable torque.

The highly developed art of gear-cutting permits the use of moderately high speed motors, which is desirable from the standpoint of first cost as well as performance characteristics. With herringbone gears it is not uncommon to use reduction ratios as high as 15 to 1.

Fig. 9. Installation View of Contactor and Switchboard Panels Used with Induction Motor Driving Mine Hoist, Showing Recent Design of 150-ampere 2200-volt Air-break Primary Reversing Contactors

As large direct-current motors can be designed to operate with good efficiencies at the low speeds required they are usually direct-connected to the hoist drums and the use of gears eliminated. The use of commutating poles and compensating pole face windings for hoist motors and Ward Leonard generators has overcome all difficulty in handling the heavy peak loads encountered in this service.

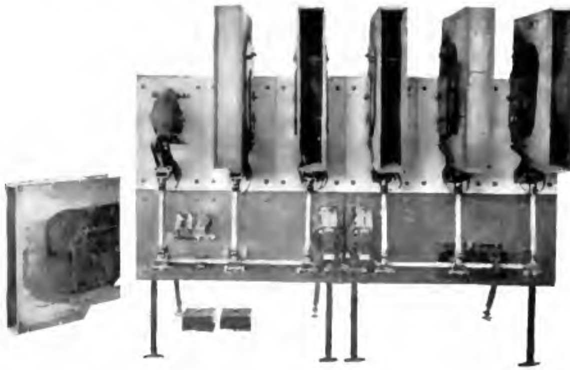

Fig. 10. Triple pole Air-break Primary Reversing Contactors for Use with large 2200-volt Hoist Induction Motors

Resistances and Controller Steps

Difficulty was early encountered in some instances because of insufficient capacity in the resistances used with rheostatically controlled motors. Due to the frequency of starting and the necessity of operating at creeping speeds for shaft and rope inspection, etc., and the liability of occasional reversal at full speed, the resistance for the mine hoist motor must be specially designed with these requirements in view, the resulting rheostat being very much heavier than that required for occasional starting duty, or for crane service. For the same reasons the controller must provide, in addition to the steps required for properly accelerating the hoist, a suitable number of points for speed regulation.

Contactor Control

Experience indicates that with few exceptions motors of 100-h.p. capacity or larger for mine hoist service cannot be successfully handled by drum controllers due to the magnitude of the currents and the frequency with which the circuits must be made and

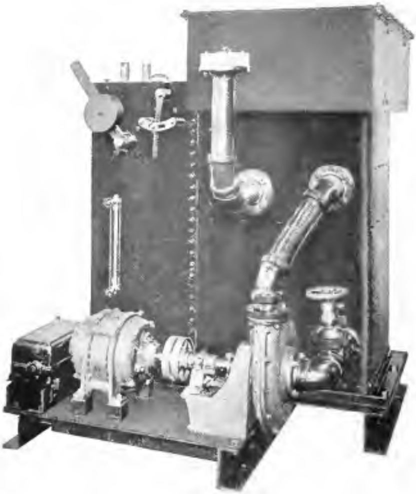

Fig. 11. Successful Type of Liquid Secondary Rheostat for Control of Mine Hoist Induction Motors. Operating Lever is on opposite side of Tank

broken. These requirements have been met successfully by the use of magnetically operated switches (so-called contactors) for both the primary and secondary circuits. With this type of control the motor currents can be interrupted as frequently as necessary with only an occasional renewal of tips, and the operator's controller need be only large enough to handle the small current required for operating the contactors. At the same time, automatic acceleration of the motor is attained, thereby protecting it from abuse and the power supply from excessive current demands.

Because of advantages in transmission, wiring, etc., it became desirable to use primary voltages of 2200 volts for induction motors for hoist service, especially in medium and large capacities. This necessitated the development of contactors (Figs. 9 and 10) for interrupting the currents in air for reversing the primary connections of the motor, as practice had demonstrated the unsuitability in this service of switches breaking currents under oil, the failure of this type being due to the rapid wearing of the tips and carbonization of the oil and the liability of explosions in the tank during jogging, due to the rapid accumulation of gas. This type of contactor has been built in large numbers and has been successfully applied to hoist motors up to and including 1800 h.p. continuous capacity at 2200 volts.

Liquid Rheostats

Although for most induction motor-driven hoists of less than 500-h.p. capacity, control using contactors and grid resistance providing

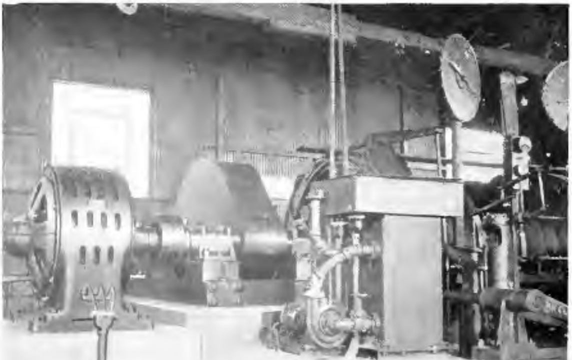

Fig. 12. Typical Geared Induction Motor-driven Mine Hoist with Liquid Rheostat Secondary Control, Utah Apex Mining Co., Bingham, Utah (500-h.p. Motor Continuous Rating)

not less than eight balanced and properly graduated steps for both directions of rotation have proven entirely successful in controlling the movements of the hoist under all operating conditions, it has been found desirable for larger motors, and to a lesser extent for smaller sizes, to use a rheostat utilizing a liquid as the resistance medium in order to obtain a larger number of partial speed points. As it was found that liquid rheostats embodying the principles of the liquid starters already used to some extent in other applications were entirely unsuitable for hoist service, a design was developed which has met all the requirements of successful operation. The chief feature of this rheostat (shown in Fig. 11), which is used only by the General Electric Company, is the use of two separate resistance sections, whereby a high initial resistance is provided for slow speed running at light loads and a low final resistance for operation at full speed. In contrast to other types, this high resistance ratio remains permanent, and at the same time danger of flash-over between phases when the motor is reversed at full speed is eliminated. Rheostats of this design were supplied in considerable numbers for the replacement of those of foreign manufacture in the South African mines, and have been widely applied to hoists in this country, the largest being used in con-

Fig. 14. 1400-h.p., 90-r.p.m., D-c. Motor Driving Cylindro-conical Drum Hoist at Consolidation Coal Co., Fairmont, W. Va., Flywheel Motor-generator set installed in adjoining room

Fig. 13. Double Drum First Motion Hoist Driven by 1800-h p., 80-r.p.m., D-c. Motor on Ilgner-Ward Leonard System Installed at the Elm Orlu Mining Co., Butte, Montana

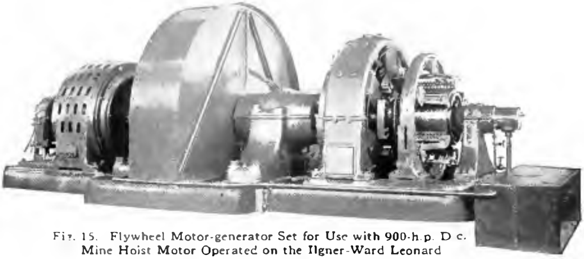

Fig. 15. Flywheel Motor-generator Set for Use with 900-h.p. D-c. Mine Hoist Motor Operated on the Ilgner-Ward Leonard System, Showing In-board Arrangement of Flywheel

nection with an 1800-h.p. induction hoist motor. In Fig. 12 is shown a typical installation with a moderate capacity hoist.

Direct Current Systems

While the large majority of electric hoists in this country are driven by induction motors with rheostatic control, the extreme nicety of control and high degree of safety of operation obtained with direct current motors operating on the well known Ward Leonard system commends its use for all high speed shaft hoists, and for those in the operation of which a higher efficiency is needed, particularly coal hoists.

Fig. 16. Liquid Slip Regulator of Recent Design Used in Connection with Flywheel Motor-generator Sets Supplying Power to D-c. Mine Hoist Motors Operating on Ilgner-Ward Leonard System, Showing Oil Switch for Short-circuiting Operating Motor

Flywheel Motor Generators

It is often impossible for the power supply system to operate under the heavy peak loads imposed by large hoist drives without seriously affecting the voltage regulation and interfering with the operation of other apparatus supplied from the same station. In such cases some form of load equalizing equipment is necessary, whereby the extremely fluctuating hoist load may come on the supply lines as a more uniform demand. This is commonly effected by combining with the Ward Leonard power set a flywheel and regulating device to permit the wheel to supply all energy required by the hoist above the average value over the complete cycle. There are numerous installations using this system in both this country and abroad, among the more recent being the 1800-h.p. equipment at the Elm Orlu Mining Company at Butte, Montana (Fig. 13), and the duplicate 1400-h.p. coal hoists at the Consolidation Coal Company, Fairmont, W. Va. (Fig. 14). Flywheels built up of rolled steel plates permitting of high stresses and consequently of high peripheral speeds can usually be made much lighter than cast wheels, resulting in lower cost and lower running losses, and often at the same time simplifying the problem of supporting bearings. Wheels of laminated steel plates up to 50 tons weight have been built for this service. In Fig. 15 is shown a flywheel motor-generator set as used for large direct-current mine hoists.

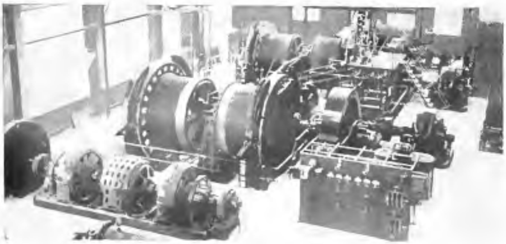

Fig. 17. Installation View of Two Automatic Mine Hoists Operating Entirely without Attention from Operator but Capable of Instant Manual Operation at Will. Inspiration Consolidated Copper Co., Miami, Arizona

Slip Regulators

In a recently developed design important improvements have been made in the automatic regulating device used in connection with the flywheel equalizing equipments previously mentioned. In all forms of this device, commonly called a liquid slip regulator, use is made of tiles or earthenware cylinders for separating the electrodes, and with all difficulty has been experienced due to leakage and frequent breakage of these barriers. With the newest type (Fig. 16) the entire design is greatly simplified and both of these troubles have been entirely eliminated.

Safety Features

The matter of safety in the operation of mine hoists has, owing to its great importance, received a large amount of attention in the design of the electrical system, electrical power being pre-eminently suited to the application of safety methods. Devices may be applied simply for the protection against damage due to overwinding and various other emergency conditions which may develop in the electrical equipment itself or in the system as a whole. As electric braking is available, the mechanical brakes are relieved of much use and consequent wear and tear, their use with hoists operating with Ward Leonard control being confined almost entirely to holding the loads. With this control loads of any value can be lowered at any partial speed and brought to rest without resorting to the mechanical brakes, and the power developed by the descending load returned in part to the power system.

The degree of safety and accuracy of control which may be secured in the operation of direct-current mine hoists is well exemplified in the installation at the Inspiration Copper Company, Miami, Arizona, of two automatic main hoists which operate entirely without regular attention from an operator. In these two hoists (Fig. 17), which have been in successful operation since 1915 and have a combined capacity of 1000 tons per hour from a depth of 630 feet, the loading, starting, dumping, and stopping are all accomplished entirely automatically, although by the simple throw of a lever switch the equipment can be instantly put under manual control.

The Ventilation of Coal Mines

By H. W. Chadbourne

Power and Mining Engineering Department, General Electric Company

Coal mining is attended by the liberation and formation of various gases which are injurious to the health of the workmen and animals and are violently explosive under certain conditions. To dilute and sweep away these harmful and dangerous gases, an abundance of fresh air must be supplied to the mine passages. The chemical and physical characteristics of these gases are described in the first section of the following article; the natural, furnace, and mechanical methods of ventilation in the second section; and the electric motor driven fan equipment and air courses in the third and concluding section.—Editor.

In coal mining it is necessary to keep all passageways and working places in a healthful and safe condition for work. To accomplish this there must be maintained a circulation of fresh air that will dilute, render harmless, and sweep away the noxious gas produced by the breathing of men and animals, the burning of lamps, the condensation of powder, the decay of timber and other organic matter, the gases occluded from the coal faces, and the fine coal and slack. Also if gasolene mine locomotives are used, their exhaust gives off more gases to be diluted and swept away. Not only is the oxygen of the air consumed in the operations performed in a mine, but a portion is also absorbed by the freshly exposed faces of coal. Before proceeding with the subject of ventilation, it is desirable to call attention to some of the gases which are given out by the newly exposed coal faces and the underlying and overlying strata. These vary widely in different coal beds. The gases occur in the seams of coal which are usually under considerable pressure due to weight of the strata above them. As these gases each have their separate effects, their combined effect is usually complicated. We can study their individual characteristics only and judge their combined effect when present in firedamp mixtures.

GASES

Hydrogen (H)

Hydrogen is very light. It burns with a pale-blue, non-luminous flame, but will not support combustion. It forms a highly explosive mixture with air or oxygen, especially in the proportion of two parts hydrogen to one of oxygen or two parts hydrogen to five of air.

Oxygen (O)

Oxygen is a non-poisonous gas. It is a great supporter of life and combustion. Oxidation or the union of any other element with oxygen is simply another term of combustion in its broadest sense. This union of elements or combustion takes place at all temperatures but faster at the higher temperatures. Heat is caused by the chemical action due to the interchange of atoms, and this heat is often sufficient to ignite the gas formed.

Nitrogen (N)

Nitrogen is odorless and inert. It does not readily combine chemically with other gases. It has no life-giving or combustion power, and simply dilutes the oxygen. There are about four parts nitrogen to one part of oxygen in the air normally. The gas is not poisonous, but if taken into the lungs without oxygen it smothers life.

Marsh Gas or Methane (CH)

Methane is also called light carbureted hydrogen. This is one of the chief gases occluded from coal seams. It is lighter than air, and diffuses very rapidly forming a fire-damp mixture. It burns with a blue flame, but will not support combustion. A lighted oil lamp placed in it will go out at once. It is non-poisonous but it suffocates like nitrogen. Pure methane is non-explosive but when diluted with five parts air it becomes explosive. At 9.5 to 1 parts it reaches its maximum explosive condition, and at 13 to 1 and beyond it again becomes non-explosive.

Other Hydro-carbons

All gases that are combinations of hydrogen and carbon are called hydro-carbons. Methane is the principal coal-mine gas of this character, the others are called heavy hydrocarbons. These are olefiant gas (C_2H_4) and ethane (C_2H_6). Like methane, these are the result of changes during the formation of the coal; but, unlike methane, they have been formed in the absence of water and therefore have more carbon. They possess a higher illuminating power and burn with a brighter flame than methane. They lower the temperature of ignition when present in fire-damp and consequently render the mixture more dangerous. Otherwise, like methane, they do not combine with any of the other mine gases except possibly oxygen, carbon-dioxide (CO_2) and water (H_2O).

Carbonic Oxide (CO)

Carbonic oxide is often called white damp. This gas to some extent is occluded from coal but mostly is formed by slow combustion of carbon in waste places where air is limited. It is also formed in large quantities when the flame of an explosion is projected into an atmosphere in which coal dust is suspended.

It is lighter than air. It is combustible, having a light-blue flame. It also supports combustion, being the only mine gas that burns and also supports combustion. This is a very dangerous characteristic as it extends an otherwise local explosion. It has the widest explosive range of any mine gas except hydrogen.

Carbonic oxide is very poisonous and acts on the human system to produce drowsiness and stupor, followed by actue pain in the head, back, etc.

Carbonic Acid (CO_2)

Carbonic acid is often called black damp or choke damp and is heavier than air. It is the result of the complete combustion of carbon in a plentiful supply of air, the product of breathing of men and animals, the burning of lamps, and other complete combustion. It is always present in occluded gases. It is not combustible and does not support combustion. This gas diffuses very slowly into air and is very difficult to remove by ventilation. Although not poisonous it acts to suffocate by excluding oxygen from the lungs.

Carbonic acid, when present in fire-damp mixtures, has the opposite effect to carbonic oxide, as it narrows the limits of explosion. One part CO_2 to six parts fire-damp is not explosive, but with less than this proportion of CO_2 the mixture is explosive.

Sulphureted Hydrogen (H_2S)

Sulphureted hydrogen is heavier than air, and sometimes occurs as an occluded gas from coal seams but usually it exudes from the strata above or below the coal. It has a disagreeable odor, is extremely poisonous, and is known by miners as "stink damp." It is exceedingly dangerous when in considerable quantities. When mixed with seven times its volume of air it is violently explosive.

Fire-damp

The name fire-damp usually relates to any explosive mixture of methane and air, although in some localities it refers to any mixture explosive or not. It is rarely found without being in mixture of some other gases.

After-damp

After-damp is the name given to the gaseous mixture that exists after an explosion of gas. Its composition is exceedingly variable and admits of no general analysis.

The chief products of a complete explosion of fire-damp are carbonic acid (CO_2), watery vapor, and nitrogen. However, an explosion is seldom complete. As there is usually a lack of air for the complete combustion of fire-damp, a large amount of carbonic oxide (CO) is formed and is therefore present in the after-damp. The presence of this gas renders the after-damp far more dangerous, because the gas is very poisonous, is not easy to detect by workmen, and is combustible.

METHODS OF MINE VENTILATION

Natural Ventilation

There is always pressure on the air in mines. This is true whether the column of air is vertical or at a slope, and is caused by the difference in temperature of the incoming and outgoing air. This pressure forces air through the air-passages and workings of the mine. The volume of air passing through the mine varies directly with the pressure and inversely with the resistance of the air passages.

Although this method may be suitable for small non-gaseous mines, it is very rarely used. Some of the objections to its use are that the air pressure varies with the external air temperature. The direction of pressure may be reversed from winter to summer and at intermediate times the pressure will be light or even none at all, and may vary with the force or direction of the wind.

TABLE I

Name	Symbol	Specific Gravity	Combustible	Explosive	Rate of	
					Diffusion	Transpiration
Air		1.000	No	No	1.000	1.000
Carbonic acid	CO_2	1.529	No	No	0.812	1.237
Carbonic oxide	CO	0.967	Yes	Yes	1.015	1.034
Sulphureted hydrogen	H_2S	1.19	No	Yes	0.95	
Oxygen	O	1.106	Yes	No	0.949	0.903
Hydrogen	H	0.069	No	Yes	3.83	2.066
Nitrogen	N	0.971	No	No	1.014	1.030
Olefiant	C_2H_4	0.078	Yes	Yes	1.019	1.788
Ethane	C_2H_6		Yes	Yes		
Marsh gas	CH_4	0.559	Yes	Yes	1.344	1.639

Experiments have shown that these gases are given out at 300 to 2500 cu. ft. per ton of coal mined, and as previously stated, some of them are released from pressures up to 300 lb. per sq. in.

Table I gives the rates at which the different gases transpire into the mine and diffuse themselves into the air. Each man breathes about 400 cu. ft. of fresh air per day. The Illinois mine law for instance calls for 100 cu. ft. of air per man per minute and 500 cu. ft. per animal per minute in non-gaseous mines, and 50 per cent additional for gaseous mines.

Therefore, knowing the average conditions of gas given off per ton of coal in a certain mine, and the volume of fresh air needed for the men and animals, we can calculate the amount of air necessary to circulate through the mine to dilute and sweep away the gases.

With this information we can proceed to lay out a suitable ventilation system for each section of the mine.

The amount of this natural pressure can be calculated for any given difference of air temperatures, and thus the volume of air at any time be determined.

Furnace Ventilation

In this case a furnace is used to raise the temperature of the up-cast air so that it will be lighter than the down-cast air. This gives more pressure and insures the air always travelling in the same direction. The chief point to be considered is the correct size of furnace.

This type of ventilation should not be used in gaseous mines, and in some cases it is prohibited by law. It is, however, used in many mines liberating gas. In such cases the furnace fire is fed by air from the incoming air course, only taking enough to maintain the fire, the return current from the mine being conducted by means of an inclined passageway into the shaft from 50 to 100 feet above the furnace. At this point the heat of the furnace gases is not sufficient to ignite the mine gases. The presence of carbonic acid in the furnace gases also renders the mine gases non-explosive. In

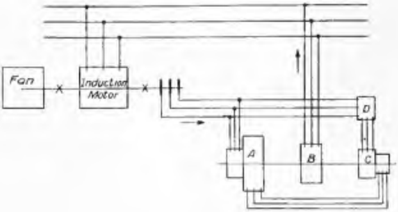

Fig. 1. Diagram of Connections of Fan Motor with Speed Regulating Set

other cases, instead of using the incline shaft, a sufficient amount of air is taken from the incoming air shaft to dilute the outgoing air below the explosive point before it reaches the furnace.

Sometimes a stack is built over the up-cast air shaft to get a greater height of light air and therefore more pressure on the down-cast air.

Mechanical Ventilation

There have been a number of mechanical methods tried for ventilating mines:

The wind cowl by which the wind pressure on the surface is brought to bear effectively upon the mine air-ways.

The waterfall and the steam jet.

The fan or blower.

Mine ventialtion fans are of two types, the disc fan and the centrifugal fan.

The disc fan has its blades set radiating from a central shaft and inclined to the plane of revolution. This is a propulsion fan and ventilates by propelling the air through the air-ways.

The centrifugal fan has its blades set at right angles to the plane of revolution. These blades may be straight and set radially or sloping forward or back; or they may have curved tips. With a fan of this type the centrifugal force of the air in the blades creates a pressure towards the tips of the blades and a vacuum towards the center. Air is taken in along the shaft and expelled radially or tangentially. This latter type of fan is used almost exclusively at the present time for ventilating mines.

Again, fans may be used to exhaust the air from a mine or to force air into it. In the first case the pressure is above atmospheric and in the latter case it is below. The exhaust system is more generally used.

Sometimes, due to certain conditions in a mine, it is desirable to reverse the direction of the air current temporarily. In other words, if the pressure system is being used to change to the exhaust system. If a fan with straight and radial blades were used the direction of rotation would be changed to produce the desired results; but as most fans have curved blades they are not capable of reverse operation and it then becomes necessary to make mechanical changes in the air ducts so as to reverse the inlet and outlet of the fan.

The matter of fan speed is a very important one. A small fan at high speed may give the same pressure and volume as a large fan at lower speed. There are, however, a number of conditions which make it desirable to have a variable-speed fan. For a given fan with a given size outlet the pressure varies nearly as the square of the speed, the volume directly as the speed, and the power required as the cube of the speed

Fig. 2. 250-h.p. Induction Motor Belted to Mine Fan

Constant-speed Fan Motors

There are some conditions such as long tunnels (or old mine workings which have to be kept ventilated but in which there is no appreciable physical change) where a constant amount of air is necessary 24 hours a day all the year. For this constant-speed work, the standard induction motor is perfectly adapted. It can be remote controlled if necessary, and it requires no attention except to the oiling system and that only at long intervals.

The choice as to whether a squirrel-cage or phase-wound rotor is used depends on the size of the motor and on the capacity of the transmission line and power service to supply the maximum peak requirements. Generally speaking, squirrel-cage motors should be used up to about 200 horse power, and phase-wound or slip-ring motors above that capacity.

Adjustable-speed Fan Motors

When a mine is in the early stages of development only a small ventilating capacity is required, but later as the workings grow more air is necessary. Also there are times, due to falling roof or other blockades in the air passages when a higher pressure is desirable with a smaller volume.

Under these conditions an adjustable-speed fan is desirable and almost necessary. It is therefore the usual practice to use fans of low or moderate speeds, arranged for increased speed when required.

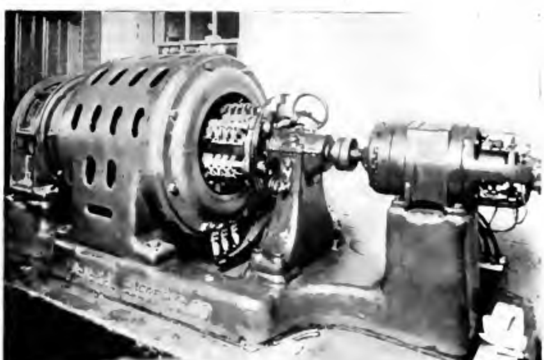

Fig. 3. Speed Regulating Set for Induction Motor Shown in Fig. 2

For adjustable-speed motors one naturally thinks first of direct current. The characteristics of a direct-current motor are well suited for adjustable-speed fans, and a large number of such installations [illegible]. These motors, however, require attention to the commutators and brushes and the transmission of direct current is not economical

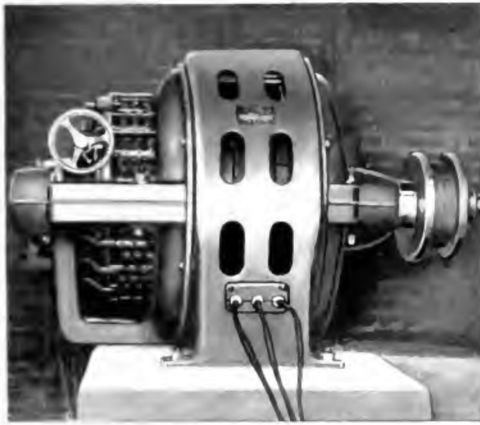

Fig. 4. 100-h.p., 375/187.5-r.p.m., Brush Shifting Motor Driving Mine Fan

except for very short distances. Therefore alternating-current motors are used almost entirely.

Rheostatic Control

There are a number of methods for adjusting the speed of alternating-current motors. The first and simplest utilizes the standard induction motor with slip rings or phase-wound rotor and external resistance in the rotor circuit. This motor starts with a small current input and for a given resistance in the rotor circuit it runs at constant speed for a given fan load. As the fan load rarely changes except due to a change in speed, we can obtain any speed or fan output desired by varying the resistance. The principal objection to this system is that it is inefficient. For instance, for half-speed operation, the power required by the fan will be the cube of $\frac{1}{2}$ or 0.125 or $12\frac{1}{2}$ per cent of full load, but there must be dissipated an equal amount in the resistance plus the losses in the motor itself. Thus we have an efficiency of less than 50 per cent.

In spite of this low efficiency, however, a large number of these motors have been and are being installed for this class of service.

Fig. 5. Fan House Containing 100-h.p. Motor (Fig. 4) and 100,000-cu. ft. Fan.

Dynamic Regulation

There are a variety of different dynamic regulation methods which can be used. Under rheostatic control the energy from the rotor circuit is dissipated as heat. In the dynamic methods this energy is put back into the line. The most common of these systems is that of a regulating set, the connections of which are shown in Fig. 1.

Referring to Fig. 1, the slip rings of the induction motor are connected to a commutator motor *A*, which therefore receives power at a frequency varying with the slip of the fan motor. These frequencies are low and the capacity of this commutator motor is small compared with that of the fan motor. The commutator motor drives an induction generator *B* slightly above synchronous speed so that it supplies power back to the line. The amount of this power is proportional to the slip of the fan motor, less the losses in the regulating set. Machine *C* shown in Fig. 1 is an exciter, and *D* is a rheostat for regulating the speed of the fan motor.

This arrangement gives exceptionally good operating characteristics, together with high efficiency and power-factor. Its only objection is the additional first cost of the set.

Fig. 2 shows a 250-h.p. motor belted to a mine fan. The speed of this motor can be reduced 25 per cent by the speed-regulating set shown in Fig. 3.

Brush Shifting Motors

For fan motors of 300 horse power or less, a brush-shifting motor gives a very simple, efficient and easily operated machine. This motor is started, its speed changed and even reversed by means of shifting the brushes. With a certain brush setting no torque is developed and under this condition the motor will not start even if the line switch is closed. The brushes are shifted by a worm gear and hand wheel to obtain the desired speed. This type of motor gives stable operation for fan service down to 70 per cent below synchronism.

More of these motors are being used each year, and the large number which have been installed to date are operating successfully.

Fig. 4. shows a 100-h.p., 375/187.5-r.p.m. motor driving a fan which gives 100,000 cu. ft. of air per minute. Fig. 5 shows the fan house for this installation.

Air Courses

Having briefly considered the reasons for ventilation, the amount of air necessary, and the different ventilation systems, we will now consider the matter of air courses or the methods of getting the fresh air where it is needed and those of taking away the vitiated air. This is of primary importance and is a complex one. No definite rules can be given for any particular mine, but some of

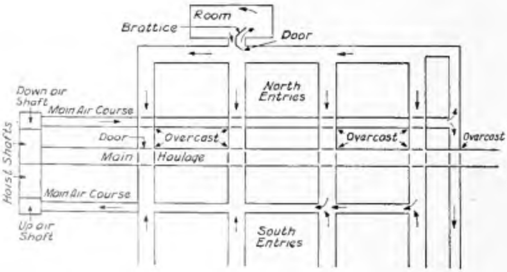

Fig. 6. Diagram of Air Courses

the general principles can be described and some methods sketched.

In small mines the continuous-current system is used, i.e., a single current of air passes through all the rooms and passageways without being split or divided at any point. This system could not be used in large mines.

The system used in larger mines is the divided or split air circuit. The air passes through the mine in a number of independent parallel paths. Some of the advantages of this system are: Less power is required to pass the same volume of air through the mine, because the paths are shorter and the area is greater. Fresher air is supplied to the men at work, as the air has not passed over any other coal faces, etc. The air is under better control, each section can be given the amount necessary for it, regardless of any other section. Gases from one section are not carried into another section. An explosion in one section is less apt to be transmitted to another section. If there is a fire and one section must be closed to smother the fire, the other sections are not affected. This system, to some extent, avoids doors in the main haulage roads. The velocity of the air may be reduced, thus causing less inconvenience to the workmen.

About the only disadvantage of this system is that it necessitates the building of bridges or air crossings at points where the air is split or where it is to be carried over the parallel entry.

For economical reasons the main haulage road may be used as an air course, but there are a number of objections to this method. If the return air comes out the main haulage road, the men are w[illegible] drafts all the time wh[illegible] health. If the fre[illegible]h air [illegible] haulage road the upper part of [illegible] liable to freeze in the winter, [illegible] the men work part of the time [illegible] draft, the outcoming load [illegible] passages and doors are nece[illegible] haulage road.

It is therefore advisable to have the incoming and outgoing air courses separate from the main haulage road. A rough diagram of this method is given in Fig. 6. All air should be carried to the back of the mine and allowed to pass the mine faces and workings on its way out.

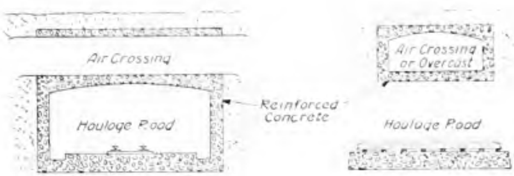

Fig. 7. Method of Building Air Crossings

Air Crossings

Ventilating doors are necessary only where the development of cross-entries is not sufficient to warrant the expense of building over-casts or air bridges. In order to ventilate a pair of cross-entries turned off the main headings, without the use of doors to deflect the air, it is necessary to build an air bridge by which the intake or return air current circulating in the cross-entries can be carried over or under the haulage road. This does away with doors in the haulage road. Keeping the number of doors low reduces delay and possible accident in haulage and eliminates the expense of trapping and repairs. Fig. 7 shows the method of building air crossings.

Mine-type Motors

By L. C. Mosley

Power and Mining Engineering Department, General Electric Company

The mine-type motor in addition to being what its name implies, is particularly suitable for such steel mill auxiliary drives as approach tables, straighteners, soaking pit covers, etc. It represents the culmination of the combined endeavor of the mine operator, engineer, and electrical manufacturer to produce the best motor for the purpose. The following article outlines the unfavorable conditions under which it has to operate and describes the construction of the motor in detail.—Editor.

Due to the character of the work in and around mines and steel mills which requires motors of a different construction from the standard open type of induction motor, the HI or mine-type motor has been designed to meet these requirements. Since this motor was to be applied to special service, the matter of its design was discussed freely with engineers familiar with the requirements, and in its development the suggestions of these engineers were incorporated.

To appreciate better the factors which had to be taken into account in its design, a brief review will be made of the conditions under which the motor has to operate. The drive of an anthracite coal breaker is about as severe as any to which an electric motor has been applied. The breaker buildings as a rule are immense wooden structures which sway and vibrate, and as a result the motors in the breaker are subjected to excessive vibration and many shocks. Constant vibration tends to crystallize the shaft, loosen the laminations, break the bars of squirrel-cage rotors, and chafe the insulation on the coils. The atmosphere surrounding the motor is charged with everything from fine coal dust to dropping pieces of coal, and all exposed parts of the motor are covered with dirt and dust. The fine, sharp coal dust works its way into the windings of an open type motor; and while this dust is a very good non-conductor as long as it is dry, it becomes a very good conductor as soon as moistened, which may occur as water is used in the process of separating the slate from the coal. Another factor to be taken into account is the starting duty which is very heavy under those emergency conditions that require the machinery be started when full of coal.

Fig. 1. Mine-type 50-h.p., 900-r.p.m., 440-volt Back-geared Induction Motor

Fig. 2. Mine-type, 25-h.p., 900-r.p.m., 440-volt, Squirrel-cage Induction Motor Showing Bosses for Mounting Back Gear

In the bituminous fields, much of the coal is shipped as run-of-mine or screened only; but there is an increased tendency to furnish washed coal and as a result washeries are being installed. Motors applied in these washeries are subjected to conditions quite similar to those in an anthracite breaker.

In the mines themselves, motors are used mostly for pumps and small hoists. This duty is not so severe as that in the breakers, but the motors are frequently subjected to dampness and dripping water which necessitate the use of a mine-type motor.

For steel mill auxiliary drive the motors are subjected to severe vibrations and to rapid reversals, and must operate in buildings where the atmosphere is filled with dust and small bits of metal. As in these respects the conditions in steel mill work are similar to those in mining operations, these motors are equally satisfactory in both services.

Construction

One distinctive feature of the mine-type motor is its heavy construction, as is shown by the big shaft and bearings and the width of frame. Another feature of the motors built in sizes up to and including the 75 h.p. at 900 r.p.m. is the mounting of the back-gear bracket on the stator frame. Fig. 1 shows a motor having this back-gear feature.

The frame is of the box type, without openings, and is made of cast iron of exceptionally heavy section. On machines up to and including 150 h.p. at 720 r.p.m. the bosses for the back-gear attachment are cast on one side of the frame; and in order that the bosses shall be far enough apart to make the support of the bracket rigid and to give a sufficient width between the feet to make a rigid support for the motor, the frame is made exceptionally wide. By having the bosses cast on each frame, the back shaft can be mounted any time desired. Fig. 2 shows the motor without the back gear and the method of mounting the bracket.

The back-gear bracket is made of one casting which is attached to the frame with four large bolts placed as far apart as possible, as is shown in Fig. 3. The bearings are made of cast iron lined with hard babbitt and are arranged for waste lubrication. They are split horizontally, have broad seats at each end, and are interchangeable but not self-aligning. By using the [illegible] the back shaft can be removed without disturbing the alignment of the bearings, and the bearings can be replaced without removing the back shaft. The motor bearings can be replaced without removing the rotor or the lower half of the shield, and the rotor can be removed on the end opposite the gear without disturbing the back-shaft attachment.

Fig. 3. Back Geared Attachment for Mine-type Induction Motor

Fig. 4. Front and Pulley End Bearing Brackets of Mine-type 50-h.p., 900-r.p.m., 440-volt Wound-rotor Induction Motor

Both end shields are split horizontally and are held together by large square-head bolts which are placed so as to be as accessible as possible. The shields are totally enclosed with the exception of openings at the bottom for the inlet and outlet of air. These holes may be left open or may have a short length of pipe attached to bring in fresh air. The shields are interchangeable on the two ends of the squirrel-cage motor, but the wound-rotor machine has a longer shield on the collector end and is supplied with a hand hole and cover in the top half to give ready access to the brushes. The pulley end shield on both wound-rotor and squirrel-cage motors has a shroud attached to assist in the ventilation of the machine, and the upper half of each end shield has two tapped holes for air-gap measurement. On the wound-rotor machines, the brush studs are securely bolted to the end shields as is shown in Fig. 4.

In all cases large bearings are used, split horizontally and are interchangeable, being the same on both front and pulley end. Each bearing has two oil rings and two broad seats, one at each end of the lining, hence they are not self-aligning. Considerable trouble had been encountered on bearings having a single seat when used on a geared motor for very severe service due to the vibration pounding the seats out of shape.

Fig. 5. Mine-type 35-h.p., 600-r.p.m., 550-volt Wound-rotor Induction Motor Driving Shaker Screen and Picking Table, Davis Coal & Coke Co., Thomas, W. Va.

Fig. 6. Mine-type, 25 h.p., 900-r.p.m., 440-volt Squirrel-cage Induction Motor Installed on Crusher at Truesdale, Breaker, D. L. & W. Co.

Special attention has been given to make the bearings both dust proof and as free from oil leakage as possible. The oil-well covers are lined with felt and are held closed by a spring. Both bearings have overflow oil gauges.

Both the motor and back-gear shafts are of very heavy construction, so as to minimize the vibration and lessen the tendency of the shafts to crystallize. In order to make the rotors interchangeable, the motor shaft is made for pulley extension whether the motor is to be belted, geared, or otherwise.

In the design of the rotor, special attention has been given to making it as rigid as possible to resist the shocks and vibrations arising from gearing. The rotor spider has an extra long bearing surface on the shaft, to which it is securely keyed. The squirrel-cage rotors have electrically welded end-rings of large section and ample radiating surface, and the conductors are forced in the slots without any slot armor or wedges, thus insuring a rotor which is practically indestructable unless injured by some mechanical means. The windings of the wound-rotor motors are similar to those used on standard machines, except that the windings have special moisture resisting insulation. The collector rings are made of brass and are shrunk on the shell over insulation, the shell being pressed on the rotor shaft.

As straight slots are used on the stator, the coils are exactly shaped, form wound, moulded and completely insulated before being placed in the slots, the same as are those used in standard motors with straight-slot stators. All stator windings are insulated to resist moisture. Space blocks welded to adjacent punchings are used to separate groups of laminations and thus form ventilating ducts.

Since the continuous rating of an electrical machine depends on the amount of heat which it will dissipate, special attention has been given to the ventilation of the mine-type motor. Sheet iron fans are attached to the rotor flange on the pulley end of the motor and these fans draw air from the outside through the ventilating hole in the bottom half of the end shield. To prevent the air from being forced through the spider and out the other side of the machine, thus failing to strike the windings and punchings, a deflector is placed on the end of the rotor opposite the fan. The air current is thus divided, part of it being forced up over the stator windings and part of it being forced through the rotor ducts, thus keeping the temperature of the machine at a safe operating value. If the surrounding air contains much foreign material, it is desirable to have clean air circulate through the machine; and to accomplish this, a short length of pipe is attached to the holes in the end shields to bring in air from the outside.

Applications

In coal breakers the mine-type motor is used for driving crushers, belt coal conveyers, shaker screens, and picking tables. Fig. 5 shows a 35-h.p., 600-r.p.m., mine-type motor, without back gearing, belted to a shaker screen and picking table. Fig. 6 shows a 25-h.p., 900-r.p.m. back-geared motor driving a crusher.

For driving small underground hoists the mine-type motor has been applied very successfully. Fig. 7 shows a 30-h.p., 900-r.p.m. motor of the mine-type driving a sinking hoist in a mine. This same type of motor may also be applied to small underground pumps as is shown by Fig. 8. Due to the heavy character of the work and to the dampness usually encountered underground, both installations require a motor of the mine-type, the enclosing features tending to keep the dripping water from the windings and the heavy construction tending to reduce vibration.

A considerable number of mine-type motors have been installed for steel mill auxiliary drive, such as approach tables, straighteners, soaking pit covers, etc., where the character of the work is closely akin to mining requirements. These motors operate in buildings where in some cases the temperature of the air is considerably higher than is ordinarily encountered. To meet this condition, if found necessary, the stator and rotor windings can be given a special heat resisting insulation. For operating soaking pit covers, reheating furnace doors, valve mechanisms, and shears, squirrel-cage motors are used; while wound-rotor machines are used for the operation of approach and leveller tables, straighteners, and chain conveyers.

Although primarily designed for steel mill and mining service, these motors can be applied to other classes of duty which require an enclosed ventilated motor of heavy construction. In logging operations, motors of the mine type have been in[illegible] to the loading platform[illegible] The [illegible] portable and the motor installed on [illegible] subjected more or less to outdoor conditions, thus necessitating the use of an enclosed ventilated motor. The service is somewhat akin to hoisting, in that frequently high torque is required for starting, and to meet this requirement a wound-rotor machine is applied as it can give a starting torque considerably in excess of normal.

Fig. 7. Mine-type, 30-h.p, 900 r.p.m., 220-volt Wound-rotor Induction Motor Back Geared to a Sinking Hoist. Tennessee Coal Iron & R. R. Co., Muscoda Red Ore Division, No. 8 Mine

Fig. 8. Mine-type, 15-h.p., 720 r.p.m., 220-volt Squirrel-cage Induction Motor Geared to a 5-in. by 7-in. Triplex Sinking Pump, Tennessee Coal, Iron & R. R. Co., Muscoda, Red Ore Division, No. 8 Mine

Electricity as Applied to Loading and Unloading Coal and Ore Boats

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The application and advancement of electricity, in loading and unloading coal and ore during the past twenty years, are comprehensively detailed by the author. The increase in handling capacity and the enlarging of dock areas served by handling machinery have been a necessary development due to the vital importance of steel and coal as related to the Nation's industries. To meet the re-construction demands of the near future, additional applications and installations of similar apparatus may be expected. This article was read as a paper before a meeting of the Society of Terminal Engineers, held in New York City on March 18th of this year.—Editor.

The history of the application of electricity in loading and unloading coal and ore has been a record of continuous advancement during the past twenty years. The handling agency has advanced from the wheelbarrow to the twenty ton bucket. The capacity has increased from practically zero to 900 or more tons per hour. The dock areas covered by handling machinery have increased from the first small pile to mammoth places of 1,000, 000 or more square-feet area. The importance of the industry has risen from the first literally "one-horse" concern to a position where it is a big economic factor in our country's most vital industries, viz., steel and coal. During this development, electricity has been the only form of power which came in as an experiment and stayed with the industry, making its presence felt more and more both as to size and ramifications of its use.

Electricity was first used for light, then simply for hoisting, then for propelling, then for lowering, and finally replaced all other mediums of power for braking, such as man power, air, etc.

This article will first review briefly the history of the development in unloading boats, by describing installations which are typical of the various epochs in development, and second give a summary of modern methods of electrification, and third describe a number of loading plants.

Unloading Boats

As much of the material as practical is transferred immediately from boats into railroad cars. The remainder of the material is placed in a large storage pile alongside the boat and re-loaded into railroad cars at a later date. The problem is, first, to get the material out of the boats as quickly as possible so as to save time and demurrage charges; second, to handle the material for as short a distance and as few times as possible so as to effect economy of operation; third, to have the material held in storage in such a way that it is readily available for railroad cars when they can be secured, or to fill orders from customers as they come in; fourth, as a corollary of the third problem, it is necessary to store coal of a certain kind in a certain pile. This means that a dock will be filled up with a large number of piles of different kinds of coal, and the same is true of ore.

As late as 1875 ore and coal were unloaded from boats in wheelbarrows, Fig. 1. Men loaded the wheelbarrows in the hold of the boat and horse or steam power was used for hoisting them to the level of the coal pile. Men would then wheel them over a temporary trestle. This was a slow, expensive, and dangerous operation.

In 1883 bridge tramways were introduced, Fig. 2. These could move along the boat a slight distance. Material was loaded into tubs in the hold of the boat by men and hooked on to hoist ropes. A steam engine was used to hoist and also to propel to the pile, where it was automatically dumped. This introduced a great saving in time, men, speed and safety. This was followed by the introduction of self-filling grab buckets, having two ropes. When one rope is pulled, the bucket closes in the material and fills itself, when both ropes are pulled, the bucket is hoisted, when one rope is let go, the bucket opens and dumps its load.

In 1901 the first modern electrically operated dock was installed at the Northwestern Fuel Co., Dock No. 1, in Superior, Wisconsin, Fig. 3. This consisted of four unloading towers, each having a two-ton self-filling grab bucket, and three stocking and reclaiming bridges. The power supply is 250 volts, direct current. This dock is still in operation and able to compete both in economy and speed with more modern docks. Remote magnetic control is used for motors, and friction brakes for lowering the buckets. These brakes are operated

Fig. 1. Method of Unloading Ore from Boats About 1875

Fig. 3. The First Electrically driven Coal Unloading Dock Built in 1901 for North western Fuel Company, Superior, Wis.

Fig. 2. Three Bridge Tramways Built for the New York, Lake Erie & Western Railroad Company, Cleveland, Ohio, in 1883

Fig. 4 Three Rope Operated Coal Bridges at Berwind Fuel Company's Dock, Superior, Wis

manually. The coal is dumped from buckets into the hoppers near the top of the tower and goes either into railroad cars immediately under the hoppers or back to a temporary receptacle from which it is removed by a stocking bridge to a pile behind the wharf.

The first large electric bridges to cover the storage pile, handling coal directly from the boat to the stock pile, were installed in 1907 at the Berwind Fuel Company's Dock in Superior, Wisconsin, Fig. 4. This method combines the storage machine and the unloading machine in one unit thus effecting a saving of several operations. This installation consisted of three rope operated bridges and was later increased to four. The capacity of the buckets now ranges from four to five tons. The length of the bridges are 506 ft., span 295 ft. Power supply, 440 volts alternating current 25 cycles. The hoist and rack (or sidewise propelling) motors total four 225-h.p., one 300-h.p., and six 75-h.p. motors. There are numerous other auxiliary motors.

In this type of bridge one motor and hoisting machine is used for hoisting the bucket; another motor and hoisting machine for propelling the bucket across the storage pile. The motor and hoisting machine are stationary. All brakes are manually operated through levers. There are two operator's cages per bridge. The one near the boat is used when unloading coal, the one farthest from the boat is used when loading coal at the rear end of bridge. The three original bridges have unloaded 10,500 tons in 18 hours; the present four bridges have unloaded 16,500 tons in 13 hours.

Electrically-operated locomotive cranes with grab buckets are located at the rear of the bridges to assist in loading cars.

About 1908 or 1909 a new type of bridge was brought out, called the "man-trolley." This consists of a trolley car, which carries all hoisting and propelling machinery as well as the operator and bucket, running on overhead rails from the boat to the pile. It is claimed for this type of bridge that it eliminates a lot of rope and allows the operator a close view of his bucket at all times.

In 1910 three coal bridge equipments were installed at the Pittsburgh Coal Dock and Wharf Co.'s Dock No. 7, Rice's Point, Duluth, Minn. These bridges were equipped with three 225-h.p., 500-r.p.m., 440-volt hoist motors and magnetic control; six 112-h.p., 750-r.p.m., 440-volt rack motors and magnetic control; and three 112-h.p., 750-r.p.m., 440-volt bridge moving motors with drum control. Manually operated brakes are used on the principal motions. The power supply is 25 cycles, alternating current.

Fig. 5. Coal Bridge Equipments Installed at Pittsburgh Coal Dock & Wharf Co.'s Dock, No. 7, at Rice's Point

A general view of the dock is shown in Fig. 5. The present length is 1250 ft., width 764 ft., and the depth of the coal about 40 ft. Storage capacity is about 825,000 tons of bituminous coal. There are three double-span bridges, about 576 ft. long, each equipped with a trolley, next to the dock face; and two single-span bridges about 300 ft. long at the rear of the dock, which can be aligned with any one of the three double-span bridges and operated with them, thus making a single bridge 876 ft. long. A single-span bridge can be used for transferring a trolley car from one double-span to another in case of breakdown.

There are four man-trolleys, each equipped with a $5\frac{1}{2}$ ton bucket. The three bridges working simultaneously on a 10,000-ton boat, when depositing coal into hopper at

Fig. 6. Coal Bridge and Power Plant of C. Reiss Coal Company at Manitowoc, Wis., 1911

Fig. 8. 375 kw. Curtis Steam Turbine Installed at C. Reiss Coal Company's Dock in Manitowoc, Wis.

Fig. 7. Pier End of C. Reiss Coal Company's Coal Bridge at Manitowoc, Wis., Showing Electrically-driven Screening Plant

Fig. 9. North western Fuel Co.'s 312 ft. Coal Bridge with 12 Ton Bucket Equipped with Four Mill type Motors and Dynamic Braking Control

the front of the bridge, can unload the entire cargo in about twelve hours.

Some of the first "man-trolley" type of coal bridges were equipped with alternating-current motors for hoisting and propelling and air brakes for lowering and stopping the motions. Experience showed, however, that the amount of wear on the brakes required that they be expectionally large in order to be reliable, and consequently dynamic braking was used. This was obtained by separately exciting the alternating-current motors with low voltage direct current. When the benefits of dynamic braking were fully appreciated, direct current became more popular for the "man-trolley" type of bridge because it readily lent itself to the use of dynamic braking.

Figs. 6, 7 and 8 show one of the early, large size, direct-current operating, "man-trolley" type bridges with power plant. This bridge was installed at the Manitowoc, Wis., plant of the C. Reiss Coal Co. All necessary power is generated by a direct-coupled Curtis steam turbine at 250 volts. Dynamic braking, in conjunction with air, is used on all of the principal motions of the "man-trolley."

Fig. 7 shows a near view of a screening plant which is attached to the pier end of the bridge. This plant is equipped with a number of elevators, belt conveyors, screens, etc., for classifying the coal as it is loaded into the cars. Coal is fed into the screening plant through a large hopper by means of the grab bucket. Great economies in the handling and marketing of coal are effected by this screening plant. This illustrates an adaptation of electric power which would not be practical were steam used for hoisting coal.

Fig. 7 also shows a view of a typical boat on the Great Lakes used for carrying bulk material. All of these boats have hatches with 12 foot centers. The smaller ones have less than 17 hatches and some of the largest have as many as 38. They carry from 7,000 to 14,000 tons of bulk material. The hatches are large enough to permit a 12-ton coal bucket or a 20-ton ore bucket to enter, fill itself with material and be hoisted out. The engine is aft and the captain's quarters are forward.

Fig. 8 shows a Curtis steam turbine and switchboard used for supplying power to the bridge at Manitowoc. Usually power is supplied to this type of dock from an a-c. high-tension power system through a rotary converter. Direct current, 550 volts, seems to be the typical form of power in the more recent docks. In some cases flywheel equalizers are used to absorb the power peaks and thus reduce power rates. This extra material is not required as much now as formerly because most power companies are large enough in capacity to make a rate which is as favorable without a flywheel equalizer as with one.

A very large and modern "man-trolley" bridge thoroughly equipped with dynamic-braking controllers was installed at the Northwestern Fuel Co.'s Dock No. 1, Superior, Wis., in 1913. Fig. 9. It carries a 12-ton digging bucket or a 6-ton clean-up bucket. A digging bucket, in closing, draws coal across the beam of the boat and necessarily leaves about 10 or 15 per cent of the cargo in unreachable piles under the hatch coaming. A clean-up bucket, in closing, draws coal along the beam and thus gathers up, without the formerly used expensive hand-shoveling, practically all of the coal which the digging bucket leaves. Thus another big economy was introduced. This problem has been solved in another way by mounting the hoisting machinery on a turntable and revolving the digging bucket when cleaning up.

The overall length of the bridge is 712½ ft., the span is 551 ft. There are four 230-h.p. motors used for hoisting and racking the bucket.

Fig. 10. Mill Motor Which is Used on Bridge Hoists

Capacity of this bridge is 880 tons per hour maximum when propelling coal back from the boat 220 feet. It has unloaded a 10,000-ton boat in 17 hours and 50 minutes. The tremendous weights and speeds make it imperative that dynamic braking be used for lowering the buckets and stopping the trolley car. The amount of heat which has to be dissipated would make it entirely impractical to use friction braking.

Figs. 10 and 11 show the sturdy motor and control panel which is used with direct current for this type of work. On account of the extremely heavy shocks and frequent starts and stops, it is necessary that the most rugged type of electrical machinery be employed.

For unloading ore and limestone, the rope-operated grab bucket has been used extensively and the methods of handling are the same as previously described for coal.

A large portion of the ore is unloaded by a power-operated bucket carried on a stiff-leg by a tremendous walking beam. Fig. 12 shows a plant of four 15-ton Hulett unloaders and one ore bridge operated by direct-current motors Union Dock Company, Ashtabula, Ohio. Each unloader has an aggregate of

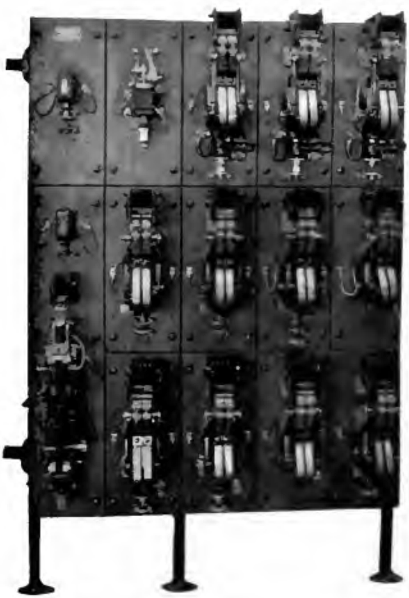

Fig. 11. Reversible Contactor Panel for Control of Series Hoist Motor with Dynamic Braking Lowering, Used on Material Handling Bridges

810 h.p. of motors. This plant has a maximum unloading capacity of 60 tons of ore per minute and has unloaded a 10,000-ton boat in four or five hours.

Fig. 12. 15 Ton Hulett Unloaders and Ore Bridge at Union Dock Company, Ashtabula, Ohio. Each Unloader has an aggregate of 810 h.p. of motors

Fig. 13. Cristobal Coaling Station, Panama Canal

Fig. 15. Hammer Head Tower Coal Hoist at LaBelle Iron Works, Follansbee, W Va.

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Fig. 9. North western Fuel Co.'s 312 ft. Coal Bridge with 1½ Ton Bucket Equipped with Four Mill type Motors and Dynamic Braking Control

Fig. 13. Cristobal Coaling Station, Panama Canal

Fig. 15. Hammer Head Tower Coal Hoist at LaBelle Iron Works, Follansbee, W Va.

Fig. 14. Hammer Head Tower Coal Hoist at LaBelle Iron Works, Follansbee, W. Va.

Fig. 16. Towers for Hoisting Limestone at the D. M. & N. Docks, West Duluth, Minn.

Fig. 13 shows a large coaling station which was erected by the Isthmian Canal Commission at Cristobal, Panama. This station is unique because of its great storage capacity and rapid handling facilities; also on account of the difficulties which had to be overcome in designing apparatus to withstand the very severe climatic conditions on the Isthmus. The following data regarding this installation will be of interest:

Storage Capacity

Coal pile 1700 ft. long by 307 ft. wide by 35 ft. high above water, 385,000 tons, dry storage.

Coal pile 500 ft. long by 307 ft. wide by 27 ft. deep, below water, 100,000 tons wet storage.

Total ground storage capacity—485,000 tons.

Wharf bunker capacity—1500 tons.

Equipment

4 cargo unloaders (steam) 250 tons each, capacity 1000 tons per hour.

2 stocking and reclaiming bridges, 315 ft. span, 1000 tons each (electric), capacity 2000 tons per hour.

4 reclaiming bridge diggers, 500 tons each (electric), capacity 2000 tons per hour.

4 delivery machines, 500 tons each (electric), capacity 2000 tons.

28 conveyor cars, 10 tons each (electric), capacity 2000 tons per hour.

1 wharf bunker (electric), capacity 1500 tons per hour.

1 viaduct, double track, 29 ft. high, surrounding coal pile.

1 transforming and distributing station, 2900 kv-a.

1 administration tower.

Power supply 440 volts, 3 phase, 25 cycles. System of operation is as follows:

Coal is hoisted by steam towers at left of dock into hoppers; is then carried through chutes into small cars. These cars are electrically self-propelled without an operator at 200 feet per minute and can carry ten tons of coal. They go around the edge of the dock and dump coal either in a wharf bunker in the foreground or into reloading machines at the right of the dock or they cross the bridges and dump the coal into the storage pile. They go in continuous circuits and they are stopped and started wherever desired by an operator who stands at the desired point. The coal is reclaimed from the storage pile by four digging towers; then dumped into hoppers at the top of the digging tower and carried through chutes into the aforementioned small cars. It can be propelled in these cars to the wharf bunker in the foreground or to the reloading towers at the right of the bunker. The reloading towers carry the coal by means of belt conveyors from the hoppers to chutes which spill it into barges.

Figs. 14 and 15 show a coal handling plant which is used for unloading barges at the By-Products Coke Plant of the LaBelle Iron Works, Follansbee, W. Va. The power supply is 440 volts, 3 phase, 60 cycles. Dynamic braking for lowering the large buckets is obtained by means of small direct-current motors which are coupled to the shafts of the large alternating-current hoisting motors. These small direct-current motors serve as exciters for the stator windings of the alternating-current motors, and thus is obtained a system of dynamic braking which is very closely comparable to the operation of a direct-current hoist motor. The cranes are of the hammerhead type and use motors with magnetic control with "plugging" feature for stopping on the racking motion and also on the turning motion. This plant is unique on account of its geographical layout. Two towers are so installed that either can be run on a large track down to the water-front, and there used for unloading coal from barges either into a belt conveyor which carries the coal directly to the By-Products Plant or into bottom dump larry cars which carry it back to the storage area. Coal is dumped from these larry cars into a pit and removed from the pit by the other crane. These cranes run along a curved track and can be switched so that they are interchangeable in location.

Fig. 16 shows some tower cranes at the Limestone Dock of the D. M. & N. R. R. Co. in West Duluth, Minn. Power supply here is 440 volts, 3 phase, 25 cycles. The unique part of the system is that regenerative braking, in conjunction with air brakes, is used for lowering the buckets.

Prior to 1916, steam-driven coal hoists were used almost exclusively where extremely high rope speeds and light buckets were required for hoisting coal from small barges to power-house bunkers; but the development of an electric motor with exceedingly light flywheel effect in its armature made it possible to secure the desired rapidity in starting, stopping and reversing a motor-driven hoist, so that the benefits of electric operation were at once rendered available for this particular class of power application.

A coal tower hoist of this type, Fig. 17, was installed at the Essex Street Station of the Public Service Electric Company of New Jersey, to give a rope speed of 1260 ft. per minute, with a lift of 180 ft. The bucket capacity is two tons of coal and two round trips per minute are made.

This initial installation was placed in service early in 1916, and has given entire satisfaction in operation. It is the first direct-connected motor-driven hoist designed for such high speeds and rapid acceleration as were required in this instance, and its successful application opened up a wide field of usefulness for motors having rotors with very light flywheel effect.

Fig. 17. Coal Tower Essex Station, Public Service Electric Company, Newark, N. J., 1½-Ton Bucket. Bucket Speed 1230 ft. per Minute

The equipment at the Public Service Co.'s Essex St. Station is being duplicated and another tower, making use of the same kind of electrical apparatus, was placed in operation in June, 1918, at the Westport Station of the Baltimore Consolidated Gas, Electric Light and Power Co. This tower is also being duplicated.

At the Baltimore Consolidated Plant the hoist can handle a two-ton bucket with a vertical lift of 115 feet at the rate of three round trips per minute. This is of special interest in that it attains a capacity in excess of anything which has been claimed for similarly constructed steam-operated towers.

In conjunction with this coal tower, the Baltimore Consolidated Gas, Electric Light and Power Co. installed an electrically operated cableway (Fig. 18) about 1000 ft. in length, which is unusual for this particular service in that the control for the hoist motor is located near the center of the storage pile and 426 ft. from the head tower in which the hoisting apparatus is housed.

The stationary head tower is 240 ft. high and the traveling tail tower, which is 90 ft. high, permits the bucket on the cable to reach any part of the roughly triangular storage area. The conveying speed is about 1100 ft. per minute and the weight of the bucket when empty is about 8500 lb. and when full somewhat over 14,000 lb.

A 450-h.p., 440-volt, 25-cycle motor is used to drive the hoist through air actuated clutches which are controlled by means of solenoid operated valves. The friction brakes are similarly air-operated and electrically-controlled.

Application of Electricity to Coal and Ore Handling Bridges

In applying electrical apparatus to coal and ore handling bridges, the electrical engineer studies the detailed requirements of each bridge builder's machine, and co-operates to bring out their best individual features. Some of the commonly used practices and recommendations are outlined below:

DIRECT CURRENT

Substations

Rotary converters or synchronous motor generator sets with flywheel motor balancer sets, where power rates warrant the extra expense, are used. It is customary in a large station to have one spare power unit.

Main Hoist

Series-wound open-mill motors are used, equipped with shunt-wound shoe-type solenoid brakes, if required. The open type of motor is preferred on account of heating limitations, but the motor should be protected from the weather by a "dog-house" which provides for ventilation. The solenoid brake is arranged with a cutout attachment for speeding up its operation. Sometimes compound windings are used on the hoist motors in order to save power consumption especially where two separate hoists are used for one bucket.

Automatic magnetic current-limit control is used. This has the following features:

1. Smooth automatic acceleration for hoisting, providing utmost motor capacity without damage to the commutator.

2. High speed kick-off for opening the bucket with least possible separate excitation for series fields. This saves time and current.

3. High speed lowering with only 5 or 10 per cent full load current for separate excitation, and automatic deceleration with relays set at a lower value of current than was used for hoisting. This enables a high lowering speed to be used without damage to commutator when stopping.

3. Drift point on master controller to allow coasting thus saving power.

4. Provision for combination [illegible] of solenoid brake and dynamic braking for stopping.

Boom Hoist

Series-wound, totally-enclosed, crane-type motors with shoe-type, series-wound solenoid brakes and dynamic braking drum controller

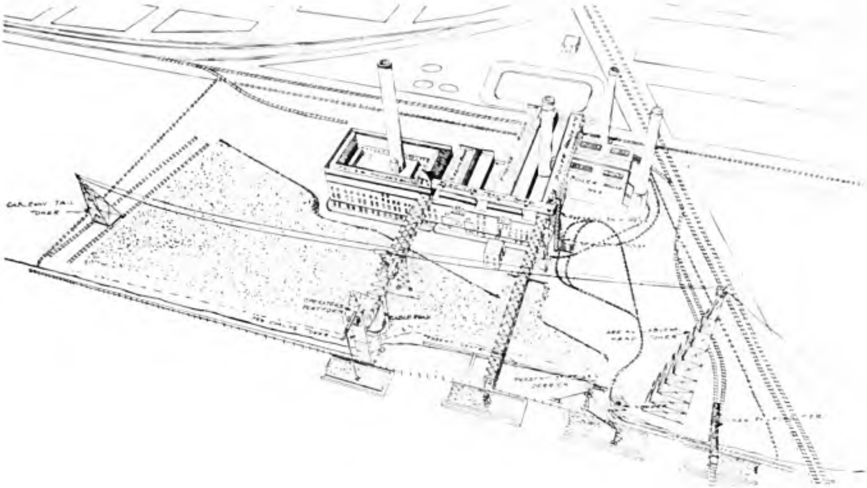


Fig. 18. Perspective View of Cableway and Coal Tower at Baltimore Consolidated Gas & Electric Company's Worth Street Station

4. Low torque at start for closing bucket gently when cleaning up.

Back Motion

Series-wound, open-mill motors are used. They should be protected from weather and yet ventilated, so that heating will not be a limitation. Shunt-wound, shoe-type brakes are provided in some cases. Automatic magnetic current-limit control with dynamic braking is used when bridge builder desires dynamic braking. This must have the following features:

1. Proper starting torque to "inch" loads.

2. Proper number of points to give smooth acceleration and deceleration for two reasons: (a) to get most output from motor without undue shock; (b) to get maximum average rate of acceleration and deceleration without slipping the wheels (this is especially valuable in wet weather).

with heavy duty resistors. Sometimes a mill-type motor is specified in order to duplicate other motors in service.

Bridge Propelling

Series-wound, totally-enclosed, weatherproof, crane-type motors, equipped with series-wound, totally-enclosed disc-type solenoid brakes. The brakes are over size in order to provide high torque for holding in a wind storm. Drum-type controllers suitable for either one or two motors are used, and these controllers have slow-down and creeping speed points so as to provide the maximum of safety when propelling in a wind storm, and so as to stop smoothly in spite of the high torque solenoid brake which is necessary for safety. Remote magnetic control with masters in the trolley cab are provided in some special cases where a lot of bridge propelling work has to be done.

Fig. 19. Ore Dock No. 2, Duluth & Iron Range R. R., Two Harbors, Minn. The spouts are lifted by electric motors

These magnetic controls provide the same creeping speeds as do the manual controllers.

Rail Clamps

Auxiliary motors and control for rail clamps. They work in conjunction with bridge propelling control.

Protective Devices

Circuit breakers, overload relays for use with contactors and push-button-reset, limit switches.

ALTERNATING CURRENT

Main Hoist

Open crane-type motors are used for all except the most severe or rapid service. Mill-type motors or large pillar-block motors of mill-type construction are used for most rapid or severe service. For very high-speed hoists, running at 1000 ft. per minute and above, specially designed, slow-speed, high-torque, low flywheel-effect motors are used for direct coupling to the hoist drum. This construction eliminates gear losses, wear and noise and insures a quick start which is consistent with the high rope speeds.

For controlling small hoists at around 100 ft. per minute, drum-type controllers with shoe-type solenoid brakes are used. For controlling large slow-speed hoists, automatic magnetic controllers with solenoid load brakes are used. For controlling large high-speed hoists automatic, magnetic controllers, with dynamic braking, are used, making use either of a separate motor generator set or preferably where space permits, a direct-coupled direct-current motor for excitation. For all sizes of hoists where the bridge builder takes care of the necessary braking, plain reversible or non-reversible automatic magnetic control is used.

All alternating-current contactors are operated by alternating current and no direct current is necessary.

Back Motion

Open crane-type motors for ordinary service and especially rugged mill motors for the very heavy service are used. For controlling these motors ordinary reversible drum controllers are provided for small sizes. For larger sizes reversible automatic magnetic

Fig. 20. Control Panel and Motor Geared to Line Shaft Which Operates Twelve Small Hoists for Lifting Spouts, Duluth & Iron Range R. R. Docks, Two Harbors, Minn.

control is used with necessary extra steps for "plugging" where needed for braking. In a few rare cases, dynamic braking is required with direct-current power for separate exci-

Fig. 21. Radial Incline Conveyor and Balancing Bin B & O Coal Loading Pier, Curtis Bay, Md.

Fig 23. Trimmer Conveyor Tower Showing Projecting Loading Boom and Conveyor Belt, B & O Coal Loading Pier, Curtis Bay, Md.

Fig. 22. General View of B. & O. Coal Loading Pier, Curtis Bay, Md.

Fig. 24. One of the Four Transverse Bridges Showing Location and Operation of Main Conveyor Belts, B. & O. Coal Loading Pier, Curtis Bay, Md.

tation, supplied from a small motor generator set.

Boom Hoist

Open crane-type motors with solenoid load brakes and special rheostatic control, This permits the boom to be lowered by regenerative braking and stopped smoothly by the solenoid load brake.

Bridge Motion

This requires open crane-type motors with shoe-type solenoid brakes in "dog-houses" for protection against weather, or totally enclosed crane motors with shoe-type brake using some form of guard for the brake. Totally enclosed mill-type motors with shoe-type solenoid brakes (having guards for the solenoid brakes) are used in some cases, especially where duplicates of other material in a mill are desired. If one motor alone is used for propelling the bridge, it is advantageous to equip it with a multiple magnet solenoid brake so that one magnet can be used for giving a smooth stop and the other magnet for giving extra high torque for holding in a wind storm. Where two motors or four motors are used for propelling the bridge, it is advantageous to equip all of the motors with solenoid brakes and, in stopping, first set one half of the solenoid brakes so as to provide a smooth stop and then set the other half for holding against the wind. Manual type controllers, either for one or two motors, equipped with necessary drift points, for handling solenoid brakes as outlined, are provided.

Rail Clamps

Small motor generator sets, capable of giving power for hoisting and d-c. dynamic braking for lowering, are useful in handling the very large weights required.

Protective Devices

Circuit breakers, overload relays for use with contactors and push-button-reset, also limit switches are all required.

Loading of Boats

At the head of the Great Lakes, ore is loaded into boats from large trestle piers which carry hoppers and chutes. Fig. 19. As first constructed these chutes were operated by man power and much labor was required and a great deal of time lost. Subsequently, the chutes were hoisted and lowered by means of electric motors. The most popular practice is to drive about twelve hoisting machines from one motor. The motor is left running continuously when no hoisting is to be done and chutes are manipulated one at a time by means of clutches which attach the hoisting mechanism to the motor-driven shaft. A very convenient and readily adapted method of drive would be an individual motor and controller for each hoist. The motors could be extremely small because of the low hoisting speed required. The controllers could be conveniently grouped in pulpits of eight.

440 volts, alternating current seems to be the most practical power supply.

Figs. 20, 21, 22 23 and 24 show a large installation for handling coal from car dumpers through belt conveyors to a ship at the coal loading pier of the Baltimore & Ohio R. R. Company, Curtis Bay, Baltimore, Md. Its equipment at the shore end of the pier consists of two steam-operated dumpers, capable of handling 45 100-ton cars per hour, which in service have actually dumped 50-ton cars at the rate of 60 per hour

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

The pier, 700 ft. long by 110 ft. wide, carries longitudinally four main 60-inch belt conveyors driven at 525 ft. per minute by four 300-h.p. motors and two 48-inch belts driven by two 150-h.p. motors. Each 60-inch belt trips coal into movable cross conveyors which spill it into ship-holds on either side of the dock. Each 48-inch belt trips coal into a movable incline boom conveyor which spills the coal, for trimming, in the boats. A trimmer is on each side of the dock. The six movable conveyors are carried on traveling bridges. Each movable conveyor can be moved up, down, in, out or sideways while carrying coal—thus obtaining great flexibility and speed. Each movable conveyor with its longitudinal belt and feeders is controlled entirely by one operator—all starting, stopping and speed-variation is "fool-proof" and work the belts always in proper sequence.

Instead of some 200 or more exposed trolley wires for carrying power and control circuits along the dock and over the bridges, use is made of twelve flexible cables which lay on the face of the dock and are gathered from the dock to bridges on counter-weight-operated cable-reels.

550 volts direct current is used. The aggregate maximum rated capacity of the pier is 8000 tons per hour.

As an indication of the speed with which ships can be loaded at this pier, 8000 tons of

Fig. 25. General View of High Lift Car Dumper Installed at Semet Solvay Coke Plant, Indiana Harbor, Ind.

coal were stored in the hold of a steamer in three hours twenty minutes, including all necessary hand trimming for the proper stowage of the cargo.

On the Great Lakes it is customary to dump coal from railroad cars directly into boats. Figs. 25 and 26. Years ago steam was used entirely for performing these operations, but modern car dumpers are making use of electricity for several reasons: first, it is more economical; second, it is more accurately controlled and hence causes less damage to railroad cars; third, it permits of the use of traveling car dumpers which would not be so practical with the traveling steam plant; fourth, it readily lends itself for use with limit switches and other conveniences which are needed on high lift car dumpers where the car is raised vertically for a certain distance and then turned around a knuckle; fifth maintenance costs are not so great. Many electrically operated car dumper plants have consisted of a Barney car hoist for shoving the railroad cars onto the dumper and a dumper for turning the car over.

Fig. 26. High Lift Car Dumper, Car in Completely Dumped Position, Installed at Semet Solvay Coke Plant, Indiana Harbor, Ind.

Direct current has been the popular form of power for this type of plant because it lends itself so readily to the exacting control requirements of the Barney car hoist. For plants which contain no Barney car, alternating current with dynamic braking of the type described for the LaBelle Iron Works towers on page 359 is equally as practical and more economical than direct current.

With the recent advances which have been made in the art of controlling high speed freight and passenger elevators, it is highly probable that alternating current will soon be adapted to meet all requirements for Barney car hoists.

Car Dumpers

By Jas. A. Jackson

Power and Mining Engineering Department, General Electric Company

The ideal railroad freight receiving yard or dock is equipped with means for unloading the cars quickly upon their receipt, thus releasing them for further duty immediately. For this service, the car dumper has been developed to handle free flowing bulk freight such as coal, crushed stone, etc. The following article explains the operation of the two principal types of dumper; the turn-over type and the lift-and-turn-over type, both of which dump sidewise. The motive power requirements for their operation are described and the suitability of direct-current and alternating-current equipment is fully discussed.—Editor.

Car dumpers are used for dumping coal, ore, limestone, or other kinds of free flowing bulk freight from open-top standard railway cars commonly known as gondolas. The operation is carried out by inverting the car until all its contents are dumped.

The devices for this purpose may be divided into two general classes; viz., the side-dump type and the end-dump type. The end-dump type however is so little used, particularly in this country, that no effort will be made to cover it in this article.

The side-dump type can be further divided into two general classes, the turn-over type and the lift-and-turn-over type, each of which can be either movable or stationary. The first of these does not elevate the car any more than is actually necessary to turn the car into an inverted position. When of the stationary type, they are usually used to dump into transfer cars or onto conveyors; while if movable, these auxiliary devices can be omitted, and the dumping take place directly onto stock piles or into boats. The second type elevates the car vertically for some distance, before starting to invert it, so that it will be high enough to discharge directly into large vessels or high storage bins. This type is seldom made movable on account of its height.

The general construction of all types of dumpers consists essentially of a structural steel framework, rectangular in form, containing a cradle to which the car is securely clamped during the entire dumping cycle. This clamping is done entirely automatically by an ingenious system of clamps, actuated by counterweights, which are so arranged as to accommodate themselves to all sizes of cars. In most dumpers, these counterweights serve two other purposes; the first being to assist in starting an overturned car in the downward direction, and the second being to slide the car sidewise and hold it firmly against the side of the cradle. In order to accomplish this sidewise sliding, the track on the cradle is carried on a platen which is supported on wheels and moves in guides to keep it in alignment. Some of the clamp counterweights are connected by ropes to this platen in such a manner that, as soon as the cradle starts to move upwards, the platen and car move sidewise until the car comes up against the wooden bumpers on the side of the cradle. It is then held there throughout the dumping period until the cradle arrives at a point a short distance from the bottom, at which point a series of mechanical arms come into play and push the platen back against the action of the counterweights. This lines up the dumper tracks with the

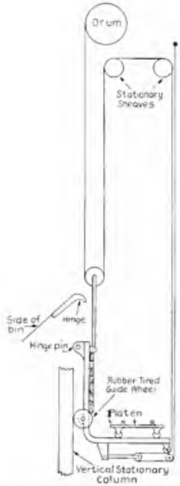


Fig. 1. Roping Arrangement of Lift-and-Turn-over Dumper

stationary tracks and, as the top clamps have been automatically released, the car is ready to be pushed off the dumper by the next loaded car bumping into it. From the foregoing, it will be seen that a car is supported on the bottom, top and one side throughout the dumping period.

The operation of a lift-and-turn-over dumper is similar to that of the turn-over type, just described, so far as the rotation and the action of the platen and counterweights are concerned. In addition, however, the cradle and car are first lifted vertically to the desired height at which point the hinge on the cradle engages the rotation pin. This engagement stops the vertical motion but the roping is so arranged that the motion of the cradle is immediately changed to one of rotation, thus dumping the car. In lowering, the reverse operation occurs, viz., the cradle is first rotated to a horizontal position at which point the hinge and its pin are unlocked, permitting vertical motion downward to the starting level. Fig. 1 shows one method of roping to accomplish this purpose. To prevent severe shocks and strains, the speed of the cradle is much reduced at the moment when the hinge pin engages in hoisting and when it disengages in lowering. When disengaging, wheels on each end of the cradle come up against vertical guides which maintain the alignment of the cradle during the vertical lift and, unless the speed is very low, a severe side thrust is thrown on the dumper framework. With electrically operated dumpers, these slow-downs are obtained automatically by limit switches, as will be explained later.

The power required for operating a car dumper is necessarily quite large, both on account of the heavy weight to be handled and on account of the speed which must be made in order to make the dumper a profitable investment. Ordinarily, the horse power requirements for the cradle hoist alone run from 400 to 800 horse power, and even to 1000 horse power in some cases, to which must be added the requirements for any auxiliary machinery such as the Barney haul, pan hoist, revolving chutes, conveyors, etc.

Throughout the operating cycle of any specific dumper, the power requirements are continually varying due to the shifting center of gravity of the load, to the changing lever arm on which the rope acts, and to the action of the counterweights. This makes a very irregular power curve which varies in shape according to the physical dimensions and design of the cradle. In other words, almost any two different designs of dumpers will give different shaped power curves. Fig. 2 shows a typical rope load curve for a revolving type dumper, and Fig. 3 shows one for a lift-and-turn-over dumper.

For some reason which does not seem to be entirely clear, the majority of dumpers installed up to within the past few years have been steam operated. The most plausible reason seems to be that electric power in sufficient quantities has not been available in many places. Electricity certainly has many advantages over steam, and, if obtainable, is the most desirable form of power to use. If steam is used, it generally requires a small isolated plant with non-condensing engine and its attendant high condensation losses, poor boiler economy, high stand-by charges, large maintenance charges, large labor requirements, and general all-around low efficiency. Electric power is more economical, for no power is consumed except when the dumper is actually moving. It is more flexible, for the control can be entirely automatic after the dumper has once been started by the operator. It requires less ground space, for all the electrical machinery can be installed in a house on top of the framework which supports the cradle. Lowering can be very accurately controlled by dynamic braking, and can be varied over a wide range of speed if necessary without any special attention on the part of the operator. The maintenance is low and the

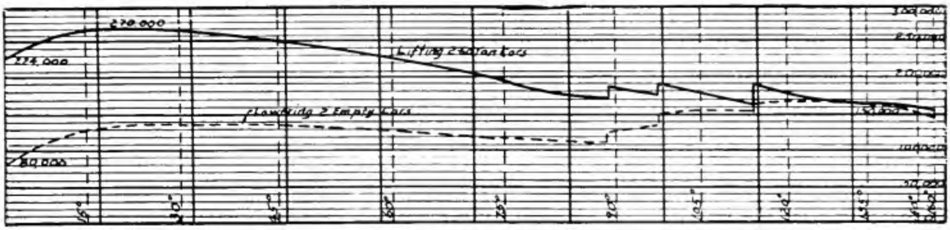


Fig. 2. Typical Rope Load Curve for Revolving Type Dumper

labor requirements are small, as, aside from the operator, it is only necessary to have an electrician give the equipment a regular daily inspection and renew such wearable parts as contactor tips, controller fingers and segments and motor brushes when necessary. It enables the operator's cab to be conveniently located at the most desirable point. Electric power is essential on the movable type of dumper, for in this case the entire dumper structure with its machinery travels on tracks so as to dump at different points, which makes it necessary to conduct the power to the dumper by trolley wires.

If electric power is to be used, the question of direct current versus alternating current immediately comes to mind. Unquestionably, direct current has some advantages for this service, although an alternating-current equipment can be designed which will give very satisfactory operation. From the rope load diagrams it will be seen that braking is required throughout the entire lowering cycle. This action can be obtained very simply and safely by dynamic braking with direct-current motors; whereas with alternating current, dynamic braking requires a more complicated equipment, and it is not so safe as with direct current. Furthermore, the torque characteristics of direct-current motors are somewhat more favorable for the service and the torque is independent of the voltage. Direct-current control equipment can be laid out to give emergency dynamic braking which will prevent a runaway should the power supply fail and the solenoid brake fail to hold the load. This cannot be done with alternating-current power and the solenoid brake must be depended upon to prevent damage in emergencies. Positive low speeds while starting, stopping, and at the rotation pin are easier to obtain with direct-current than with alternating-current equipment.

A typical direct-current installation would consist of one or more heavy design motors with solenoid brakes such as are used in steel mill service, controlled by magnetic control equipment, and operated from a master switch in the operator's cab.

The motors should preferably be compound wound with sufficient shunt field to give a no-load speed of about 150 per cent full-load speed, although series motors are often used very successfully. Compound-wound motors give a more uniform speed regardless of the weight of the car being handled. Also, dynamic braking and a "kick off" can be obtained more efficiently, since the shunt field can be depended upon to insure excitation instead of separately exciting the series field as would have to be done with a series motor. The size of the motors must be carefully calculated from a duty cycle worked out from the rope load curve, Figs. 2 and 3. The service is such as to require an open frame motor as the heating is too severe for a totally enclosed motor. In figuring a duty cycle, the rest period between trips plays a very important part in determining the best size of motor and should be given very careful consideration. It would seem advisable in many cases to work out two duty cycles, the first of which would be based on handling the maximum number of cars possible for two hours, i.e., the rest period would be a minimum. The second cycle would be based on the average number of cars which the dumper would be likely to handle in a ten-hour day. This would give a longer rest period as it is very unusual to be able to bring loaded cars to a dumper as fast as it can handle them for ten consecutive hours. Motors could then be selected which would handle the average ten-hour load continuously and the maximum load for two hours without overheating. This would result in an economical electrical layout.

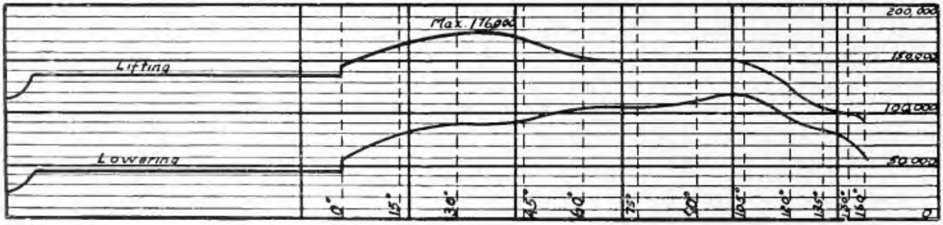
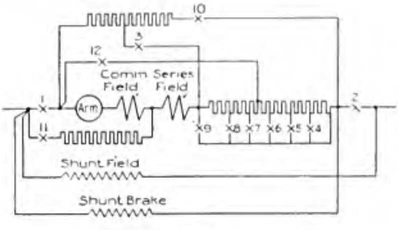


Fig. 3. Typical Rope Load Curve for Lift-and-Turn-over Dumper

The motors should be equipped with full-torque shoe-type solenoid brakes, usually shunt wound to secure more economical operation in lowering.



Contactor Sequence

Contactors	Lower Points						Off	Hoist Points					
	6	5	4	3	2	1		1	2	3	4	5	6
1								•	•	•	•	•	•
2	•	•	•	•	•	•		•	•	•	•	•	•
3						•	•	•					
4		•	•	•	•	•	•	•	•	•	•	•	•
5			•	•	•	•	•			•	•	•	•
6				•	•	•	•				•	•	•
7					•	•	•					•	•
8						•	•						•
9						•	•						•
10	•	•	•	•	•	•	•						
11	•	•											
12	Closes by Gravity if Power Fails at Any Time												

Fig. 4. Elementary Diagram of D-c. Control Equipment for Use with a Compound-wound Motor on a Car Dumper

The magnetic control equipment must be laid out to give automatic acceleration in the hoisting direction by cutting out series resistance and must give at least one positive low-speed point by a resistance shunting the motor. In the lowering direction a "kick-off" torque must be provided to accelerate all parts to full speed rapidly, after which the torque must change to dynamic braking automatically and thus lower the load safely at the correct speed.

Automatic deceleration should be provided in the lowering direction to prevent too high torque and current peaks with consequent dangerous mechanical strains when the master switch is thrown suddenly to the "off" point. The control must have a speed protective relay to prevent too high a speed when it is found necessary to lower a loaded car. It should retain dynamic braking connections in the "off" position of the master switch and also maintain a dynamic braking circuit in case the power fails. A limit switch geared to the hoist drum must automatically provide an automatic slow-down and stop at each end of the travel; and, in the case of a lift-and-turn-over dumper, it must also provide an automatic slow-down and acceleration when passing the rotation pin in each direction. Fig. 4 shows a scheme of control which can be installed to perform all these functions, and Fig. 5 shows the speed-torque curves obtained with a compound-wound motor. These speed-torque curves show only the hand controlled points. There are, of course, other automatic points for both hoisting and lowering to insure smooth acceleration and deceleration. In the hoisting direction, point *6* is the characteristic curve of the motor; and, if the load on the dumper is such as to require 100 per cent torque, the motor will run at 100 per cent speed on this controller point. Point *1* hoisting gives a positive creeping speed for starting, stopping, and at the rotation pin on lift-and-turn-over dumpers. In using the lowering curves it is necessary to consider that an empty car is being lowered and that the friction of the dumper, ropes, and hoist parts assists in holding back the load. An empty car will probably not weigh more than 25 per cent of the combined weight of the car and its load, hence, neglecting all friction, only 25 per cent dynamic braking torque would be required to lower it. However the friction losses will further reduce this to about 15

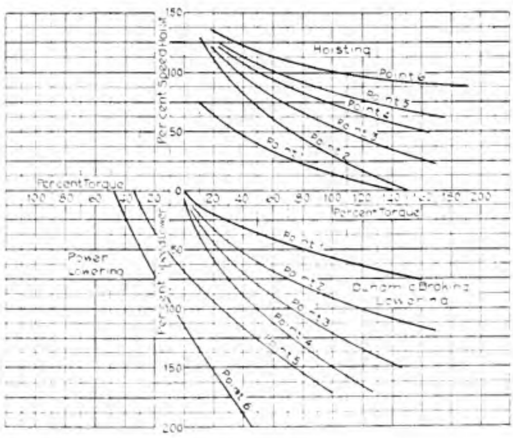
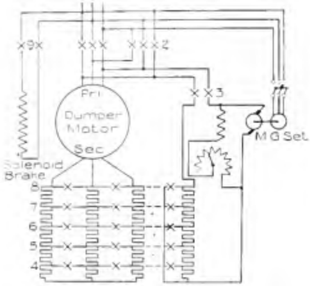


Fig. 5. Speed-Torque Characteristic Curves of a Compound wound Motor Controlled as Shown in Fig. 4



Contactor Sequence

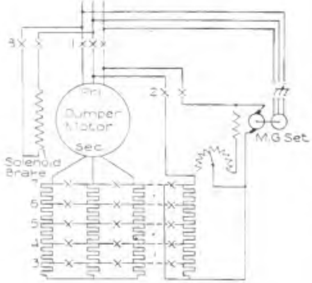
Contactors	Lower Points					Off	Hoist Points				
	5	4	3	2	1	Off	1	2	3	4	5
1							•	•	•	•	•
2	•										
3		•	•	•	•						
4	•		•	•	•			•	•	•	•
5	•		•	•	•				•	•	•
6	•		•	•	•					•	•
7	•			•	•						•
8	•				•						•
9	•	•	•	•	•		•	•	•	•	•

Contactors 1, 2, 4, 5, 6, 7 and 8 are Triple Pole. No. 3 and 9 are Double Pole.

Fig. 6. Elementary Diagram of A-c. Control Using Dynamic Braking on All Lowering Points. No Kick-off Provided

per cent so that to find the speed at which an empty car would be lowered we must find the intersection of the 15 per cent dynamic braking torque line with the point *6* lowering curve, which shows a speed of 143 per cent. The speeds on other controller points may be found by following the 15 per cent torque line to the intersection with the other curves. If necessary to lower a loaded car, a dynamic braking torque of from 35 to 50 per cent will be required depending upon the efficiency of the dumper. On point *6* this would give a speed of from 180 to 210 per cent which is too high, hence a speed protective relay (actuated by motor voltage) is set to operate at about 160 per cent speed thus throwing the connections of the control equipment back to point *5* regardless of the operator. This change reduces the speed to from 110 to 125 per cent which is satisfactory. Of course the shape of the lowering curves can be readily changed to meet specific operating conditions by shifting the resistor taps to increase or decrease the ohmic values of the various steps.

If alternating-current power has to be used, the motor must be of the wound-rotor slip-ring type with open frame and be equipped with a full-torque shoe-type solenoid brake. The control should be full automatic and provide current-limit acceleration in the hoisting direction. In lowering, either of two different schemes can be used. The first uses dynamic braking throughout the entire lowering cycle by applying direct current, from a small special motor-generator set, to one phase of the stator winding of the induction motor. The second uses regenerative braking except during the slow-down period when dynamic braking would be applied by supplying direct current to the stator winding as in the first case. This second scheme has the advantage of being more economical in power and it provides a "kick off" to get the car started down quickly. It has the disadvantage that in changing over from regen-



Contactor Sequence

Contactors	Lower Points					Off	Hoist Points				
	5	4	3	2	1	Off	1	2	3	4	5
1							•	•	•	•	•
2	•	•	•	•	•						
3		•	•	•	•			•	•	•	•
4		•	•	•	•				•	•	•
5			•	•	•					•	•
6				•	•						•
7					•						•
8	•	•	•	•	•		•	•	•	•	•

Contactors 1, 3, 4, 5, 6 and 7 are Triple Pole. No. 2 and 8 are Double Pole.

Fig. 7. Elementary Diagram of A-c. Control Using Both Dynamic Braking and Regenerative Braking when Lowering

eration to dynamic braking there is an instant when there is no power at all applied to the motor and means must be provided to prevent the solenoid brake from setting at this time. Furthermore, it is more complicated than the first scheme. If the first scheme is used, the dumper must have sufficient downward pull in any position to break the static friction and accelerate all the machinery as no "kick off" can be provided. This slows up the cycle. With either scheme, the solenoid brakes must be depended upon to stop the load if power fails as no emergency dynamic

control and Fig. 9 [illegible] curves. An examination of [illegible] that speed regulation at practi[illegible] torque values is not good. For [illegible] 15 per cent dynamic braking torque [illegible] gives a speed of 90 per cent. A [illegible] increase in torque increases the speed [illegible] per cent. This is an inherent detriment [illegible] this method of control and shows the neces[illegible] for a reliable speed protective device a[illegible] brake. Point 6 lowering on Fig. 9 shows [illegible] the opposite effect as the speed is almost constant over widely varying torque values and

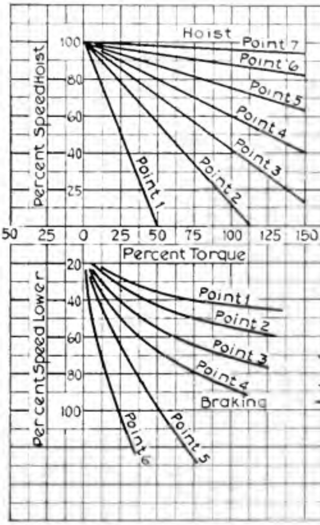


Fig. 8. Speed-torque Curves of A-c. Motor Using Only Dynamic Braking for Lowering

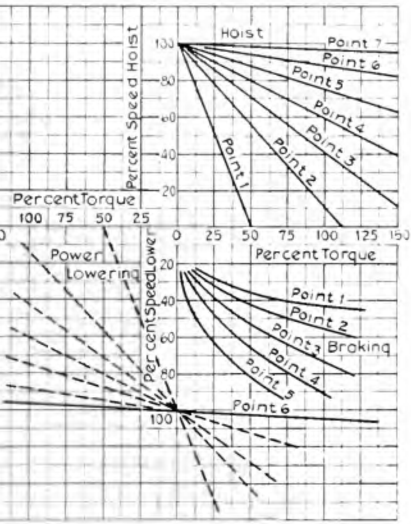


Fig. 9. Speed-torque Curves of A-c. Motor Using Both Regenerative and Dynamic Braking for Lowering

braking can be obtained. For this reason it is advisable to have a separate powerful emergency brake, weight set, and operated through a suitable trigger which will trip from a flyball governor if the speed attains a definite amount above normal. Both schemes require a special motor-generator set for supplying direct-current excitation at the proper voltage. Fig. 6 shows an elementary diagram of connections for the scheme using dynamic braking only; and Fig. 8 shows the speed torque curves obtained from such a control. Fig. 7 shows the connections for the combined regenerative and dynamic braking

is only a few per cent over the synchronous speed of the motor. However, higher speeds can be obtained by leaving resistance in the secondary circuit of the motor as shown by the dotted curves but here again speed regulation becomes poorer as the secondary resistance is increased.

With either scheme of control, a failure of power supply shuts down the motor-generator set supplying the direct-current excitation and stops the dynamic braking immediately. This throws the entire work of stopping the machinery on the friction brakes, hence the necessity for their positive reliability.

The shape and general layout of a car dumper is such that two or even four small motors operating in parallel work to better advantage than a single large motor and consequently dumpers are generally built in this way. The characteristics of direct-current series motors are such that two or more operating in parallel will inherently divide the load equally when hoisting and it is not at all difficult to make them divide the dynamic braking load by adjusting the resistors. Compound-wound motors will usually divide the load near enough for all practical purposes when hoisting and they also can be easily made to divide the braking load when lowering by resistor adjustment. Alternating-current slip-ring motors, however, have characteristics which do not favor parallel operation as their speed-torque curve is too flat over a wide range of torque; hence the layout of an alternating-current operated dumper might have to be such as to sacrifice some good points in the machinery design and arrangement to make it adaptable to one motor operation.

Where two or more direct-current motors are operated in parallel, it is customary for each one to have its own contactor panel and resistor and to operate all the panels in parallel from one master switch. With such an arrangement a disabled motor or panel can be quickly cut out by disconnecting switches and the operation continued at reduced capacity.

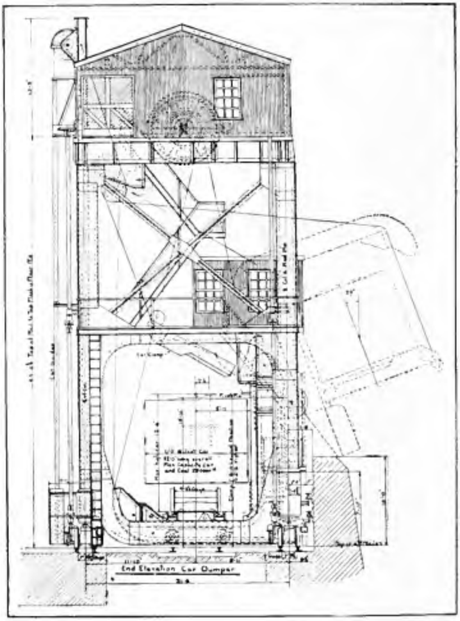


Fig. 10. End View of Lift-and-Turn-over Stationary Type Car Dumper, Electrically-operated by 4-175 h.p. Continuous-rated Motors. Capacity One 100-Ton Car Every 2½ Minutes

Fig. 11. Car Dumper Showing Cradle in Lowest Position with Car in Place Ready for Hoisting

Fig. 12. Lift and Turn-over Car Dumper. Cradle Just Past the Rotation Pin

Electrical Equipments for Movable Highway and Railway Bridges

By H. H. Vernon

Power and Mining Engineering Department, General Electric Company

The designer of bridges has found electricity the ideal motive power for operating the movable span bridges which cross navigable waterways. The application of this form of power, supplied by a central station, eliminates the heavy and wasteful standby losses that would be incurred by an isolated steam plant at the bridge. Electric drive is reliable and lends itself readily to the application of interlocking and indicating devices. In the following article the various types of movable span bridges are defined and illustrated, and then the complete alternating-current and direct-current electrical equipment which may be applied to their operation are described in detail.—Editor.

There are several types of movable highway and railway bridges in use, some of which will be described in this article.

Swing Span Bridges

This type consists of a span whose weight is either supported at the center on a bearing of phosphor bronze discs, or on conical roller bearings or wheels of small diameter which run on a steel plate track some distance from the center of the bridge span. (Figs. 1, 2, and 3.)

As will be seen from the illustrations, there is plenty of room for a pier in the water without interfering with navigation, and this consideration often determines the type of bridge that is used.

Draw Bridges

There are a large number of bridges over canals and narrow streams, and where land is not valuable a drawbridge is sometimes erected. This type of bridge is mounted on wheels and somewhat resembles a large transfer table. There are several means of moving the span, viz.:

1. Mount the motor or motors on the movable span and gear to the wheels.
2. Have the tracks on which the bridge runs arranged on a slight incline so that the bridge is pulled up hill by a motor geared to a hoist drum and lowered down the incline by gravity.
3. Use a level track and have a motor geared to a double hoist drum. One drum pulls the bridge open and the other pulls it shut. (Fig. 4.)

Vertical Lift Bridges

The movable span of this type of bridge travels in a vertical plane and always stays in a horizontal position. It is used where there is not much boat traffic requiring high head room for masts and stacks, as it is only necessary to raise the bridge sufficiently to give clearance between the boat and the bottom of the bridge, instead of taking it to the extreme top position thus saving time. (Fig. 5.)

Bascule Bridges

There are three distinct types of bascule bridges, viz.:

1. Scherzer roller bascule, which consists of one or more leaves with a section of a large wheel at one end. The leaf is counterbalanced and rolls on a flat plate track.

Fig. 1. Driving Mechanism on a Swing Span Bridge

Note small wheels on which weight of span is carried.

The racks to which the motor or motors are geared are mounted on the stationary part of the bridge, and therefore the motors turn through an angle of approximately 90 deg. with the motor shaft as an axis. It is necessary to arrange the motors with some form of lubrication other than oil rings. (Figs. 6, 7 and 8.)

Fig. 2. Swing Span Bridge in Closed Position

Fig. 3. Swing Span Bridge in Open Position

Fig. 5. Lift Bridge

Fig. 6.

Fig. 4. Horizontal Draw Bridge
Note tracks and wheels on which the bridge span runs

Two Single Leaf Scherzer Baseule Bridges. One Open and the Other Closed

Fig. 7. Scherzer Double Leaf Bascule Bridge in Closed Position

Fig. 8. Scherzer Double Leaf Bascule Bridge in Open Position

Fig. 9. Strauss Single Leaf Bascule Bridge in Closed Position

Fig. 10. Strauss Single Leaf Bascule Bridge in Open Position

Fig 11 Strauss Single Leaf Bascule Bridge in Closed Position and Three Lift Bridges in Background. One of the Lift Bridges is Open and Two are Closed

Fig. 13. Rall Double Leaf Bascule Bridge in Open Position

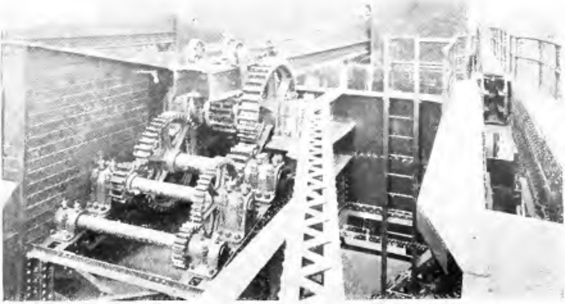


Fig. 12. Operating Mechanism for Opening and Closing One Leaf of a Rall Bascule Bridge

Fig. 14. Rall Double Leaf Bascule Bridge in Closed Position

2. Rall type, which is similar to (1) except that a pair of wheels are used at one end of the movable span and the action in opening the bridge is somewhat like a two-wheeled dump cart with the body of the cart attached to the ground. When the wheels are moved backward one end of the leaf of the bridge is raised. (Figs. 12, 13 and 14.)

3. Strauss bascule bridges open in the same manner as (2), but use a main trunnion on which the leaf turns. A large walking beam is used, one end of which is connected to the bridge leaf, and the other end to the counterweight. The racks to which the motors are geared are either pinned at one end to the stationary part, or to the movable part of the bridge. If the racks are pinned to the stationary part the motors are mounted on the movable span and therefore must be arranged so that they can revolve through an angle of approximately 90 deg., using the motor shaft as an axis. If the racks are pinned to the movable span the motor may have oil ring lubrication, as it is stationary. (Figs. 9, 10 and 11.)

Fig. 15. 30-h.p., 1200-r.p.m., 3-phase, 60-cycle, 440-volt Totally Enclosed Motor Arranged to Turn Through an Angle of 90 Deg.

This type of bridge, especially the double leaf, is the safest because when it is open it forms its own barrier and it is impossible for a train or car to run off the stationary span into the water.

Electrical Equipment

The electrical equipment for the different types of bridges is about the same, and therefore we shall consider that for a double leaf Strauss bascule bridge. As alternating and direct-current equipments are used successfully, both types will be described.

Fig. 16. 3-phase, 60-cycle, 440-volt, Totally-enclosed Motor with Solenoid Brake

ALTERNATING-CURRENT EQUIPMENT

Main-operating Motors

Standard practice is to use totally enclosed slip ring motors, rated on a twenty minute 55 deg. C. rise basis and with bearings arranged with wick lubrication. The normal torque of the motors should be twice that required to overcome the friction of the bridge, and starting torque should be at least twice the normal torque. This is necessary in order to provide sufficient torque to overcome static friction under adverse conditions and to open and close the bridge when a high wind is blowing. The motors drive through a pinion which is either mounted on the motor shaft or on another shaft which is connected to the motor shaft by means of a coupling. (Figs. 15 and 16.)

Solenoid Brakes

Spring-set shoe-type solenoid brakes capable of holding 75 to 100 per cent motor torque are mounted on the collector ring end of the motors. Spring-set brakes are used in order that they may be effective at any position of the motor when opening or closing the bridge. The brakes must be arranged so that they can be released by hand, because it is sometimes necessary to operate the bridge on failure of power.

Emergency Brakes

Spring-set emergency brakes are usually used which will hold from 100 to 125 per

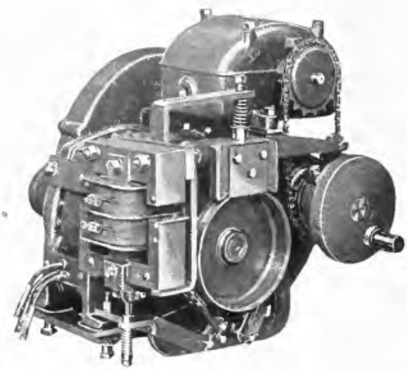


Fig. 17. Motor-operated Lifting Mechanisms for Emergency Brake

cent of the normal torque of the motor, and they are mounted on an extension of the motor shaft. Standard solenoid brakes can be obtained to hold 2800 pounds torque at one foot radius, and sometimes two of these large brakes are used instead of one in order to obtain the braking torque required.

Controllers

Either drum controllers or panels containing magnetic switches are used. The former are more common, and a great many single and two-motor controllers with a drift step are in use. One standard arrangement is to use a drum controller that controls two motors in parallel and energizes the solenoid brakes on the first step without applying power to the motors, thus obtaining a drift step. Another standard arrangement is to use two single motor controllers arranged with a drift step, and quite frequently these two controllers are geared together so that they can be operated by one handle. The gearing connecting the two controllers is so arranged that it can be thrown out of mesh and either controller operated singly. (Fig. 18.)

Resistors

Resistors for the motors consist of one or more sections of cast grids. With the controller on the first power step the motor or motors will exert approximately 35 per cent of normal torque. The current-carrying capacity of the resistor is quite liberal and frequently they are laid out to carry full load rotor current on any step of the controller where it is possible to develop full load torque or more. On the first two or three steps it is only necessary to have current-carrying capacity equivalent to the torque exerted by the motor on these steps respectively.

Lock Motor

Regardless of the size of the main motor or motors, the lock motor is almost always of a 5-h.p. totally enclosed squirrel-cage type rated on a basis of 10 minute 55 deg. C. rise. This motor is arranged with metalline bearings and a spring-set shoe-type solenoid brake so that it can be tilted at an angle of 90 deg. in a direction at right angles to the shaft. (Fig. 19.)

Controller

As a squirrel-cage motor of this size is thrown directly on the line, a drum type reversing switch is used. The reversing

Fig. 18. Main Motor Controller

switch is so arranged that it energizes a contactor in the motor circuit, and no push button or other auxiliary short circuiting switch is necessary to bridge the limit switch after it has tripped out the contactor. (Fig. 20.)

Limit Switches

A geared type limit switch is used for each leaf of the bridge. This limit switch shuts off power from the motors when the leaves have reached their upper and lower limits. The limit switch does not handle the motor current direct, but operates a contactor in the motor circuit. In addition to shutting off power at each end of travel the limit switch shows by means of lamps the open, nearly open, nearly closed and closed positions of the bridge.

A track type limit switch is used on the lock to shut off power from the motor in each direction, and in addition it completes a circuit when the lock has been withdrawn. The circuit which is completed is the contactor coil circuit of the leaf motors thus interlocking the leaf motors with the lock. When the lock is in, power cannot be applied to the leaf motors, but as soon as the lock has been withdrawn power can be applied and the leaves opened.

A track type limit switch is used to show by means of lamps the open and closed positions of the lock. (Fig. 21.)

In order that power may not be applied to the lock motor until after the bridge has closed, a track type limit switch is used that opens as soon as the bridge leaf opens. This opens the lock motor contactor coil circuit, and no power can be applied to the lock motor until the leaf closes and allows the limit switch to close again.

Normally open push button stations are used to short circuit the limit switches in order to fully open or fully close the lock and fully close the bridge leaves after the limit switches have cut off power. (Fig. 23.)

Fig. 19. 5-h.p., 900-r.p.m., 3-phase, 60-cycle, 440-volt, Totally Enclosed Lock Motor with Spring-set Solenoid Brake

Switchboard

A bridge equipment is [illegible] out a switchboard, and therefore all electrically operated bridge[illegible] have a switchboard consisting of one [illegible] panels mounted on suitable frame[illegible]

Fig. 20 Drum Type Reversing Switch for Lock Motor

taining the following material: voltmeter, ammeter, main line switch, main line circuit breaker with overload and low voltage release attachments, double or triple-pole magnetic switches or contactors for the leaf and lock motors, overload relays for the leaf and lock motors, triple-pole cutout switches in each motor circuit, and double-pole fused switches for each lighting circuit, such as operator's house, machinery house, signal lights, navigation lights and bridge lights. (Fig. 22.)

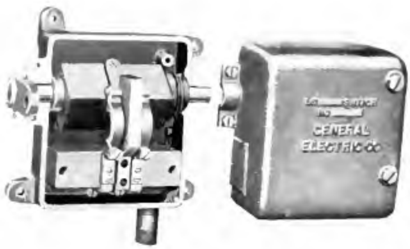


Fig. 21. Track Type Limit Switch

The indicating lamps to show the different positions of the leaves and lock are placed behind bull's-eye lenses mounted on a slate panel. This panel is suitable for wall mounting, and is placed so that it can be conveniently seen by the operator. (Fig. 25.)

DIRECT-CURRENT EQUIPMENT

Main Operating Motors

Series wound totally enclosed crane or mill-type motors rated on a basis of 30 minute 50 deg. C. rise (crane type) or 75 deg. C. rise (mill type) are used. The normal torque should be about twice that required to overcome the friction of the bridge. The motors are arranged with either grease cup or oil waste

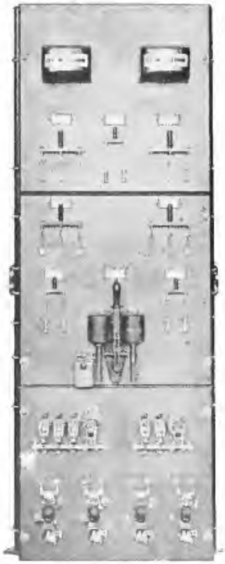


Fig. 22. Switch Board for Alternating-current Strauss Bascule Bridge Equipment

lubrication so that they will operate successfully when tilted through an angle of 90 deg. as described above. (Fig. 24 and 26.)

Solenoid Brakes

The solenoid brakes are of the same type as those used for alternating-current equipments, and are shunt wound to obtain drifting on the motors.

Controllers

When two motors are required not exceeding 50 h.p. (total), 230 volts, the controller used is of the two cylinder type, one for cutting resistance out of the armature circuit and the other for reversing the motors and by-passing the leaf limit switch. It is arranged to energize the solenoid brakes on the first step without applying

Fig. 23. Push Button

power to the motors, thus providing a drift step. (Fig. 28.)

Resistors

The resistors are of the cast grid type, and sufficient resistance is provided to give about 35 per cent of normal torque on the first power step of the controller. The current-carrying capacity is sufficient to allow full load current to flow continuously on all steps of the controller where full load torque or

Fig. 24. 25-h.p., 725-r.p.m., Series Wound 230-volt Motor

more obtains without exceeding a temperature rise of 350 deg. C. On the steps where less than full load torque obtains the current-carrying capacity is arranged accordingly, that is, on the first power step current flows to produce 35 per cent torque, and the first division of the resistor is laid out to carry a current equivalent to this torque.

Lock Motor

The lock motor is usually 5 h.p., 725 to 800 r.p.m. series wound, totally enclosed, and arranged with grease cup or oil waste lubrication.

Solenoid Brake

A shoe-type spring-set shunt or series wound solenoid brake is used to stop and hold the motor armature when power is cut off at each end of the travel.

Controller

The controller shown in Fig. 27 is used, and no auxiliary short-circuiting device to short-circuit the limit switch is necessary to energize the motor in the opposite direction after the limit switch has shut off power if two single pole magnetic switches are used.

Resistor

A grid type resistor is used for 230 volts and a resistor consisting of wire wound units for 550 volts. As the duty is extremely intermittent the resistor used is the same as the standard crane duty resistor.

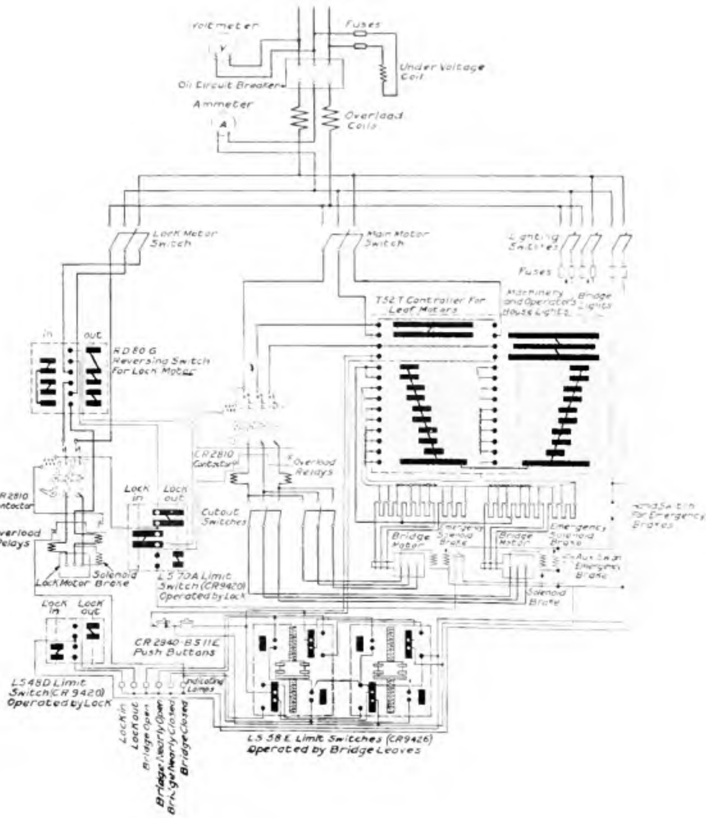


Fig 25. Diagram Alternating-current Control Equipment

Fig. 26. 150-h.p., 230-volt, Series Wound Motor with Solenoid Brake

Fig. 27. Controller for Lock Motor

Fig. 28. Controller for Main Motors

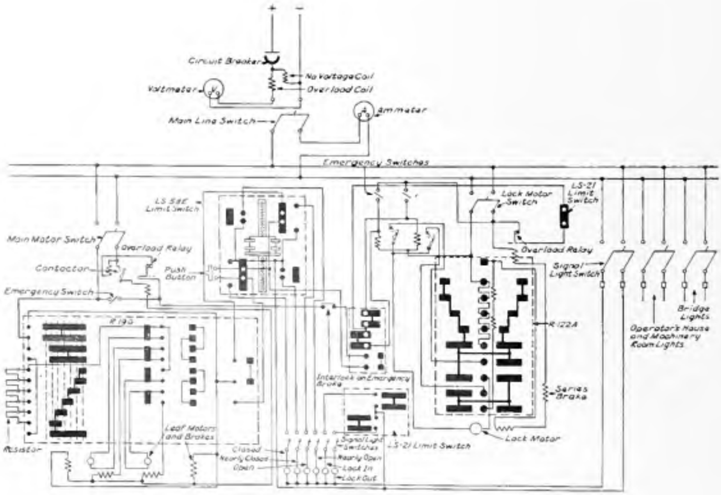


Fig. 29. Direct-current Control Equipment

Limit Switches

The limit switches are the same as those used for alternating-current equipments.

Switchboard

The switchboard is made up of one or more slate panels containing the following material: ammeter, voltmeter, double-pole single-throw main line switch, single-pole circuit breaker with low voltage and overload attachments, three single-pole magnetic switches, one for the leaf motors and the others for the lock motor, about four double-pole single-throw switches with enclosed fuses for lighting circuits, and six single-pole single-throw fused switches for the indicating signal lamps.

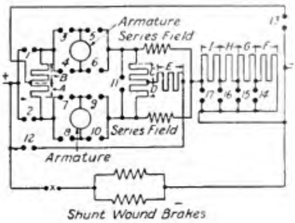


Fig. 30. Schematic Diagram of Control for Two Series Wound Direct Current Motors, Giving Power and Dynamic Braking in Both Directions

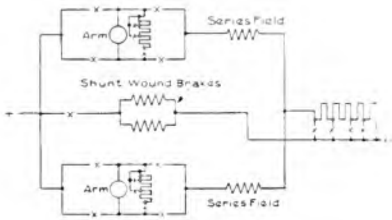


Fig. 31. Schematic Diagram of Control for Two Series Wound Direct Current Motors, Giving Creeping Speeds, Dynamic Braking and Power in Both Directions

Quite frequently emergency switches mounted in a sealed glass case are provided to short-circuit the limit switches, or limit switches and magnetic switches. In case an emergency arises the glass case must be broken and the switches closed, thus doing away with all interlocking for the time being. (Fig. 29.)

Electrical equipment for the other types of bridges mentioned is practically the same as that described above, except that if the main motors are stationary standard oil ring lubrication and gravity-set brakes are used.

For swing span bridges it is not necessary to use a limit switch to shut off power at each end of travel, as no damage can be done even though the bridge does [illegible] indicator is used to [illegible] lamps the closed, nearly closed, [illegible] and open position of the span. The [illegible] is so arranged that it makes no difference whether the span travels through [illegible] deg. or 90 deg. and then back to the [illegible] position.

Large bridges using two or four motors 100 h.p. each or more use magnetic control and the motors are usually connected permanently in parallel. On large equipments it is advisable to use dynamic braking to slow down at each end of travel, and there are two standard methods of doing this. (Fig. 30.)

This scheme gives full power and dynamic braking in each direction, and it is necessary to use the balancing resistors shown so that the motors will divide the load evenly. As the series fields are separately excited to insure that the motors will build up during dynamic braking, a small amount of power is wasted. (Fig. 31.)

Creeping or low speed is effected by shunting the armatures, and if the load overhauls the motors, dynamic braking will obtain. After the shunting resistors are opened up, full power obtains. More power is wasted during dynamic braking with these connections than with the connections shown in Fig. 30.

The Operation of Oil Wells by Electric Power and the Resulting Gain to the Oil Producer

By W. G. Taylor

Power and Mining Engineering Department, General Electric Company

Since the use of electric power for oil well work was reviewed in this magazine several years ago there has been a large growth in this application, and this has naturally resulted in many refinements as well as some important improvements. Very interesting figures which have been obtained on the effect of motor drive on oil production are here presented in connection with a complete discussion of the numerous phases of the work. The author has taken pains to explain the electrical features in a clear and simple manner for the benefit of oil men not fully familiar with motor drive.—Editor.

Before discarding the time-worn method of engine drive in the oil fields, the oil producer must be convinced of two things: first, that his company will profit by making the change; and second, that his field men who use the equipment can continue to satisfactorily perform all of the various operations necessary in oil field work in accordance with the usual practice. With electric power now in use on so many wells in various fields, it requires but little investigation to find that oil well motors for individual well pumping produce more oil, do so at less cost, and furthermore, make considerable general improvement in operation.

INCREASED PRODUCTION

Fuel Saving

The oil fuel consumption for steam-engine pumping is from 3 to 15 barrels per well per day, depending upon the depth of well, the pumping speed, and other local conditions. For instance, in Texas the average is about 10 to 12 barrels. When such wells are electrified, all of this oil fuel can be added to net production, and this, it will be appreciated, is no small gain. Even if oil fuel is used to produce electric power, a modern turbo-generating station will require only half a barrel or less per well per day.

When gas engines are replaced by motors, of course no oil fuel is saved, but more gas is available for the market, and there is much less production lost from shut-downs.

Decrease of Shut-downs

It is only recently that oil men have begun to realize the amount of time lost, and consequently of production, due to avoidable shut-downs in pumping operations. Engine and boiler trouble, reversing clutch troubles, gas shortage, water shortage, freezing in cold weather, rod breakage, and valve and cup troubles caused by vibration and jerking motion are all greatly reduced and some are entirely eliminated by the use of electric drive. An excellent example of this fact is furnished by the records, given in Table 1, of shut-downs for all causes during normal operation of two groups of wells in adjoining Kansas oil fields. The reduction in lost pumping time obtained by the use of motor drive in this case indicates a resulting increase in production of about 15 per cent.

The most convincing figures are those which an oil producer can obtain from his own property. The time reported daily for shut-downs should be classified under:

(1) Engine, clutch and boiler troubles.
(2) Gas or water shortage, or freezing in cold weather.
(3) Rod breakage, including time required to pull and replace rods or tubing on this account.
(4) Cup and valve troubles, including time required to pull and replace rods or tubing on this account.
(5) All other causes.

TABLE I

Comparison of Pumping Time Lost from Shut-downs with Gas Engine and Electric Drive Under Similar Normal Operating Conditions in Kansas, Pumping on the Beam

	Gas-Engine Drive Augusta Field		Electric Drive El Dorado Field	
	Nov., 1917	Feb., 1918	Oct., 1918	Nov., 1918
No. of wells	208	216	26	27
Per cent of available pumping time lost, all causes	23.3	28.2	10.7	9.8
Per cent of available pumping time lost, engine or electric troubles only	4.8	8.15	1.98	0.63

Care must be taken that the time recorded for shut-downs represents the actual amount of available pumping time lost, particularly on head-wells, which are pumped less than 24 hours a day, and which are often reported as being shut down 24 hours when the pumping time really lost is perhaps a much shorter time. On a 24-hour well every hour it is shut down represents a loss.

After the shut-downs are thus classified for a period of a month or two, or long enough to establish a record of average conditions, an analysis with reference to electric drive should be made on the following basis:

(1) Electric troubles will not cause over 2 per cent loss in time due to shut-downs.
(2) There will be no gas, water or freezing troubles with electric drive.
(3) The time lost from rod breakage will in most cases be cut in half if motors are installed.
(4) Although definite figures are at present not available, it may safely be assumed that valve and cup troubles will be reduced several per cent with motor drive.
(5) The other causes of shut-downs will probably not be materially affected as a whole, though some troubles will occasionally occur which would be directly or indirectly remedied to a considerable extent by electric operation.

An analysis of this nature has convinced more than one oil company that it could not afford to continue operating with engines.

That rod breakage is to a considerable extent due to engine drive has not always been appreciated. The oil well motor during pumping does not pick up the rods with a jerk as is the case with steam and gas engines, the speed of the bandwheel being practically constant for the entire revolution. The rods are therefore less liable to crystallize with resulting breakage causing shut-downs. This condition with engines may be somewhat improved by use of a counterbalance on the walking-beam, though it does not make full compensation because of the greater change in speed with engine drive as the result of even a small change in load.

With reference to rod breakage, the field superintendent of a large company in California which operates about 250 wells, of which 100 were then electrified, stated that after motors were installed this trouble was not 60 per cent of the amount experienced with steam engines. Another company using gas engines in the El Dorado field in Kansas found that the very large amount of rod trouble which had been experienced on about 30 wells almost wholly disappeared after electrification.

Time Saving

In addition to a reduction of the number of shut-downs, electric drive shortens or eliminates many delays, such as those caused by steam lines full of water after an idle half hour, or by the usual necessity of getting up steam after longer periods of idleness, or by the engine sticking on center and obliging the operator to make a trip back to "kick it off" or by the difficulties frequently encountered in starting gas engines.

In "pulling" a well, a motor will pull the first "stand" of tubing as fast as the last one, practically regardless of the load to be lifted, while with engines the speed is considerably reduced on the heavier work.

The well-cleaning gang soon finds that quicker work can be done with motors in "spotting" rods and tubing when screwing them up, and that practically no delay is caused by over-travel when hoisting or lowering rods and tubing. This is all due to the fact that more accurate control is obtained than with any form of engine drive. As a result, the well is often put back in production sooner than with other forms of drive.

Production is frequently lost at the flush period during the time taken to set a pumping engine after drilling has been completed. No necessity for this delay exists with electric drive, for all of the pumping equipment can be installed before the drilling engine is removed, or the well can be pumped by a small motor temporarily lined up on the derrick floor while the permanent equipment is being placed and wired. Ordinarily less than an hour is necessary for the change when the proper arrangements are made.

Uniform Pumping Speed

By a drop in steam pressure and quality, or in gas pressure, many a barrel of oil has been lost to the producer who uses engines for pumping. It is well known that a change of one or two strokes per minute from the proper pumping speed frequently results in a very large variation in the daily production. That motors are far superior in this respect in maintaining production is best illustrated by three cases which will be cited.

Several wells have been equipped with two-speed oil well motors by the Birch Oil Company at Brea, California, and every well shows an increase in daily production over that previously obtained with steam-engine drive. This increase, which is undoubtedly due to the various causes discussed in the foregoing paragraphs, varies from 5 to 41 per cent. Records kept on one of these wells clearly indicate the effect of the more uniform pumping motion which is now obtained. The production over a period of 90 days after the installation of the motor was 10 per cent more than for the previous 90-day period. The maximum production of 380 barrels per day with engine drive was increased to 424 barrels per day with motor drive. One day this well was again operated by steam so that a transformer could be changed, and the production for that day dropped 45 barrels.

TABLE II

Comparative Production with Steam Engine and Electric Drive Under Identical Operating Conditions on the Same Well, Pumping by Engine at Night and by Motor in Daytime. Burma Oil Company, Singu Field, Upper Burma, India

	AUG., 1916		SEPT., 1916	
	Bbl.	Per Cent	Bbl.	Per Cent
Oil pumped by motor	1311	42.5	1310	45.4
Oil pumped by engine	1777	57.5	1587	54.6
	Hrs.	Per Cent	Hrs.	Per Cent
Total time motor operation	271	36.5	270	37.5
Total time engine operation	473	63.5	450	62.5
Barrels per hour, motor	4.84		4.82	...
Barrels per hour, engine	3.75		3.52	...
Increase in production due to motor drive		28.5	...	36.0

TABLE III

Increase of Production Obtained with Electric Drive by an Oil Company in the Spindletop Field, Texas, Pumping from a "Power"

	Total Bbl.	Bbl. per Day	Bbl. per Well per Day
Eight wells on steam, January and February, 1918	9340	158.4	19.8
Same eight wells, electric power, March and April, 1918	10791	176.9	22.1
Increase (11.6 per cent)		18.5	2.3

The Burma Oil Company in 1916 operated a well in the Singu field, in Upper Burma, India, by a two-speed oil well motor in the daytime and by steam-engine at night. The engine was used as a countershaft when the motor was running. Both the motor and the engine ran under normal operating conditions. Table 2 gives the results, which offer unquestionable evidence of the superiority of electric operation.

In the Spindletop field in Texas, an oil company electrified a steam-engine-driven "power," pumping eight wells, and increased their production as shown in Table 3. This increase was due partly to the shortening of time lost from shut-downs and delays and partly because of the more uniform pumping speed. If to this were added the amount of oil saved which had been consumed as fuel, the total increase in production would be in the neighborhood of 40 per cent.

Several California men who have had considerable experience with oil well motors over a number of years are of the opinion that the more uniform pumping speed has a material effect in establishing better oil channels underground leading to the wells, and in keeping them more nearly free from sand and caving. This can reasonably be believed, and indicates the probability of a longer and more productive life of the wells, as well as less frequent necessity of cleaning them out.

LOWER OPERATING EXPENSES

Enormous waste and losses have long been as much a feature of oil production as large fortunes suddenly accumulated. They still remain so in many places, but to the average man of the fields they are much less evident, though far more general. It is really not so surprising that operating expenses are usually susceptible of extensive reduction, and that the use of oil well motors offers the means of obtaining remarkable results in this respect. This fact is well demonstrated by a few examples selected from numerous available records for pumping on the beam, which are given in Tables 4, 5, 6 and 7. It must be remembered that the greatly diversified conditions encountered in the oil fields cause a wide variation in the costs of operation, though these check closely for similar conditions. The depth of well, the production, the size of pump, the pumping speed, the distance between wells, the number of wells operated, the gravity of the oil and the amount of water pumped with it all have their influence. Some other results, taking into consideration only those items affected by the change to electric drive, such as fuel, water, labor, maintenance, and electric power, are given below.

The British Consolidated Oil Corporation, Ltd. (now the Indian & Colonial Development Co.) made a saving in excess of 22 per cent on 12 wells in the California Midway field.

TABLE IV

Comparative Costs of Gas-engine and Electric Operation of Wells Pumping on the Beam by a Large Oil Company in California

	PER WELL PER DAY	
	Gas Engine	Electric Motor
Labor, including pumpers, engine repair men and electricians	$0.893	$0.580
Fuel or electric power	0.000	0.800
Repairs	0.076	0.024
Lubricating oil, waste, packing and miscellaneous	0.186	0.038
Interest (7 per cent) and depreciation (10 per cent on engines, 4 per cent on motors)	0.509	0.263
Production lost from shut-downs on 50-barrel well, at 40 cents per barrel	0.586	0.014
TOTALS	$2.250	$1.728

Saving by electricity over gas, per well, per day	$0.52
Average saving per well per year	$189.80

NOTE.—These records were obtained prior to 1917, since when there have been large increases in the cost of several of the items.

TABLE V

Comparative Costs of Steam and Electric Operation of 68 Beam Wells by an Oil Company in California. Depth 800 to 1050 Feet. Gravity of Oil 14.5 Deg. B.

	Total per Month
Steam:	
Oil fuel at $1.23 per barrel	$17,650.50
Labor	2,527.00
TOTAL	$20,177.50
Electric:	
Power	$2,425.00
Labor	1,435.00
Interest, 6 per cent on cost of electrical installation	602.00
TOTAL	$4,462.00
Saving by electricity over steam, per month	$15,715.50
Average saving per well per year	$2,773.32

TABLE VI

Operating Costs of 15 Steam-engine [illegible] and 11 Motor-driven Wells Pumping on the Beam During the Same Period on the Same Property in California. Average Depth 1100 Feet. Gravity of Oil [illegible] B.

15 Steam Wells:	
Oil fuel at $1.23 per barrel	[illegible]
Labor, 6 firemen at [illegible]	[illegible]
Oil fuel at $1.23 per barrel [illegible] boiler feed water	[illegible]
Boiler repairs	[illegible]
TOTAL	$2,[illegible]
Cost per well per year	[illegible]
11 Electric Wells:	
Power	[illegible]
Repairs	[illegible]
TOTAL	[illegible]
Cost per well per year	[illegible]
Saving by electricity over steam, average per well per year	$1,914.42

NOTE.—The same pumpers and roustabouts handled both groups of wells. One boiler cleaner was employed for the steam wells and one electrician for the electric wells. Repairs are the average for 5 years operation.

TABLE VII

Comparative Costs of Pumping Eight Beam Wells by Steam and by Electricity in the Midway Field, California. Depth 1000 to 2800 Feet

Steam	Sept., 1912	Oct., 1912
Oil fuel at 50 cents per barrel	$469.00	$305.50
Labor	448.00	448.00
Water	449.99	457.83
Boiler compound, lubricating oil and grease	30.00	30.00
Totals	$1396.99	$1241.33
Average cost per well per year		$1978.74

Electric	Jan., 1913	Feb., 1913
Power	$340.00	$329.90
Labor	435.00	381.50
Water	71.00	53.90
Lubricating oil	17.50	17.50
TOTALS	$863.50	$784.80
Average cost per well, per year		$1236.22
Saving by electricity over steam, average per well per year		$742.52

NOTE.—Since these records were obtained there have been large increases in the cost of several of the items.

In the Coalinga field in California, one oil company installed motors on a group of wells and discarded twelve boilers, thereby making a saving of 63 per cent in operating expenses.

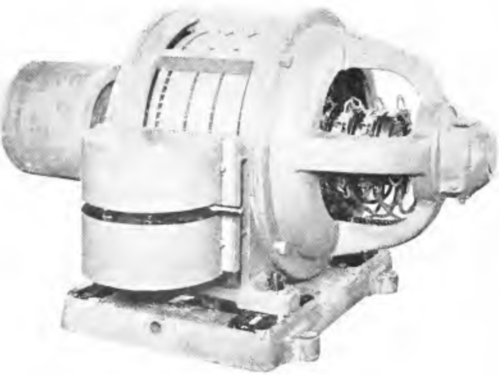


Fig. 1. 30/15-h.p. Two-speed Oil Well Motor for Pumping and Pulling Operations

The Salvia Oil Company (formerly the Wabash Oil Co.) in the Coalinga field could not produce enough oil, above that used for fuel, to pay operating expenses, and was thereby forced to suspend operations until two enterprising operators, recognizing the possibilities of electric drive, took over the property, installed motors on all the wells, and are now actually paying dividends.

Another company saved 24 per cent on 12 wells, and another 40 per cent on 107 wells.

Fuel

As oil wells usually require from 60 to 120 kw-hr. per day for all operations associated with pumping on the beam, reaching in exceptional cases about 200 kw-hr. maximum, it is clear that electric power at prevailing rates is much cheaper than oil fuel for steam operation. It may also be less than gas fuel where the latter has any market value.

Further important points with respect to fuel consumption are that with electricity there is no power consumption when idle, no fuel required to get up steam and no losses from leaky engine valves and piping. Losses from the last cause are well known to be considerable in the oil fields. Their worst feature is that they increase from year to year. Oil men not familiar with electric power will be interested to know that corresponding electrical transmission losses are not only very low but remain at a fixed percentage throughout the life of the equipment.

Labor

Down in Louisiana in the Jennings field there is a lease with 23 steam-engine-driven wells on which six firemen and four pumpers are required. Adjoining is another lease with 13 wells electrically operated. Power is generated on the lease. Two men at the power plant and one man at the wells keep things going and have an easy time of it. The condition is by no means exceptional.

The writer asked a pumper in the El Dorado field in Kansas how he liked motors.

Fig. 2. A Complete 30/15-h.p. Two-speed Oil Well Motor Equipment Installed by a Large Oil Company in Coalinga Field in California. Photograph Made Before Completion of Housing

They had been on his wells about a month. "Fine," he said; "I don't have anything to do. At first I was sore because the farm boss gave me a lot more wells to look after, but now they run themselves." Investigation proved the truth of what he said. The man had been busy all the time with gas engines, though with a smaller number of wells under his care. In general, one pumper can look after about 8 to 12 gas engines, 10 to 15 steam engines, or 15 to 20 motors, depending upon the distance he has to walk to reach them. One electrician can maintain the equipment where several gas-engine and boiler repair men would be necessary, and fewer firemen or none at all are required, according to the extent of electrification. This saving in labor has become very important since wages have increased, and in a number of instances has been the deciding factor for making the change to electric drive.

Water

The cost of either boiler feed water or engine jacket water runs high in many fields because of its scarcity. Even then the quality is bad for the boilers. This expense becomes a thing of the past after motors are put in, the saving alone in many cases being more than the cost of electric power.

Repairs and Lubrication

There are more than 2000 electrically operated oil wells which have been operating for periods of from 1 to 12 years at which the average repair expense on the electric equipment has not been 1 per cent of the first cost. In comparison, there are several hundred gas-engine wells which have operated not more than 4 or 5 years, at which the engine maintenance exceeds 11 per cent. For steam engines and boiler plants, 5 per cent is considered a low figure. The saving in expense for boiler tubes and compound, both high because of bad water, and the reduction in the amount of oil necessary for lubrication, contribute largely to the advantage of electric operation.

Only about 20 to 25 per cent of the investment necessary for a stock of repair parts for gas engines is required for motors, both because of the much lower rate of depreciation and of the fact that there are fewer parts to wear out.

Fig. 3. Another View of the Same Installation Shown in Fig. 2

OTHER ADVANTAGES

In several more respects motors are a big improvement for oil well work, the following being worthy of mention:

Fig. 4. A 30/15-h.p., Two-speed Oil Well Motor Showing General Arrangement Used by the Associated Oil Co., in the California Fields

Safety

Greater safety of operation is obtained, as the motor cannot run away when the rods part.

Explosions are eliminated and the fire risk greatly reduced, thus lowering insurance rates.

Accidents are fewer. One company in the Mid-Continent fields found from an analysis of accidents to its employees that one third resulted from the necessity of "treading" the flywheels of gas engines to start them. These could not have happened with electric drive.

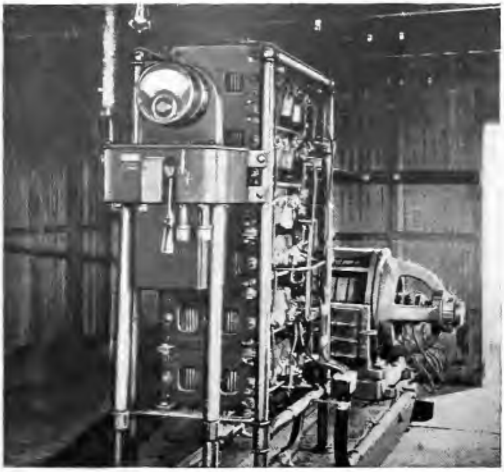


Fig. 5. An Installation by the Carter Oil Co., in the El Dorado Field, Kansas, of a Complete 30 15-h.p., Two-speed Oil Well Motor Equipment

Reliability and Convenience

As the speed of an oil well motor is practically independent of voltage fluctuations, the motor can always be depended upon to give the same speed on the same controller point for similar load conditions.

A much better motion of cleaning-out tools is produced by a motor than by a gas engine. In this respect it is like a steam engine.

Electric control is very simple, having no reverse lever or clutch pulley. Power is always ready at a turn of the controller, which is handled from the headache-post in the same manner as an engine throttle.

The power consumption of a motor can be quickly and accurately measured, and thus indicates both the condition of the well and the most advantageous operating conditions from the standpoint of cost.

Motor equipments are cleaner and quieter than engines. The belts and motor house can consequently be kept cleaner and there will thus be less rapid deterioration of the rig.

OIL WELL MOTOR EQUIPMENTS

The success of electric oil well operation has in no small measure been due to the simplicity of the induction motor and its ability to withstand hard usage and to run continuously in exposed locations and under severe conditions. To these considerations must be added the fact that the motors are built with the mechanical strength and overload capacity necessary to withstand oil field service.

Different types of equipments are used for drilling and for pumping. Drilling requires motors of larger capacity than are necessary on producing wells, and the method of control is somewhat different. It is, therefore, advisable in all cases to use separate equipments exclusively for drilling, and, as each well is completed, move the motor and control apparatus to the next new rig and put in a pumping motor as a permanent installation. The pumping equipments are therefore required in much larger numbers and are of first interest to the producer because of their direct effect on production and costs.

MOTORS FOR PUMPING, PULLING AND CLEANING THE WELL

Motors for Beam-wells

Oil men generally prefer all of the operations in connection with pumping, pulling and cleaning a "beam" well to be performed by one motor, as with engine drive. This is done by the two-speed oil well motor, with both speeds variable (Fig. 1), for which the method of control has been specially designed to satisfy the oil operator in every way. That it does so, and that many of the advantages of this type of equipment cannot be satisfactorily obtained by other means, have been conclusively demonstrated during several years' experience in the fields. The motor is built in three sizes to take care of all conditions of wells. Figs. 2 to 7 inclusive illustrate modern installations in both California and the Mid-Continent fields, and Fig. 8 shows more clearly a convenient method of mounting the apparatus on skids.

The Two-speed Feature

The motor has a wound rotor for variable speed, the latter being obtained by means of a controller and secondary resistor in the same way as with the standard type of varying-speed induction motor used in other industrial work. The oil well motor differs from the standard motor, however, in having two synchronous speeds, one of these being a low speed suitable for pumping a well, and the other a high speed, double the low speed, for pulling, bailing, "shaking up" and similar work. On the high speed the motor gives the right motion to swing a light set of drilling tools for cleaning-out purposes. The change from the pumping to the pulling speed and vice versa is made by a switch mounted on the motor frame. Both speeds are variable and reversible by the controller and resistor. The controller is always mounted near the motor, as will be seen, for instance, in Figs. 2 and 3, and is operated from the headache-post by means of a "telegraph cord" in the same manner as an engine throttle. As has already been mentioned, no [illegible] is required, hence less effort is required of the operator in controlling the motor [illegible] and he can give better attention to the [illegible] well.

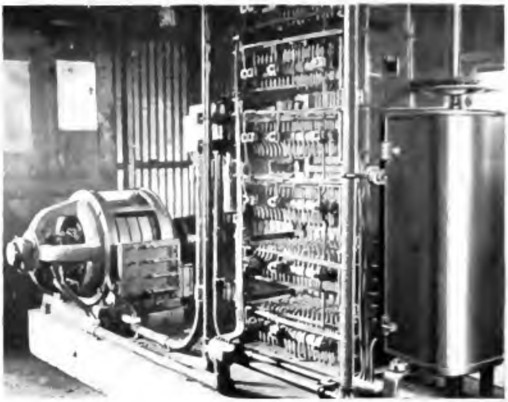


Fig. 6. One of the 30 15-h.p., Two-speed Oil Well Motor Equipments of the Empire Gas and Fuel Co., in the El Dorado Field, Kansas

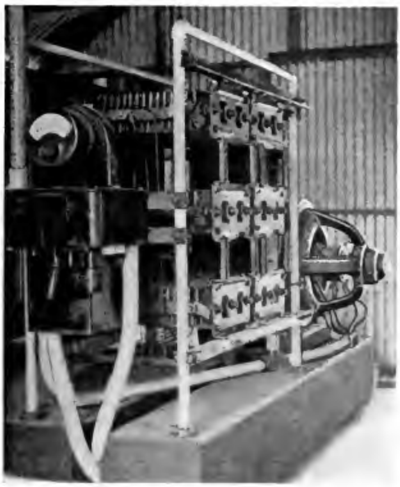


Fig. 7. Oil Well Motor and Control Apparatus on a Lease of the Gladys Belle Oil Co. Near Tulsa, Oklahoma. This is a 30 15-h.p. Two-speed Equipment

Deficiency of Y-delta Motor

In the early days of oil well operation by motors it was recognized that because of the much lower horse power required for pumping than for pulling, an improvement in efficiency would be obtained by using a motor with two different horse power ratings. Such a motor was accordingly produced, and it became known as the "Y-delta" type on account of the method of change in motor connections by a double-throw switch to obtain the two ratings. This motor, however, had only one variable speed at both horse powers, which was a great disadvantage in the fields. For good efficiency, full speed operation was necessary. Naturally this was desired for pumping, hence pulleys were usually selected for that condition. Then when the well was pulled, the speed of the band-wheel was entirely too slow for practical purposes, as it delayed getting the wells back to production, with resulting loss to the producer. Some operators tried running the motor at full speed for pulling, getting a better band-wheel speed by suitably selected pulleys, and then slowing it down for pumping by means of the controller. This not only did not enable them to get all the speed they wanted for pulling or shaking up the well but, worst of all, it immediately resulted in greatly increased power bills, thus showing up the great waste of power when pumping in this inefficient manner.

The expedient was then tried of pumping at full speed with the Y-delta motor and lagging up the bull-wheel shaft to about twice the standard size to obtain high pulling speed.

Fig. 8. This Method of Mounting the Entire Electrical Equipment on Skids is Used Extensively for Oil Wells in the Mid Continent Fields

Of course this did not bring up the bailing speed on the sand-reel or enable any shaking-up to be done, and the scheme was abandoned because for relatively deep wells the strain thus put on the bull-rope and gudgeon posts was so great that the former could not be kept tight enough to prevent slipping, and the latter in several instances were actually pulled out.

One other method of adapting the Y-delta motor to these conditions, which was attempted but which failed to solve all difficulties, was that of changing pulleys for pulling. It was such an irksome job that the pulling gang could not be relied upon to continue it, and it always caused loss of production from delay. This method was not successful for shaking-up the well, for by the time the motor had been shut down long enough to change the pulley the well had usually sanded up and required an entire pulling job, with more loss in production.

As the Y-delta motor thus failed under all expedients to perform the necessary functions in a satisfactory manner, the two-speed oil well motor with both speeds variable has superseded it, and fulfills all the requirements without any change whatever in rig or pulleys, and with a very economical expenditure of power.

Other Features of Two-speed Motor Control

The equipment is provided with a wall-mounted oil circuit breaker with inverse time limit overload trip coils and under-voltage release. If desired the motor may be protected on the pulling as well as on the pumping duty, for double-wound overload trip coils are used. These coils are so interlocked with the switch on the motor that automatically the proper coil is connected into the circuit. It is thus impossible for the operator to make an error and insert the wrong overload coil for either pumping or pulling duty. The inverse time limit feature gives protection in proportion to the amount of overload, automatically opening the circuit breaker sooner in case of extremely heavy load than when a lighter one is encountered, and thus giving the operator the benefit of the high motor capacity as long as the motor can safely carry it without injurious heating. The under-voltage release mechanism automatically trips open the oil circuit breaker in case of failure of voltage.

To prevent any accident occurring because of the "telegraph cord" breaking, the equipment may be provided, if desired by the operator, with a push-button mounted on the headache-post. This will open the under-voltage release circuit and thus trip open the oil circuit breaker.

In the manipulation of rods and tubing the quickest reversals and the highest torque of the motor—that is, its greatest ability to

Fig 9 Twenty-h p., Portable Motor Equipment for Pulling Oil Wells at the Badger Oil Co., Hosston, La.

pull—are obtained on the intermediate controller points. It is possible to equip the controller with a "current-limit" device that will automatically compel the operator to stop it at the most advantageous point until the motor has gained some speed. This is useful in teaching him how to handle an oil well motor, and furthermore it reduces the average current input while reversing, thus lowering the operating temperature of the motor.

Another refinement used with good results by many oil companies is an ammeter mounted on top of the oil circuit breaker and arranged for connection in circuit on pumping duty but not for pulling. This instrument makes it possible to tell whether the walking-beam is perfectly counterbalanced and also gives the operator an indication of when the well begins to sand up.

Motor Capacity

The size of machine for any particular well depends to a large extent upon local conditions and methods of operation, rather than upon the depth of the well alone, and for this reason these things are necessarily taken into consideration in every case. For instance, the heating of the motor on heavy work does not depend so much upon the torque required as it does upon the frequency of reversing the motor, and this is largely governed by the operating methods, which vary in different fields.

In general, experience has shown that a 30-h.p. motor rated 15 h.p. on the pumping speed (Fig. 1) is the size suitable for the great majority of wells. Sometimes where the depth is under 2000 feet or the duty is light a 25/10-h.p. motor will do the work, but on any lease requiring a 30/15-h.p. machine it is advisable to use this size on all wells for the sake of standardization and to keep the repair part stock to a minimum. Very deep wells may require a 50/20-h.p. motor.

Fig. 10. Portable Electric Hoist Used for Pulling and Cleaning Jack-wells in the Kern River Field, California

The power input for pumping will vary from day to day and even from hour to hour, and may increase considerably in a short time when the well is sanding up. For this reason the motors are given liberal rating for pumping. For handling rods and tubing the motor may be required to deliver very high power for short periods, especially in emergencies and on some of the special operations, swabbing for example, which are occasionally necessary to maintain the well as a good producer. Although such loads are several times greater than the pumping load, they are easily handled by these motors because of their enormous overload capacity on high speed, this being from $3\frac{1}{2}$ to 5 times the rating for pulling, or 7 to 10 times the rating for pumping.

Separate Motors for Each Duty

A few operators have placed a motor of small capacity at each well for pumping only, and use a portable motor (Fig. 9) or motor-driven hoist (Fig. 10) for pulling and bailing. This can be done, if desired, where conditions do not require very frequent pulling of the wells, and their spacing or the character of the country make pumping by jack power impracticable. In such cases squirrel-cage or varying-speed motors with control for reversing are used for pumping, and a high torque motor with variable speed is necessary for pulling.

Usually, however, the cost of the portable hoist, with wagon and team or a truck, together with the expense for necessary plug connections for each well, bring the investment up close to that for a two-speed oil well motor at every well.

Mechanical Arrangement for Beam Wells

The use of a motor belted to a countershaft, the latter belted to the band-wheel, has become universally standard practice for beam-wells, and all modern equipments are thus arranged. In the case of wells having a steam or gas engine already installed but of no further use, the engine has often been used as a countershaft, disconnecting the connecting-rod and putting pulleys on the shaft. A cheap and substantial pulley has been made by lagging the flywheel with wooden sections bolted to it.

The use of back-geared motors, tried several years ago, is no longer considered desirable by oil men, and the arrangement has been discarded in present practice.

Counterbalancing Beam-wells

The ease of measuring the power input to an electric equipment by a meter has directed attention to the reduction in the amount of power required to pump a well obtained by counterbalancing the weight of the rods on the beam. This relieves the motor of the necessity of hoisting the full weight of the rods on each stroke. The reduction in power is considerable, varying with local conditions from 8 to 22 per cent, and averaging about 15 per cent. Fuel consumption can therefore be materially decreased by installing a counterbalance on each beam-well, regardless of the method of drive.

Fig. 11. A 35-h.p Motor-driven Bandwheel "Power" for Pumping 32 Wells in Kansas

Rod breakage is another condition which is being improved by counterbalancing. The uneven motion of the engine, particularly of the gas engine, due to its inherent method of action as well as to its unbalanced load, causes the rods to be picked up with a jerk, and the vibration thus produced is the cause of much of the rod breakage with which every producer contends. Counterbalancing the beam has proved to be the means of greatly reducing this in many instances in the California and Mid-Continent fields, and is thus resulting in a direct saving in oil production ordinarily lost by the shutdowns occasioned by breakage.

The counterbalance is believed to be indirectly a valuable means of reducing the amount of waste emulsion in wells having considerable water. It is generally recognized that the emulsion is caused by the churning action produced by damaged or leaking cups and valves, and this damage is no doubt largely due to the jerks and vibration mentioned above. The value of the counterbalance in reducing this content therefore lies in its ability to smooth out the pumping motion.

Fig. 12. The Type of Counterbalance on This Motor-driven Well of the Empire Gas & Fuel Co. in the El Dorado, Field, Kansas, is Frequently Employed

The use of a counterbalance is recommended on every motor-driven rig. Its cost is nominal. One type is illustrated in Fig. 12 but that which is considered the best of any of the various types in use is shown in Fig. 13. The weight itself is a concrete block, supported from an extension of the walking-beam by a stirrup which may be moved to change the leverage and thus obtain the best adjustment. Suitable guides are used to prevent the block of concrete from swinging from side to side. This method of support makes the weight 100 per cent effective, which is not the case with counterbalances consisting of a heavy weighted piece of timber with one end resting on a post in the ground.

Motors for Jack-well Pumping

Wells pumped by jacks and operated in groups from a central "power" can be electrified at a comparatively low cost per well.

A countershaft is placed between the motor and the "power" and usually carries a friction clutch for starting the wells after the motor has been brought up to full speed. The use of such a clutch on every installation is desirable, as it relieves the motor of heavy starting duty and thus enables a standard squirrel-cage motor to be used, whereas otherwise it would be best to put in a slip-ring motor to make it

Fig. 13. This Concrete Counterbalance Was First Used by the Cosden Oil & Gas Co. at Shamrock, Okla., and is Considered the Most Effective Design Now in Use

possible to start the wells slowly and thus prevent breaking the shackle rods. The complete equipment is very simple. Fig. 11 shows an installation of this type. When the wells are cleaned a portable hoisting equipment is employed, such as in Fig. 10.

The power required for pumping wells by this method is affected not only by variations in the depth of the well, [illegible] the fluid rises in the well, the [illegible] oil, the diameter of tubing, the [illegible] pumping, and the general condition of the wells with respect to sand, gas and [illegible] content, but also depends considerably on how well the wells are balanced against each other. Therefore, the use of an ammeter in the motor circuit is desirable to tell [illegible] exactly.

Fig. 14. Fifty-h.p. Oil Well Drilling Motor Operating Standard Cable-tools at Well No. 3, Midway Pacific Oil Co., Fellows, Calif.

MOTORS FOR DRILLING

Cable-tool Method

The standard type of varying-speed induction motor with wound rotor (Figs. 14, 15 and 17) is the best machine for drilling, the required range in speed being obtained by resistance in the rotor circuit, as with the pumping motor, but a two-speed feature is neither necessary nor desirable. An auxiliary controller provided in addition to the main controller gives the very fine adjustment of speed required in cable drilling to make the movement of the beam accord with the natural period of vibration of the drilling line.

The main controller alone gives ten points of control; the auxiliary controller cuts in eight additional control points between any adjacent points on the main controller. This results in a total of 88 points, which are sufficient to obtain the correct speed at all times without danger of deadening the movement of the drilling bit and endangering the line and beam by overstraining them. The two controllers are operated independently from the headache-post (Fig. 16) and govern both forward and reverse operation.

Other methods of obtaining variable speed by special designs have been tried on this work, but the advantages gained, if any, were not sufficient to warrant the increased cost of apparatus or the additional attention and expense necessary to maintain it in good operating condition. Simplicity of operation is a strong point in favor of the equipment now standardized for this service, since the various drilling operations follow so closely upon each other that the driller cannot be put to the inconvenience of throwing switches or shifting clutches each time, particularly when entirely satisfactory results can be obtained without going to such trouble.

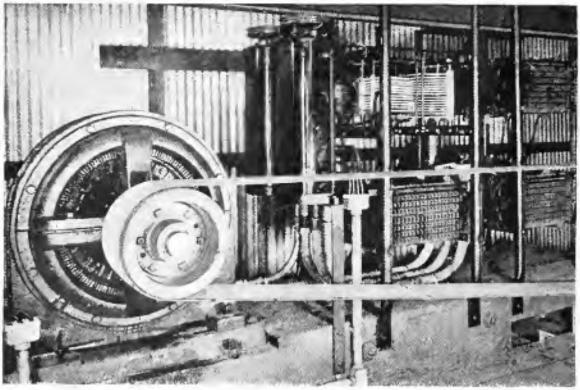


Fig. 15. A 75-h.p. Oil Well Drilling Motor and Complete Control Equipment Used for Cable-tool Drilling by an Oil Company at El Monte, Calif.

In cable drilling the beam must overspeed and allow a "free drop" of the tools on the down-stroke to get the most effective blow, and to accomplish this the motor must slow down on the up-stroke and speed up on the down-stroke. This characteristic is very satisfactorily obtained with the drilling motor by so proportioning the pulleys that some secondary resistance will be in circuit when the motor is operating at the correct drilling speed.

With electric drilling it is customary to insert an ammeter in the motor circuit and mount it where it can be easily seen by the driller. This gives him an accurate indication of the amount of strain he is putting on his casing.

Rotary Method

The same type of motor used in cable drilling is well suited for driving the rotary table and draw-works and also the slush-pump. Variable speed is needed in both cases, and although a single controller for each motor will prove satisfactory, some operators have put in a standard cable-tool outfit for the rotary drive so that it would be available to finish up the well with cable-tools when the oil sand was reached.

Motor Capacity for Either Drilling Method

The power required in drilling an oil well varies considerably for the numerous operations. Drilling itself is a fairly steady load on the motor, while the other work, particularly the manipulation of casing, is heavy and very intermittent in character. Drilling motors can exert a very heavy torque or pulling effort, and their ability to do so in an emergency is often the means of freeing a string of "frozen" casing which might otherwise have to be "landed" in the hole, thus necessitating drilling being resumed with

Fig. 16. The Two Handwheels on the Headache-Post at the Left Control This Motor-operated Cable-tool Drilling Rig at the Reward Oil Co., Reward, Calif.

a smaller string. The high torque capacity is of particular value in such operations as "spudding" casing and loosening stuck tools, and in rotary drilling it is a necessity in handling the drill pipe as well as the casing.

For the standard sizes of cable-tool and rotary rigs and tools now used in the United States, a 75 h.p. machine has been found to have sufficient capacity for all requirements in drilling wells much over 2000 feet in depth. For more moderate depths 50 h.p. may be sufficient. Local conditions must be considered in any specific case. In some foreign fields motors as large as 150 h.p. are used because of the different type of rig and methods of operation employed.

On a rotary rig it is an advantage to use on the slush-pump a motor which is a duplicate of that for drilling, as fewer spare parts are then required.

Mechanical Arrangement

The use of a belted countershaft, as shown in Fig. 14, is the accepted standard method of drive for cable-tool drilling as well as for pumping.

On account of the heavy strains to which the equipment is subjected, back-geared motors cannot be recommended for this service. A few installations have been tried using a two-speed or three-speed change-gear countershaft to obtain more economical speed variation, but they have all been discarded because of their rapid depreciation under the severe service. Furthermore, the operators generally failed to make use of the device because of the time and trouble involved. Experience has shown that the plain countershaft drive and the main and auxiliary control are satisfactory in giving all necessary speed changes.

For rotary drilling also a countershaft is needed. It is advisable to use chain drive between this and the rig as this [illegible] adapted to the usual mechanical arrangement of the draw-works, but the motor should be belted to the countershaft so that it [illegible] used for cable-tool work if necessary.

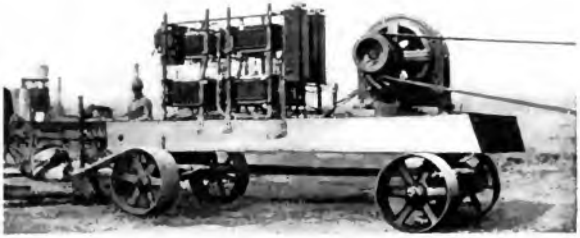


Fig. 17. The American Petroleum Co. at Coalinga, Calif., Uses This Portable Arrangement for Their Standard 75-h.p. Oil Well Drilling Motor and Control Equipment

In order to facilitate moving the drilling motor from one rig to another, a number of the operators have mounted the equipment on a heavy wooden block provided with axles so that wheels may be put on when it is moved. In one or two instances the wheels are not removed when the motor is put in drilling service, but the truck is held in position by means of struts. (See Figs. 17 and 18.)

Fig. 18. The Bank of Transformers Used for the Drilling Motor Shown in Fig. 17

Fig. 19. A 1900 ft. Well of the Midway Pacific Oil Co. at Fellows, Calif., Drilled Entirely by Electric Power

TRANSFORMERS

If an oil company purchases its own transformers, the cost of electrification is of course lower when an entire group of wells is equipped with motors, as one bank of transformers can be put in to supply power for all. Less transformer capacity is then needed, as only enough extra capacity must be put in for pulling and cleaning one or two wells simultaneously. If separate banks of transformers were used for each well they would all need to be sufficiently large for pulling and cleaning duty. The number of wells that can be operated from a single bank will depend entirely upon their relative grouping and the amount of power required to pump each one.

For drilling work it is the best practice to use a separate bank of transformers for each motor. They may be mounted on the ground near the motor, thus shortening the heavy secondary lines and making it more convenient to move the transformers from rig to rig, or the method illustrated in Fig. 18 may be used.

If it is preferred to mount them on poles, a good method is shown in Fig. 19. This is customary for permanent installations and enables the transformers to be handled readily from a truck directly underneath, thus facilitating repairs and replacements. High-voltage lines can thus be kept well away from the derrick, rigs and buildings.

LIGHTING

Electric lighting has been extensively adopted for oil field work and it renders drilling by night in gassy territory much safer than it has ever been before. On producing wells the advantage of a safe light about the rig at night needs no emphasis. The various motor-operated rigs shown in the illustrations are all electrically lighted.

Fig. 20. This Group of Wells in the California Midway Field Has Been Electrically Operated for Several Years by the Fuel Oil Dept. of the Southern Pacific R.R.

Electrification of Paper Mill Finishing-room Machinery

By W. T. Edgell, Jr.

Power and Mining Engineering Department, General Electric Company

The consumption as well as the cost of paper have advanced so rapidly during the pa[illegible] paper manufacturers are being enforced to study thoroughly the possibilities of increasing pro[illegible] reducing costs. The author in the following article points the way to a number of econom[illegible] worth serious consideration.—Editor.

The application of electric drive to the various machines used in the manufacture of paper has increased so extensively during the past decade that practically all new mills are electrically equipped throughout. Many of the older mills manufacturing book, magazine, glassene, writing, and other papers requiring special finishes, have found it to their advantage to change over to individual electric drive especially in the finishing rooms. Generally speaking overhead belt drives tend to shut off the light and are noisy, both of which features are undesirable from the view point which considers the health of the operators and the quality of their work. Furthermore, overhead belt drives are always liable to drip oil which is particularly objectionable when working on finished paper. The heavier line shafting with driving pulleys under the finishing room floor takes up a large amount of space which could be used for storage or for direct manufacturing purposes.

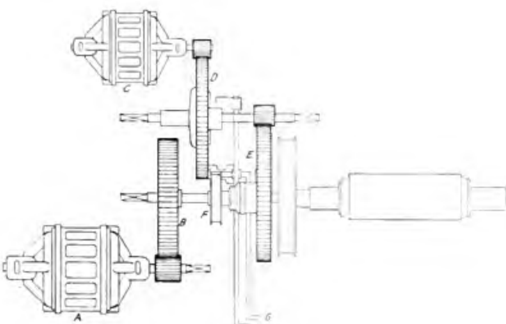


Fig. 1. Mechanical Arrangement of Two Motor Super-calender Drive, Using Mechanical Clutches

Where individual electric drive is used for each machine, the finishing room may be so laid out as to permit of the most convenient arrangement of the machinery; and in addition the room will be lighter, less noisy, and much cleaner than it would be with mechanical drive. Furthermore, the operations of the several machines in a finishing room are necessarily intermittent and independent of each other and therefore a considerable saving in power is effected by the elimination of a long line of shafting, pulleys, and belts. There is also a corresponding decrease in the maintenance costs.

The largest power consumers in a finishing room are the web super-calenders. These machines are used to give a smooth finish to paper by passing it under very heavy pressure between alternate rolls of highly polished iron and highly compressed paper or cotton. The iron rolls are hollow and may be heated. The paper is sometimes passed over a steam jet which dampens it and then between the two upper rolls and down through the stack of alternate paper and iron rolls. The degree of finish is determined by the dampness of the paper and the pressure of the rolls. Tests show that the power consumption at 500 ft. per min. paper speed varies from 0.7 to 2 h.p. per inch width of roll. The super-calender requires approximately constant torque and therefore its power requirements vary directly as the paper speed.

The principal factors which determine the motor sizes are the maximum paper speed, width of roll, number of rolls, weight and kind of paper and the finish desired. For instance, super-calenders finishing coated papers require less power than super-calenders used to finish a heavy rag paper; and light bond papers require considerably less power than heavy map or chart papers. Information on all of these points is desired in laying out super-calender drives.

The essential requirements of a good super-calender drive are a constant threading speed between 30 and 50 ft. per min., very smooth acceleration from threading speed to maximum running speed, ability to speed up or slow down smoothly and rapidly as occasion requires and to stop quickly in order to shorten delays and lessen the waste due to breaking of the paper.

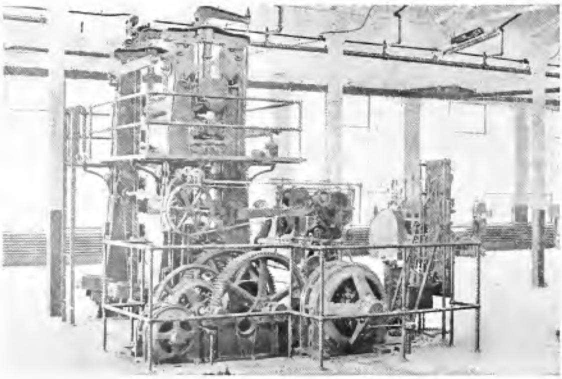


Fig. 2. Phase-wound Main Motor and Squirrel-cage Threading Motor, Driving 50-in., 9-roll Stack Paper Calender, Strathmore Paper Co., Woronoco, Mass.

With super-calenders which are belt-driven from line shafts only two speeds are obtainable, the threading speed and the maximum speed. These speeds are fairly constant if the prime mover is equipped with a good governor; but, in many mills having ungoverned waterwheel drive for the entire mill, the speed is a very uncertain factor. Because there is no adjustment of the running speed to suit different grades of paper, the calender must be driven at an average speed seldom over 400 to 500 ft. per min. which results in a production loss when compared with the speed obtainable by motor drive. The ability to accelerate smoothly from slow speed to running speed depends largely upon the condition of the friction clutch. If this clutch is worn, the calender is jerked and jarred which results in damage to the rolls and a considerable loss in production, both wastage and time due to paper breaks.

The application of individual motor drive to these super-calenders permits of very smooth acceleration, and of such speed control that the operator may quickly slow down for breaks or weak spots in the paper. Therefore it is possible with motor drive to super-calender fine papers at 700 to 750 ft. per min., and at the same time to permit super-calendering of the various grades of paper at any speed down to one half of the maximum. The use of push-button control reduces the danger hazard for the man who is handling the paper as it enables him to start or stop the machine from as many points about the machine as may be desired. It also permits him to stop the machine quickly in emergencies. Furthermore, this type of control saves the time that would otherwise be lost in climbing about the machine to reach a single control station.

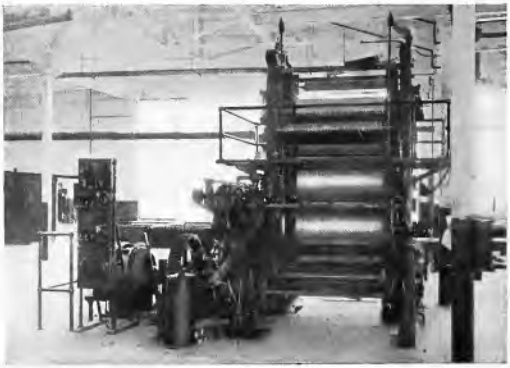


Fig. 3. Arrangement of Driving Motor, Controller, and Contactor Panel for 9-roll Stack Paper Calender, Strathmore Paper Co., Woronoco, Mass.

Various motor drives have been developed to meet conditions existing in particular mills, but in general the two-motor alternating-current drive is the most satisfactory arrangement. There are two main modifications of this type of drive, but in both cases the main motor is of the wound-rotor type while the threading motor has a squirrel-cage rotor and is selected to develop sufficient starting torque to start the super-calender from rest with the weights on.

Fig. 1 shows the mechanical arrangement of the first type. Fig. 2 and 3 are from photographs of such an equipment. In starting the oil switch on the panel is first closed; and then a push button is pressed to close the contactor and start the threading motor which drives the calender through the friction clutch *D* and the gear *E*. After the paper has been threaded through the calender, the operator starts to turn the controller handle. At the first point the main contactor is picked up, and as the handle is turned further the motor smoothly accelerates the calender to any desired running speed between 50 and 100 per cent of normal. When the large motor starts to drive the calender at a rate faster than the threading speed, the pin clutch in the gear *E* mechanically disconnects that gear from the roll shaft. The threading motor is then used to raise or lower the reel and weights and to drive the oil pump. The operator easily controls the calender speed through the controller, slowing down for weak spots and breaks. In the equipment shown in Fig. 3, the mechanical brake is released by a trip coil operated through a push button; but the equipment may be provided with a plugging resistor in the primary circuit of the main motor which will brake the calender when the "brake" button is pressed. Of course any desired number of these push-button stations may be mounted at convenient places about the calender, making it possible to start the threading motor and calender when the clutches are properly set, or in any case to stop either motor and apply the brake, from any of these stations. Overload protection is provided by relays for each motor and the control is so wired that it is impossible to start the large motor unless the controller handle is first brought to the "off" position. An ammeter is generally included to indicate the current input to the main motor. With a given speed and weight of paper, the ammeter indication will always be the same and may therefore be used by the operator as a check on the weights.

A development of this drive which eliminates the hand operated clutches and makes the equipment more completely automatic is shown on Figs. 4, 5, and 6. In this arrangement the threading motor drives the super-calender at slow speed through the

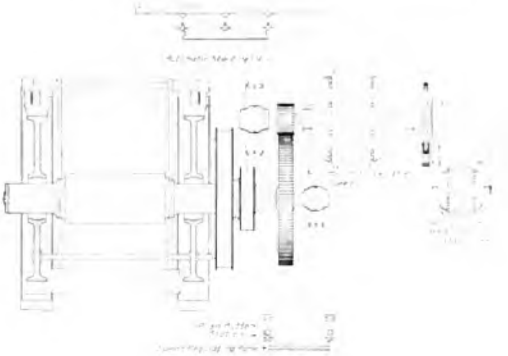


Fig. 4. Automatic Super-calender Drive for Paper Mill

ratchet clutch. When the large motor reaches a speed faster than that at which it is being driven by the small motor, the pawls on this clutch fly out, mechanically disconnecting the small motor from the super-calender. The pawls reset themselves when the motor is stopped or drops to threading speed.

The push-button stations contain three buttons marked "slow," "fast," and "stop-brake." When it is desired to start the calender the operator pushes any "slow" button which starts the small motor and drives the calender at threading speed. When the paper has been threaded through the stack, he presses the fast button and the motor then automatically accelerates at a uniform rate to the predetermined running speed. The running speed may be adjusted at any value down to 50 per cent of normal by turning the handle of a dial-switch speed regulator which has 36 regulating points. If it is desired to use only 25 per cent speed reduction for regulation, a section of the switch and resistor may be used to slow down the motor to a very low speed to take care of occasional weak spots in the paper. The motor acceleration to the speed determined by the setting of the rheostat is entirely independent of the operator. Pushing any "stop" button stops either motor which is running and a further depression of this button will automatically brake the large motor and stop the super-calender without loss of time. With this equipment, the super-calender is absolutely under the control of the operator at all times through the push-button stations which may be located at as many points about the machine as considered advisable. When desired, the regulating rheostat may be motor operated which provides a full automatic equipment operated entirely by push buttons.

The descriptions given have dealt with alternating-current equipments because the large majority of paper mills have only alternating-current power, but practically the same operating characteristics are obtained with outfits using direct-current motors.

Reference to Fig. 7 will show the difference in operating efficiencies of alternating-current and direct-current drives. The curves were drawn by plotting the horse-power inputs of 75-h.p. 300/600 r.p.m. alternating-current and direct-current motors against speed; and for any given speed the ordinate to the corresponding curve represents the horse-power input to the main motor. The horse-power input to the super-calender is indicated by the ordinates to the straight line.

It will be seen from these curves that both the alternating-current and the direct-current motors have practically the same operating efficiency at full speed. The alternating-current motor has a wound rotor with external resistance in the rotor circuit and with a constant-torque load requires a constant input regardless of the speed. The direct-current motor is designed for a 100 per cent increase in speed by field control and therefore the horse-power input within this range drops proportionally as the speed is lowered since the torque remains constant, except for a slight change in motor efficiency. The direct-current motor is however a much larger machine than the alternating-current machine because, in this case where a 50 per cent speed reduction is required, its basic speed is 300 r.p.m. against a synchronous speed of the alternating-current motor of 600 r.p.m. If a motor-generator set must be used to supply

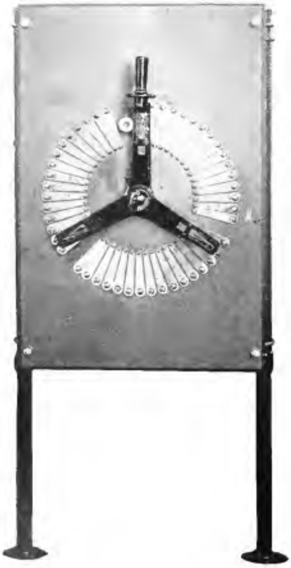


Fig. 5. Speed-regulating Panel Used with Paper Calender Control

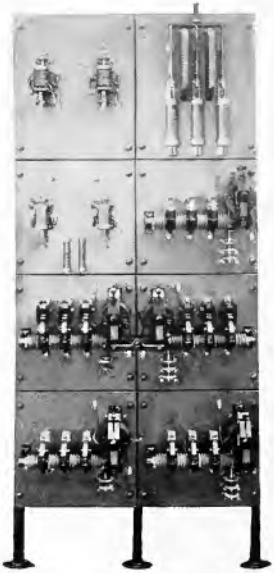


Fig. 6. 4-point Acceleration Automatic Predetermined Speed Paper Calender Controller

the direct current, the losses in this set must also be considered. In such case, the operating efficiency of the combined set and direct-current motor at maximum speed is much lower than that of the alternating-current motor alone, and it remains lower for all speeds down to approximately 81 per cent of the maximum from which point it is better than that of the alternating-current motor. If the calender is to be operated at the maximum speed only on rare occasions and generally is to be operated at a speed range from 50 to 75 per cent of maximum, the direct-current equipment even with a motor-generator set is the more economical although the first cost is higher. Below 50 per cent speed, or the full-field point on the motor, the total input will be practically constant down to low speed if the set voltage is maintained constant. The input to the threading motor will be practically the same for either alternating-current or direct-current equipments.

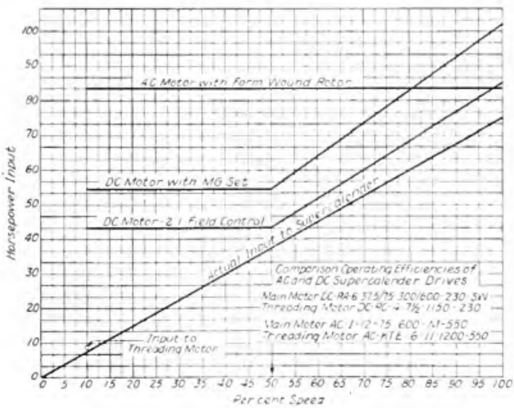


Fig. 7. Curve Showing Comparative Efficiencies at Various Speeds of A-C.-D-C. Super-calender Drives

Single motor drives, whether alternating-current or direct-current, are not generally recommended unless the speed changes are obtained by mechanical means. [illegible] percentage speeds required for threading the motor speed are very unstable and [illegible] variations in the torque requirement of the

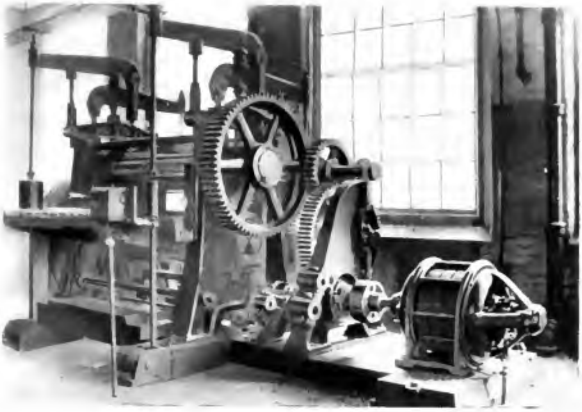


Fig. 8. 15-h.p., 600-r.p.m., 550-volt Phase-wound Reversing Induction Motor Driving Plater

calender produce large variations in speed. In both cases, assuming but a single voltage and frequency available, the speed is reduced to that required for threading by inserting resistance in the armature circuit of the motor. This means an input to the alternating-current motor equal to that required at full load, and an input to the direct-current motor at least equal to the input at basic speed. Since super-calenders are generally operated at threading speed from 15 to 25 per cent of the time, the loss of useful power in such case is appreciable.

There are certain conditions under which single motor drives will prove satisfactory. For alternating-current systems, double frequency is sometimes recommended where there are a large number of super-calenders. In such case for instance, the motor operates at running speeds from a 60-cycle circuit and for threading speeds from a six or seven-cycle circuit. Such an arrangement requires a frequency-changer set to furnish the low frequency supply; and because the voltage must also be decreased (in this instance to about 20 per cent of the 60-cycle voltage) the cost of the frequency-changer set makes the arrangement uneconomical unless there are a large number of calenders and advantage can be taken of the load-factor.

Where a direct-current power supply is available, it is sometimes advisable to use a

Fig. 9. Reversing Contactor Panel for Use on Plater Drive

single adjustable-speed motor with a double-voltage control system. If a motor arranged for 100 per cent speed increase by field control is operated at running speeds from a 230-volt circuit for instance, it will require from 50 to 55 volts across the armature at threading speed. This generally means a motor-generator set to provide the lower voltage. In either the double-frequency or double-voltage systems the control can be made automatic; and the smoothness of acceleration, the accuracy and dependability of the control will be of the same standard as that described for the two-motor equipments. In certain cases, where a large number of super-calenders are installed these single-motor drives are economical, but of course they must be laid out for the special conditions involved.

With any of the geared drives which have been described a Fabroil pinion is used on the large motor to reduce the noise to a minimum.

Sheet calenders do not present any special problems from a driving standpoint. They are generally driven at a constant speed, although in some cases where different grades of paper are finished provision is made for about 25 per cent reduction in speed to accommodate the various papers. No provision is made for threading speed as the sheets are guided through the rolls at full speed by cloth bands. The maximum speed of a sheet calender is limited by the speed at which the operator can feed in the unfinished sheets.

Squirrel-cage and wound-rotor alternating-current motors or direct-current motors are generally geared direct to the driving roll of the calenders. The power consumption will vary between 0.5 and 0.7 horse power per inch of face.

Platers are used to produce linen effects and other special surfacings. The sheets are built up in a book by placing them between zinc or other smooth metal plates if the surface is to be smooth plated or between sheets of linen or other material which will impress the surface desired. This book is passed between the heavy rolls of the platers thus impressing the desired finish on the paper. Plater drives must be particularly rugged since they are called upon to reverse the heavy plater rolls when these are under very high pressures. The three most common methods used are the belt drive with reversing pulleys, the hydraulically operated gear reversal driven by an induction motor, and the reversing motor drive. So far as the

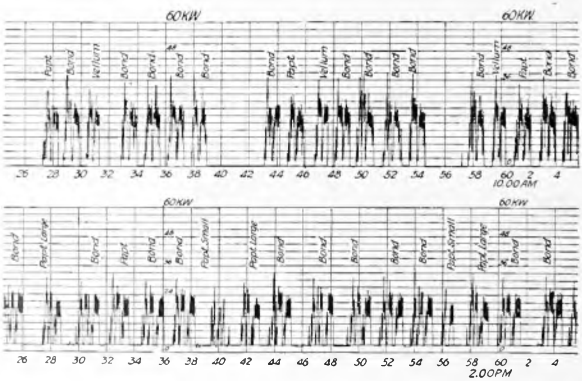


Fig. 10. Comparative Tests on Platers, the Upper One Showing Results Obtained with Alternating-current Motor Direct Connected to Plater Shaft. The lower chart shows result of test obtained with old belting device

motor is concerned, the first two methods require no special consideration. The reversing motor drive shown in Fig. 8 is a very simple, rugged, compact, and economical equipment which has been developed for this service. The illustration shows one of these reversing motors driving a heavy Norwood plater having 42-inch face by 18-inch diameter rolls revolving at about 17 r.p.m. The duty is fairly heavy, the rolls ordinarily making ten reversals a minute except on the corners where sometimes 30 reversals are made per minute. The motor is a 15-h.p. phase-wound machine direct connected to the plater shaft through a rigid steel coupling. A small drum-type controller with one forward, one reverse, and one off point is mounted on the table convenient to the operator's right hand and controls the motor through magnetically operated switches mounted on the panel. On this panel there are three contactors, Fig. 9, two of them being line contactors and the third being used to cut out a section of resistance after the motor has reversed. A simple mechanical relay actuates this contactor only after the motor has started to turn in the reverse direction. The installation is extremely simple and is entirely under the control of the operator's hand.

The following tests show the superiority of the reversing drive over the old belt-shifting equipment. The tests were made on a

Fig. 11. 7-1/2-h.p. Induction Motor Belted to Rotary Cutter and Layboy. Strathmore Paper Company, Woronoco, Mass.

36-inch Norwood plater having 17-inch diameter rolls. A comparison is made between the performance records of a 15-h.p. direct-connected reversing motor and a 15-h.p. constant-speed motor driving the plater through ordinary belt transmission, the reversals being obtained by shifting the belt. The records were made during a 2½-hour run while the plater was working on Par[illegible], Bond, and Vellum. Fig. 10 is a section of the

Fig. 12. Seybold Machine Company 64-in. Trimming Knife Driven by Squirrel-cage Motor. Byron Western Company, Dalton, Mass.

photographic record of the tests from which the data given in Table I were obtained.

TABLE I

	Reversing Motor	Belted Motor
Total number of books in 2½ hr. run	66	64
Totol kw-hr.	21.14	24.5
Per cent of time plater idle.	53.2	35.6
Power used to drive machine when idle, kw.	0.	2.74

In the recorded tests the plater output was limited by the ability of the crew to make up books to be plated. There were a sufficient number of girls to keep the platers busy when operating with a belt shifting device, but the direct-connected drive was so much faster that the crew could not keep pace with it. It is evident, however, that with a given output the power bill is diminished by 13.7 per cent. If we assume that 35.6 per cent of the total time was used up in unavoidable delays, it would still have been possible within 2½ hours to finish 16 more books on the reversing motor equipment than was possible with the belted equipment. This represents a production gain of 25 per cent.

or with the same power consumption production could have been increased 18 per cent.

Trimmers may be driven by squirrel-cage, wound-rotor, alternating-current motors or by direct-current motors. The motor is generally located on the floor or mounted on the trimmer frame and belted to the flywheel as shown in Fig. 12. In these installations the motor runs continuously, but motors have been applied to one type of trimmers which start and stop once for each cut. The control is entirely automatic. The push-button station has "start," "stop" and "jog" buttons and an additional "stop" button is used for the limit switch. Pushing the "start" button starts the equipment which automatically completes one cutting cycle unless the "stop" button is pressed. This action will stop the knife at any point in its travel. A solenoid brake is used to produce instantaneous braking.

Rotary cutters, layboys, and rewinders are all driven by individual electric motors. Typical examples of these machines are shown in Figs. 11 and 13.

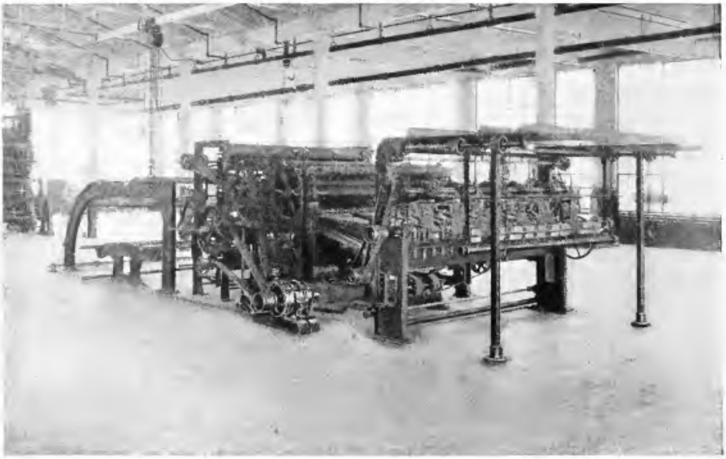


Fig. 13. 10-h.p. Induction Motor Belted to Rewinder. Strathmore Paper Company, Woronoco, Mass.

The Synchronous Motor as a Means of Reducing Costs

By Robert Treat

Power and Mining Engineering Department, General Electric Company

The increasing cost of labor and materials, without a corresponding advance in the price of product, makes it necessary for the manufacturer to study production economy in all its phases. In this connection the following article is very timely as the author convincingly illustrates the possibilities of reducing power costs by the use of synchronous motors or motor condensers. Under the usual conditions, where the induction motors on a circuit have lowered its power-factor, the addition of a properly selected synchronous motor will improve the service and increase the power capacity.—Editor.

There is no disputing the fact that both synchronous and induction motors have occasionally been misapplied in times past. The use of an induction motor when a synchronous motor would have better served the purpose has perhaps been made to a greater extent than the misapplication of the latter. The induction machine, with its extreme simplicity and ruggedness, and its fairly low first cost and maintenance has commended itself to many users who, perhaps, could have served their own interest to better advantage by a more careful consideration of the merits of the synchronous motor. There are in operation today many induction motors in places which would undoubtedly have called for a synchronous machine, if at the time of installation the latter had reached its present stage of development. As a result, many industrial systems and public utility companies are suffering from the poor power factor of a considerable induction motor load which could, in general, be improved to some extent by the proper and judicious use of synchronous motors. It is pertinent at this time, when power companies are trying to devise means for discouraging loads of low power factor by some form of variable rate, or by a charge based on kilo-volt-amperes instead of kilowatts, to inquire into the merits of that method of power factor improvement most readily at hand to the largest number of power consumers—a greater use of the synchronous motor.

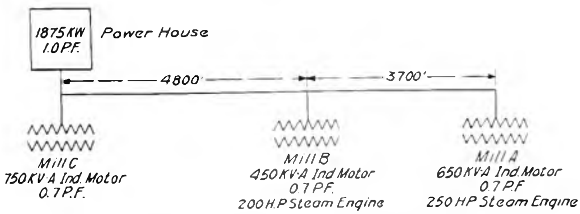


Fig. 1. The Capacity of this Low Power-factor Circuit was Increased by Replacing the Steam Engines in Mills *A* and *B* by Synchronous Motors

It may be well here to compare briefly the salient characteristics of the two machines. For any application requiring adjustable speed, obviously the phase-wound induction motor or some other form of variable speed machine will be required. For very small amounts of power, the induction motor has numerous advantages in cost, efficiency, and simplicity. A brief analysis of the comparative characteristics and advantages of the two types of machines in the larger sizes, for constant speed duty follows:

1. *First Cost:* In all but a few of the larger low speed motors, the induction motor costs the less for a given output. The difference may be quite an appreciable amount in the smaller sizes.
2. *Efficiency:* The synchronous motor has the higher efficiency at or near full load. At light loads the induction motor may have a slight advantage.
3. *Power Factor:* The synchronous motor is usually designed for unity, or 0.8 power factor leading. The induction motor power factor will usually come between 0.75 and 0.95 lagging—seldom over 0.9 except in high speed machines, and frequently less than 0.75 in small and low speed motors.
4. *Overload or Breakdown Torque:* The induction motor will carry 300 to 350 per cent load before stalling; the average synchronous motor about

Fig. 2. 600-h.p. Synchronous Motor Operating Dust Collectors

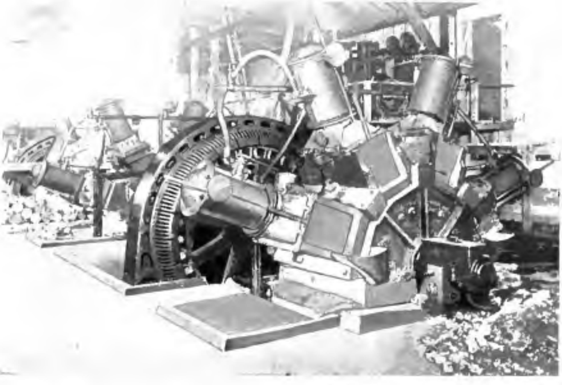


Fig. 4 1200 h.p. Synchronous Motor Driving a 4-pocket Grinder

Fig. 3. Reciprocating Air Compressors Driven by Synchronous Motors

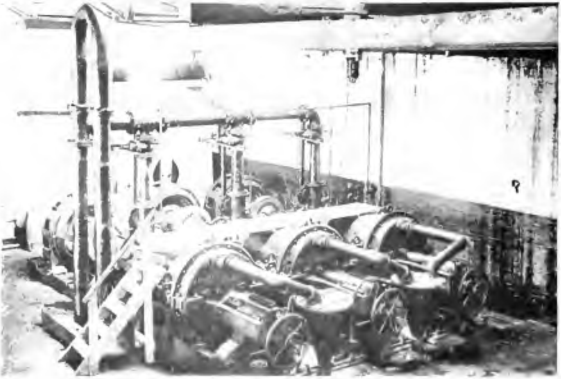


Fig. 5. Three Jordans Driven by 125-h.p. Synchronous Motors

200 per cent, which amount is ample for most applications. This value can, however, be increased where necessary by special design. When the necessity can be foreseen the torque can be temporarily increased somewhat by increasing the field excitation. Due to its flywheel effect and its amortisseur winding, a synchronous motor will withstand a transient over-torque considerably in excess of the value given for steady overload (200 per cent normal). The extent depends upon the design of the machine and the duration of the excess torque.

5. *Starting:* The apparent starting torque efficiency of the synchronous motor, that is, the torque developed per kv-a. input, lies between that of the squirrel-cage and of the phase wound induction motor. Therefore, practically any starting torque requirements which can be met by a squirrel-cage induction motor can be met to better advantage by a synchronous motor. It is not possible in the salient pole synchronous machine to approach the excellent starting characteristics of the phase wound induction motor, but on the other hand, the fact that it is not necessary in the synchronous motor to limit the resistance of the amortisseur winding on account of efficiency at full speed, as in the case of the squirrel-cage induction motor, permits the construction of a winding more efficient at starting. The starting torque of ordinary synchronous motors which is developed within the limitations of kv-a. input usually met varies from 20 to 35 per cent, depending upon the class of service. Motors have been designed for a starting torque as high as 60 per cent for special requirements.

6. *Pull-in:* In an induction motor, pull-in torque is synonymous with breakdown torque. In a synchronous motor full breakdown torque is not developed until excitation is applied to the field, and there is a point, at 95 to 100 per cent speed, where the requirements of the load may necessitate a special design in order to obtain sufficient torque. This value usually runs around [illegible] per cent. Machines have been designed for as high as 65 per cent pull-in torque and it is possible to build a machine for practically any torque which may be required. It should be [illegible] clearly realized that the requirements of starting and pull-in torque are to some extent antagonistic. High starting torque for a given input from the line requires a high resistance amortisseur winding. High pull-in torque for the same input requires a low resistance winding. Theoretically it is possible to meet almost any requirements in either starting or pull-in, provided the other is not important. But a design which gives a high starting torque necessarily has rather poor pull-in characteristics, and vice versa. The design of an actual machine is of course a compromise between the two extremes, and the resistance of the squirrel-cage winding is made relatively high or low according to whether the requirements at start or at synchronism are the more severe.

7. *Acceleration:* An induction motor with squirrel-cage winding reaches full speed in about 5 seconds; a synchronous motor in about 20 to 30 seconds. This difference may be an important factor if there is any tendency while starting up to break shafting, throw-off belts, or if there be other objections to a high rate of acceleration.

8. *Electrical Disturbance:* In case of a momentary interruption in power, or lowering of the voltage the induction motor will suffer a slight speed reduction. It will usually regain full speed upon the restoration of normal conditions, but at the expense of a temporarily large current from the line. On the other hand, under such conditions a synchronous motor quite frequently will not only remain in synchronism, but will also help to hold up the voltage. If, however, the disturbance is sufficiently severe to cause the synchronous motor to fall out of step, in a majority of cases it will not come back to synchronous speed

without being restarted. Under certain favorable conditions, as for instance a motor-generator set which loses its load at the time of disturbance, it is quite possible that synchronism may be regained immediately upon the restoration of normal conditions, without the necessity for restarting.

A synchronous motor should be considered for any application when,

(a) Variable speed is not essential.
(b) The requirement is 100 h.p. or over.
(c) Starting conditions are not such as to require a phase wound induction motor.
(d) Loads in excess of 200 per cent are improbable.
(e) The supply circuit is not subject to frequent and abnormal surges in voltage or frequency.
(f) Particularly when the power factor of the supply circuit is already low, and there is an advantage to the user in helping to better it.

A few examples will serve to illustrate the effects of installing in a given circuit either a synchronous or an induction motor of average characteristics.

Case I. A certain sub-station has a 500-kw. load at 0.75 power factor, 2300 volts, 25 cycles, which is transmitted over a half mile of No. 4 wire. It is proposed to add a 200-h.p. motor.

Case II. A 300,000-c.m. feeder in a factory is carrying a load of 150 kw. at 440 volts, 60 cycles, 0.8 power factor, at a distance of 1000 feet from the generator bus. A 100-h.p. motor is to be added.

Case III. A mill, located two miles from the generating station, has a 1000 kw. load at 6600 volts, 60 cycles, 0.8 power factor, which is supplied over a No. 1/0 circuit. Additions to capacity require the installation of a 1250-h.p. motor.

Table I shows, for the cases assumed, the losses, the terminal voltage and the annual saving effected by using a synchronous instead of an induction motor. The annual saving has been calculated on the assumption of carrying full load for nine hours per day, 300 days per year. This value may easily be modified for any particular conditions, and may be converted into dollars and cents by multiplying by the cost of power.

The values in the table are based upon the assumption that 100 per cent motor load is superimposed upon the load already existing on the circuit. The losses have been calculated for the supply circuit only, no attempt having been made to evaluate the hypothetically higher efficiency of the synchronous machine itself. Dependent upon the characteristics of the two motors, this would undoubtedly show a still further advantage in favor of the synchronous motor, which might amount to as much as 70 per cent of the saving already shown for the line.

If the motor is to operate at less than full load for considerable periods, the behavior of each type should be considered. In general, the efficiency of the synchronous machine will fall off more rapidly than that of the induction motor, and it may be somewhat the lower at light loads. On the other hand, the induction motor power factor becomes worse as the load falls, while the synchronous motor can, if necessary, supply a greater leading current than at full load. In other words, its ability to correct power factor, and thereby to keep

TABLE I

	Generator Voltage	Terminal Voltage	Kw. Line Loss	Annual Loss Kw. Hrs.	Difference in Favor of Synchronous Motor
CASE I.					
Present	2400	2220	64	173,000	
Plus Synchronous Motor		2160	84.5	228,000	73,000
Plus Induction Motor		2140	111.6	301,000	
CASE II.					
Present	480	447	6.72	18,100	
Plus Synchronous Motor		452	10.5	28,300	15,500
Plus Induction Motor		425	16.25	43,800	
CASE III.					
Present	6600	6300	39.6	107,000	
Plus Synchronous Motor		6230	117.	318,000	175,000
Plus Induction Motor		5900	183.	493,000	

line losses at a minimum, is not ordinarily impaired but rather enhanced by a decrease in its own load, even though its own efficiency may thereby fall off considerably.

If a constant voltage at the end of the supply line is of importance, the synchronous motor can assist materially in maintaining it by varying, within limits, its excitation. The induction motor is, of course, valueless for this purpose. A reference to Table I will show that in every case the choice of an induction motor results in a lower full load voltage, that is, in a greater variation in terminal voltage.

Recent improvements in synchronous motor design, the increasing cost of power (which gives efficiency a greater weight as against first cost), and the increasing recognition by the engineers of both commercial and industrial power stations of the value and importance of a high power factor load, all make for a broader and more general use of synchronous machines.

The synchronous motor is already well established in the following fields:

- Motor-generator sets, including frequency converters,
- Air compressors,
- Centrifugal pumps,
- Fans and blowers, and it has been used to a considerable extent for other specific purposes too numerous to mention.

In addition, more and more applications are being considered from time to time. Many industrial processes and methods, largely an outgrowth of combined development with the steam engine, have been electrified with induction or direct-current motors, because only these types had the requisite characteristics. It has been found in numerous cases that a slight modification in method, as for instance, closing the outlet of a centrifugal pump, or bypassing an air compressor during the starting period, would permit the employment of a synchronous motor to good advantage. As a notable example the synchronous motor has recently been applied to a copper rolling mill, a field [illegible] considered the exclusive property [illegible] and direct-current motor[illegible] noted, however, that th[illegible] machine [illegible] motor condenser of less than .40 per [illegible] factor, so that its breakdown load [illegible]

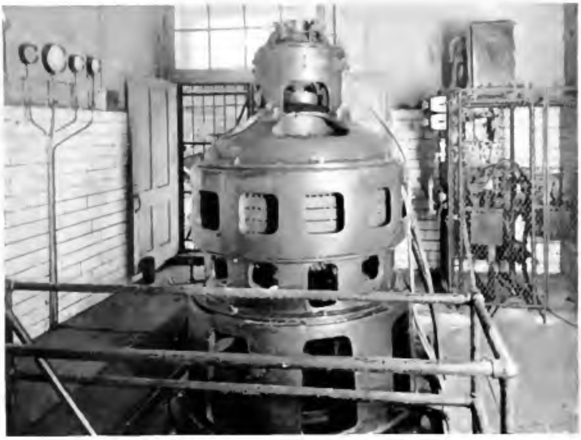


Fig. 6. Centrifugal Pumps Driven by 300-kv-a. Synchronous Motors

starting torque are a relatively high percentage of its energy rating.

Occasionally it is found desirable to install a motor of somewhat greater capacity than demanded by the requirements of the driven load, in order to furnish considerable excitation to the system. Such a machine is known as a motor-condenser. Although the proportions of motor and condenser will be fixed by the exigencies of the case, it is interesting to note that the maximum effect is obtained by combining the wattless with the power duty in equal parts.

It will frequently be found that money can be saved and service improved by replacing or supplementing an old isolated steam or gas engine plant by a synchronous motor or motor condenser. A case in point is that of an industrial concern in New York which had an arrangement somewhat as shown in Fig. 1.

The total generating capacity was rated at 1875 kv-a at 0.8 p.f., but the prime mover was of sufficient capacity to furnish 1875 kw. at 1.0 p.f. The power obtainable was therefore limited only by the power factor of the load, up to 1875 kw. Supplied from the power station through a 2300-volt line, partly of 350,000 C.M. cable and partly of No. 4/0 cable, were three mills, as shown in Fig. 1. The load at mill *A* consisted of 650 kv-a. in induction motors, and a 250-h.p. load carried by a steam engine. The load at mill *B* consisted of 450 kv-a. in induction motors and 200 h.p. on a steam engine. Mill *C*, adjacent to the power house, had a 750-kv-a. induction motor load. The power factor at each mill and at the power house was about 0.70. Although, as will be seen, the generator was already carrying a slight overload, including line losses, it was necessary to increase the capacity at mill *B* by 200 h.p. and an induction motor seemed the only logical means. This, however, would necessitate an increase not only in generating facilities, but in the strength of the line from the power house to mill *B*. After careful study, the following changes were made:

At mill *A* the steam engine was replaced by a 300-h.p., 500-kv-a. motor-condenser with automatic voltage regulator for holding constant voltage.

At mill *B* the steam engine was replaced by a 200-h.p., 300-kv-a. motor-condenser and the 200-h.p. induction motor initially responsible for the inquiry was installed.

Results:

Mill A: Power factor raised from 0.70 to 1.00.
Voltage variation reduced from 13 per cent to 0.
Steam engine shut down, and its place taken by a source of cheaper and more convenient power.

Mill B: Power factor raised from 0.70 to 0.985.
Voltage variation reduced from 11 or 12 per cent to 2 or 3 per cent.
Steam engine dispensed with.
Opportunity to install the additional 200 h.p. required without enlarging power station or line.

Line: Copper loss reduced from 140 to 50 kw.

Power House:
Power factor raised from 0.70 to 0.94.
Load on generator reduced about 200 kv-a.
Kilowatt capacity of generator increased about 30 per cent due to decrease in kv-a. load.

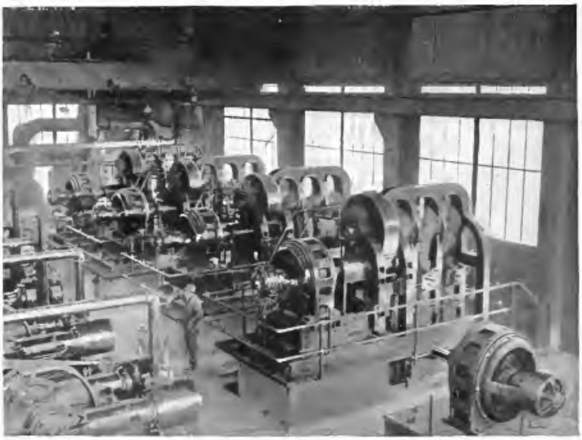


Fig. 7. Synchronous Motors Driving Triplex Pumps

Centrifugal Machines and Their Adaptability to Electric Motor Drive

By H. W. Rogers

Power and Mining Engineering Department, General Electric Company

This article discusses factors that have to be taken into consideration in adapting the electric motor to the driving of centrifugals. The starting requirements are rather severe and in order to make a correct selection of motor equipment it is necessary to know fully the conditions under which the centrifugal is to be operated, such as maximum speed, period of acceleration and duration of run, as well as diameter of basket and weight of revolving element, load, etc. These factors and the widely fluctuating duty cycle make the selection of an efficient and satisfactory motor equipment a difficult problem and one which must be worked out independently for each installation. Either direct-current or alternating-current motors may be used but the latter are in predominance. Several formulæ and curves are given which will assist in the selection of the proper motor for a given installation.—Editor.

The centrifugal machine or extractor in its simplest form consists of a perforated basket which revolves on a vertical spindle at high speed and utilizes centrifugal force for the purpose of drying, extracting, filtering, cleaning, dyeing, nitrating, etc.

The baskets are generally constructed of perforated thin metal, with strengthening rings or hoops on the outside, the bottom may be solid or removable in part for discharging by hand or may be automatically lowered and discharged when the machine has practically come to rest; the top of the basket is of a ring construction to permit of charging through the center.

The method of drive varies with different makes of machines; belted from the top or bottom, geared from the top or the bottom, or direct driven by means of vertical motors. In the latter type of drive the motor may be mounted on top of the centrifugal or suspended beneath.

The field of application for the centrifugal has become so extensive during recent years that the types of machine are as varied as the industries themselves. Centrifugals have long been used in textile mills, sugar mills, powder plants, and laundries, and are now being used extensively in the following industries:

Chemicals	Fibers
Dyes	Pelts
Sugar	Hair
Salts	Nitro-Cellulose
Crystals	Rugs
Wool	By-products
Textiles	Laundries
Cotton	Dyers
Silks	Cleaners

They have also been used for metal drying and the extraction of oil from metal chips. Their adaptability to the paper mill industry for drying bark or pulp for storage has also been investigated; but, up to the present time, it has not proven entirely successful owing to the method of discharge employed. This difficulty, however, may be overcome in time with a special machine designed for the purpose.

The usefulness of the centrifugal for separating materials is dependent entirely upon the application of centrifugal force, which varies directly as the diameter of the basket and as the square of the revolutions per minute.

$$F = \frac{Wv^2}{gR} = \frac{WRN^2}{2933} = 0.0003410\ WRN^2 \text{ pounds}$$

where

F = centrifugal force in pounds
W = weight of body in pounds
R = radius in feet
N = revolutions per minute
g = gravity = 32.16.

The magnitude of this force is shown by the curve in Fig. 1; and it will there be noted that on the 40-inch centrifugal, which is ordinarily used for sugar work, this force is approximately 570 pounds at 1000 r.p.m. and represents the force acting on each pound of syrup at the periphery to separate it from the crystals.

The principal types of centrifugals on the market today are manufactured by:

The American Tool & Machine Co.
The Tolhurst Machine Works.
The Troy Laundry Machine Co.
The American Laundry Machine Co.
The Fletcher Works.
The D'Olier Co.
The Herr Automatic Machine Co.
The Van Vlaanderen Machine Co.
The S. S. Hepworth Co.
The Heine Co.
The Watson Laidlaw & Co., Ltd.
The Pott Cassels & Williamson.

The last two concerns are both of Scotland and their machines are not used extensively in this country.

The Watson Laidlaw machine is driven by steam engine, water motor, or electric motor, but only the electrically operated machine will be considered here. The motor is of the vertical type mounted on the framework above the centrifugal and connected to it by means of a buffer coupling and centrifugal friction clutch.

The motor is thrown directly on the line and comes rapidly to nearly its full speed before the friction clutch takes hold to bring the centrifugal to speed. The motor therefore exerts a constant torque during acceleration and maintains a speed slightly below normal until the clutch ceases to slip and then speeds up due to the decreasing load. It has the advantage of a straight line acceleration but is not designed for rapid acceleration.

The power requirements are not different from those of a direct-connected motor without centrifugal clutch, in one case the losses are in the clutch and in the other case either in the motor or rheostat.

The Pott Cassels & Williamson Co. manufactures the "Weston" centrifugal which has practically the same method of drive as that of the Watson-Laidlaw Company, except that the motor armature is mounted on a sleeve on the spindle and has no buffer coupling interposed between it and the centrifugal.

The Tolhurst, Troy Laundry, American Laundry and Heine machines are generally belt driven; the Schaum & Uhlinger (Fletcher Works) machine has a bevel-gear drive; and the American Tool & Machine, D'Olier, Herr

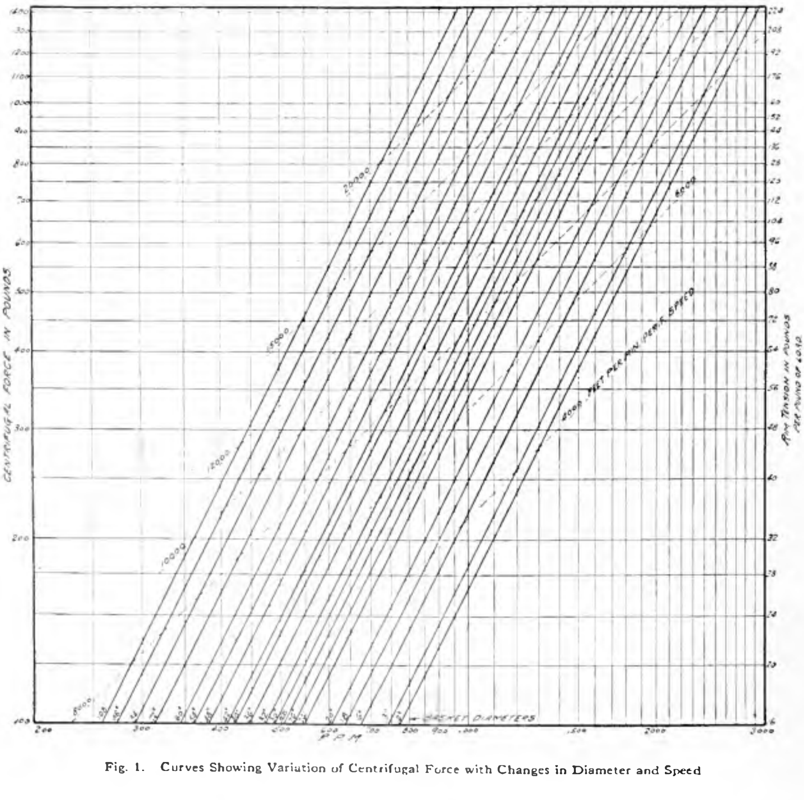


Fig. 1. Curves Showing Variation of Centrifugal Force with Changes in Diameter and Speed

Automatic, S. S. Hepworth, and Van Vlaanderen centrifugals are usually direct driven. The Tolhurst Machine Works and the Fletcher Works also manufacture direct-driven machines, the latter being of the under driven type.

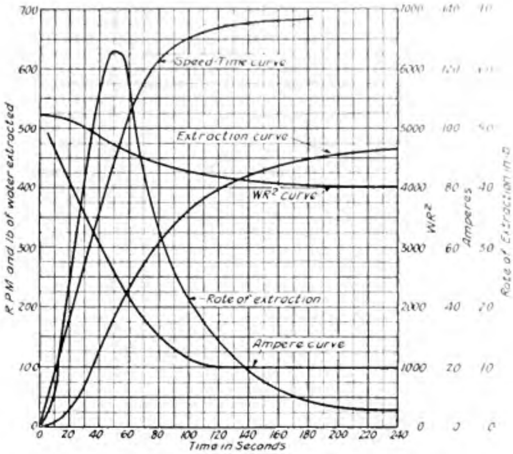


Fig. 2. 48-in. Tolhurst Extractor, 7-h.p., 1200-r.p.m., 220-volt Belted Motor
Load = 900 lb. Saturated Waste
Dry Waste = 257 lb.

The application of motors to centrifugals should never be made without a full knowledge of the size, weight, load, speed, and duty cycle of the machine as there are many factors which influence the motor capacity. The horsepower rating of a centrifugal motor is very apt to be misleading as it may be based on the friction load only without any reference to the frame size or it may have an arbitrary intermittent horsepower rating entirely dependent on the duty cycle. The rating should be based on the complete duty cycle and should give some indication of the root-mean-square value of the duty cycle.

The duty cycle varies widely and may be long or short depending on the class of work being done, e.g., in laundry, textile, chemical, wool, hair, rug cleaner, etc., the cycle may be long with from three to ten starts per hour, while in sugar, nitro-cellulose, syrup, etc., the cycle may be very short, varying from two and one half minutes to five or six minutes. Centrifugal in the dyeing and silk industries, etc., are very often equipped with two motors, the smaller of which operates the centrifugal at from 18 to 20 r.p.m. for probably 20 minutes, after which the larger motor brings it up to high speed and operates only for a period of 10 minutes and then the machine is shut down.

Centrifugals of the continuous type seldom shut down after once being started as they are automatically discharged and charged while running at low speed. They are then brought up to full speed for a predetermined period and again slowed down for discharge and charge.

It is impossible to select a motor without a full knowledge of the following factors:

Diameter of basket.
Weight of revolving element.
Weight of load. Accelerating time.
Maximum speed. Running time.
Friction load at full speed.
Braking time. Rest period.
Discharging time.

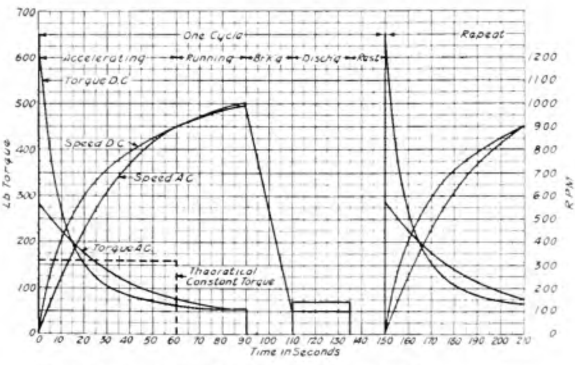


Fig. 3. Speed and Torque Characteristics of Direct and Alternating-current Motors Direct Connected

In some cases, the discharge takes place while running at low speed (150 to 200 r.p.m.) and the charge during the rest period, while in other cases both the discharge and charge take place while the centrifugal is running at low speed. In a few cases the centrifugal

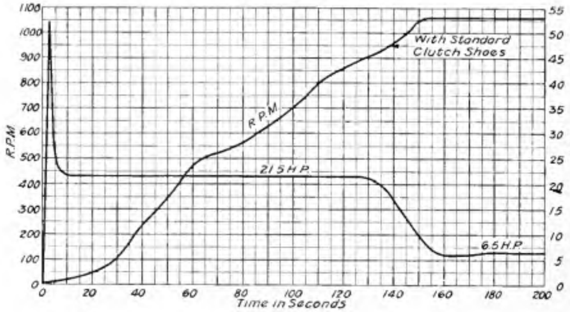


Fig. 4. Characteristics of Centrifugal with Direct-connected Motor and Centrifugal Friction Clutch

is brought to full speed empty and the charge takes place while it is running at full speed. However, as there is a possibility of having to start under full load the motor should be of sufficient capacity to accelerate the centrifugal under these more severe conditions.

The power requirements of the centrifugal may be readily calculated from the data referred to in the preceding paragraph. However, since the problem is one of inertia, the WR^2 must first be determined. This is made up of two elements: the basket and spindle, which is fixed; and the load, which varies from start to full speed. Experience has shown that the radius of gyration of the basket may be taken as about 77 per cent of the basket radius while that of the load may be taken as 86.6 per cent of the basket radius. The increased radius of gyration of the load is due to the material being thrown out toward the periphery when the machine starts; and since extraction takes place immediately the load decreases quite rapidly and reaches approximately 62 per cent of its original value at the end of the accelerating period. It is, therefore, only necessary to consider the average load during acceleration; i.e., 81 per cent of the total load at start, in calculating the WR^2 of the load. This characteristic is clearly indicated by the test curves in Fig. 2.

Substituting this value of WR^2 in the formula:

$$\text{Torque} = \frac{WR^2\,N}{307\,t}$$

the theoretical constant torque required to bring the machine up to a given speed N in a given time t may be calculated. To this value must be added the average friction torque during acceleration; and the horsepower input during this period may be derived from the formula:

$$\text{H.p.} = \frac{T \times N_s}{5250}$$

where

T = torque in foot-pounds.

N_s = maximum or synchronous speed.

In calculating the torque during acceleration or the time required for acceleration the value N is taken as 90 per cent of the maximum running speed rather than the maximum speed, because the time required to attain maximum speed from 90 per cent is practically the same as the time required to attain 90 per cent speed from rest. This is due to the constantly diminishing torque available for acceleration and is a trait inherent with both direct and alternating-current motors.

Both of the foregoing formulæ presuppose a constant accelerating torque which is not available on either the direct or alternating-current motor owing to the shape of the torque curve; consequently to obtain an equivalent effect the actual starting torque for the alternating-current motor must be approximately 50 per cent in excess of the theoretical torque, while for the direct-current compound-wound motor the actual starting torque must be approximately 450 per cent of the theoretical torque. The difference in the two types of motors may be accounted for by the fact that the torque of the induction motor is more even than that of the direct-current motor, which is very heavy at starting and falls off very rapidly.

These formulæ do not indicate the required motor capacity but must be considered with the remainder of the duty cycle in determining the root-mean-square value of horse power. The full-speed running load is very light, since it is only a matter of overcoming friction and windage; consequently, the power required during acceleration is a determining factor in the selection of a motor. The full-speed operation horse power has a distinct advantage and considerable bearing on the motor capacity since it permits of dissipating the heat incident to acceleration.

Fig. 5. 48-in. Laundry Centrifugal Extractor with Horizontal Belted Motor and Belt Tightner Head

The foregoing method of calculation may be used in connection with squirrel-cage motors where centrifugal friction clutches are interposed between the motor and the centrifugal, or with slip-ring motors where the losses are external. There are cases, however, where the heat developed during a single accelerating period results in excessive temperature and prohibits the use of a motor which might appear to be satisfactory after applying the method above. Such cases are confined almost entirely to infrequent starting, followed by a running period of either long or short duration. For this reason, it is more satisfactory to apply the watts-loss method which necessitates a knowledge of the motor windings used.

Where centrifugal friction clutches are used the energy loss during acceleration is dissipated as heat in the clutch. Where direct connected motors are used, this energy loss is in the motor rotor and is equal to the stored energy in the centrifugal basket plus the loss due to friction and windage, and the motor should have sufficient material in its rotor windings to prevent excessive heating during this period. It is really a matter of the heat storage capacity of the windings and no account should be taken of the rotor laminations as there is not sufficient time for heat conduction to take place to any great extent. With squirrel-cage motors this loss is all internal, while with slip-ring motors provided with external resistance the loss is partially internal and partially external, the rotor loss being proportional to the percentage total resistance in the rotor winding. The temperature rise in the rotor winding should not exceed 200 deg. C. during the accelerating period, which means that there should be one pound of winding for every 83.6 kw.-sec. loss if aluminum is used or one pound for every 35.75 kw.-sec. if copper is used.

Stored energy, $\frac{1}{2} Mv^2$, may be expressed in watt-sec. as:

$$\frac{WR^2 \times N_s^2}{4{,}339{,}000} \text{ or } 0.000231\ WR^2 \times N_s^2$$

where

W = weight of revolving element.

R = radius of gyration in feet.

N_s = maximum or synchronous speed.

This formula, however, is not theoretically correct for calculating rotor losses, as it gives values approximately two per cent high, and it should be modified somewhat to take account of the motor slip.

$$Watt\text{-}sec. = 0.000231\ WR^2 \times N_s^2\ (1 - S^2)$$

where

S = per cent slip.

The friction loss may be taken as:

Watt-sec. = 0.142 FtN (1 − Avg. per cent syn. speed during acceleration).

where

F = average pounds torque during acceleration.

t = accelerating time in seconds.

The rotor loss during acceleration is an important factor in determining the motor capacity, but the losses during the complete duty cycle should also be considered.

The duty cycle consists of:

(1) Accelerating period.
(2) Running period.
(3) Braking period.
(4) Discharging period.
(5) Rest period.

Since the radiating capacity of a given motor depends upon the speed at which it is running, the actual time must be shortened to take this into consideration. At full speed the radiation is considered as 100 per cent and at rest 25 per cent; during acceleration and braking it is only 50 per cent and at low-speed running it is practically the same as at rest, i.e., 25 per cent.

There are various types of drive which may be considered and have been used during recent years for this service although they cannot all be termed satisfactory in the light of present-day practice. These types may be briefly listed as follows:

I. Group Drive.
II. Individual Drive:
  (a) Belt Connection
    (1) Over Driven
      (a) Horizontal Motor
      (b) Vertical Motor
    (2) Under Driven
      (a) Horizontal Motor
      (b) Vertical Motor
  (b) Direct Connection
    (1) Through Centrifugal Friction Clutch
      (a) Overhead Motor
      (b) Suspended Type Motor
    (2) Through Flexible Coupling
      (a) Overhead Motor
      (b) Suspended Type Motor

Group driven centrifugals may utilize either direct or alternating-current motors, but necessitate a line shafting with clutch pulleys for each centrifugal to take care of starting and stopping. The main driving motor runs continuously and may be of considerably smaller capacity than the combined motor capacity of an equal number of individual motor-driven machines, since advantage may be taken of the load-factor. However, the belt maintenance is necessarily high, a larger amount of floor space is required, and the rate of acceleration may vary over wide ranges depending on the condition of the belts and clutches. The actual power consumption in kilowatt-hours will be slightly more than on individual motor-driven machines although the fluctuations in load will be smaller as the torque during acceleration is constant, while on individually driven machines of the direct-connected type the torque varies throughout the accelerating period. The use of friction clutches on individually driven machines permits of a constant accelerating torque but does not eliminate the peak load during starting, although it is of very short duration. This method of drive has the advantage of low first cost, but it is rapidly becoming obsolete owing to its disadvantages and the present tendency is towards individual motor-driven machines which are complete units in themselves.

Fig. 6. Direct-driven Centrifugal Extractor with Squirrel-cage Induction Motor. A type used extensively in textile works on long duty cycles

Of the individual motor-driven centrifugals there are many types, the larger portion of which are for alternating-current operation. The belt-driven machines are of two types, the over-driven and the under-driven; the former usually employs a horizontal motor with belt-tightener head, mounted on the floor or ceiling and operating through a quarter-turn belt as illustrated in Fig. 5 while the latter employs either a horizontal motor with quarter-turn belt or a vertical motor. Such machines are used in laundries, textile mills, shirt and collar factories, leather mills for drying hair, machine shops for metal drying, etc., and operate on a slow cycle. It was the practice to furnish these machines with slip-ring motors owing to the heavy starting conditions, but they are now being operated almost exclusively with squirrel-cage motors of the high-resistance rotor type designed for throwing directly on the line. This practice is entirely satisfactory and is permissible in the absence of low-speed discharging. It eliminates the use of starting resistances and permits of utilizing the high-speed motor, which is of less first cost than the direct-connected motor. Belt maintenance, although reduced to a minimum, is still present. Machines of this type are now being built for textile work, etc., with direct-connected motors of the high-resistance squirrel-cage type, either over-driven or under-driven.

On rapid duty cycles, such as are encountered in sugar mills and powder mills, direct-connected motors are invariably used and the equipment is of two distinct types, viz., that which employs the centrifugal friction clutch interposed between the motor and the centrifugal basket and that which employs a motor without such a device. With the centrifugal friction clutch, a motor of the squirrel-cage type may be used and it need not of necessity have a high-resistance rotor for reasons stated previously, and if the unloading is done by hand a single-speed

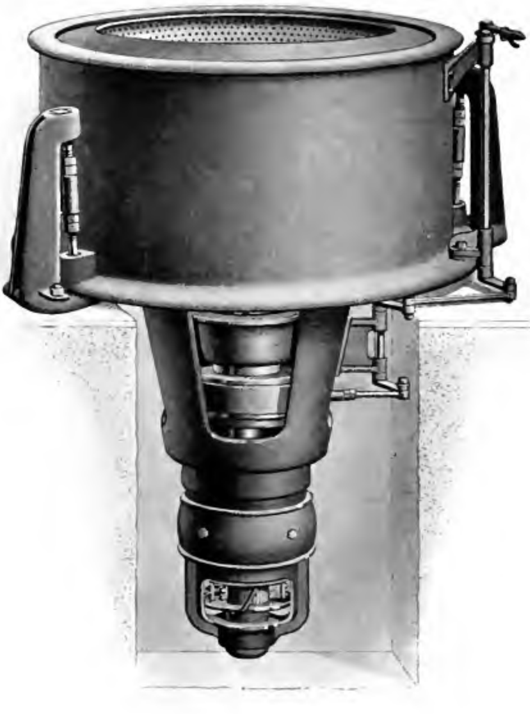


Fig. 7. Direct-connected Under-driven Type of Centrifugal Machine. This type may be furnished with or without centrifugal friction clutch

motor is all that is required. On the other hand, if mechanical discharges are used a two-speed motor becomes necessary in order to obtain the low discharging speeds required. The advantage of this method of drive lies in the smaller, cheaper motor, which is due to the fact that the motor is operating at nearly its maximum speed during the accelerating period and has lower internal losses with a greater capacity for radiating heat. This advantage, however, may be off-set by the maintenance on clutch shoes and the loss of time incident to changing them.

The control for this type of centrifugal is no simpler than that of the direct-connected slip-ring motor whether a single-speed or a two-speed squirrel-cage motor is used, since a permanent secondary resistance is always used with the slip-ring motor and this is adjusted to give the desired acceleration.

Where friction clutches are not used, it has been the practice to equip centrifugals with

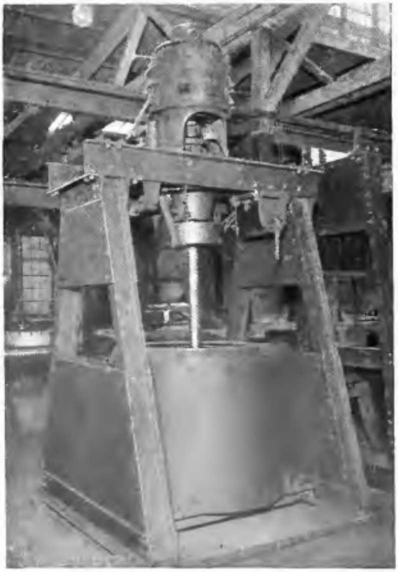


Fig. 8. 42-in. Sugar Centrifugal with Direct-connected Squirrel-cage Motor and Centrifugal Friction Clutch

slip-ring motors as it not only permits of low-speed operation for mechanical unloaders but also allows of using a smaller motor because the losses are external. It is, however, possible to utilize the squirrel-cage motor where unloading is accomplished by hand, but the rapid duty cycle necessitates a very large motor frame in order to dissipate the losses incident to acceleration. In spite of this fact, the squirrel-cage motor may be just as cheap as the slip-ring motor with its external resistance. In either event the only control

Fig. 9. Type of Motor Used for Direct Drive on Sugar Centrifugals

required is a single line contactor and master control switch with one additional secondary contactor for low-speed operation when mechanical dischargers are used. This is the simplest control and it is a mistaken idea that automatic control with its accompanying auxiliaries is ever needed. From the standpoint of power consumption there is practically no difference between the direct-connected motor with a centrifugal friction clutch and without a clutch; there is, however, a difference in the shape of the power curve during acceleration since the use of a centrifugal clutch permits the motor to come rapidly to practically its full speed. Consequently the peak resulting from throwing it on the line disappears in about five seconds and is followed by a constant input to the motor until practically full speed is attained, while on the direct-connected motor without a clutch this peak may not be so high but is sustained for a longer period and gradually decreases until full speed is attained.

The direct-connected slip-ring motor is naturally a little more expensive than the squirrel-cage motor with a clutch, but as there are no wearing parts, maintenance is a minimum and the rate of acceleration is fixed.

The Continuous-rated Motor and Its Application

By L. F. Adams

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The American Institute of Electrical Engineers has adopted two distinct ratings for electric motors, the continuous rating and the short-time rating. This article thoroughly describes the continuous-rating system, by comparison demonstrates its advantages over the earlier normal plus overload system, and explains its application in practice.—Editor.

Nations, various groups within nations, communities, and individuals are and always have been clashing—due, chiefly, to the lack of a common and accurately understood language. The possibility of obtaining such a language is problematical. The world has progressed, however, in various branches of standardization. For centuries the adoption of fixed standards of weights and measures has been of unlimited value. The industrial world, also, has come to realize the benefits of standardization; and during the first part of this century manufacturers began to place their production on a quantity basis thus lowering overhead charges, reducing stocks, simplifying factory methods, tending toward interchangeability of working parts and, most important, giving better service to the purchaser. The individualistic method of standardization, however, resulted in each manufacturer working out his own standards without due regard to those of others and naturally the outcome was as many standards as there were manufacturers. Specifications written along this idea of standardization called for apparatus which was standard for one manufacturer but special with another.

These methods, coupled with the keen competition of recent years, created a general desire on the part of all for a common standard. The individualistic method of standardization gave way to collective effort. In the electrical field this latter idea is embodied in the Standardization Rules* of the American Institute of Electrical Engineers.

The first step taken by the Institute toward the standardization of electrical apparatus was in 1898, and finally resulted in the acceptance and adoption in 1899 of certain rules coalescing the knowledge up to that time. As the art progressed, it was found necessary from time to time to make revisions and in 1911, under the direction of the Standards Committee of the Institute, there was undertaken a radical revision of the rules. Designing, consulting, and operating engineers, scientists, electrical societies, manufacturers, operating companies, users, and other interested parties were consulted. Co-operative action by these parties, representing all branches of the electric power and lighting industry, working toward a common language for the advancement of the electrical industry has given us the present-day specifications or Standardization Rules of the American Institute of Electrical Engineers. These standards, it is worthy to note, are substantially the same as those which have also been adopted by the majority of electrical societies that occupy similar positions in other countries.

The Institute Rules make certain definite recommendations covering electric machinery and apparatus. The following discussion will be confined to an interpretation of these standards as applied to motors and to motor applications.

During the past few years many important improvements have been introduced in motor construction, such as the addition of commutating poles in direct-current machines to improve commutation, better methods of insulating the windings to resist puncture, elimination of excessive hot-spots by the use of internal directive ventilation, etc. These improvements have assured a uniformity of product which formerly would not have been considered within practical limits.

Similar advances have been achieved in the application of motors and the use of the control best suited for any particular purpose. In the pioneer days, motors were usually substituted for other forms of power with but one thought in mind—to have the motor large enough. The vast amount of data now available as to the power requirements of various machines, the large number of well-trained men now engaged in the application of motors, and the unusual desire to do things better today than yesterday, means that motors must now be selected and applied with a greater degree of accuracy than was considered essential in the early days.

* Latest edition, revised 1918.

It is better to have a motor under loaded than so heavily loaded that it cannot operate successfully. On the other hand, there is no real advantage in selecting a size and type of motor which is unduly large or expensive for the work. The selection of an unduly large motor means a larger outlay in first cost and a higher yearly charge for power because of the lower average operating efficiency. In the case of alternating-current motors, over-motoring lowers the power-factor, requires a more expensive transmission line and larger generators, and causes poor regulation and greater line losses. Finally, the unused capacity of the motor is without resulting benefit to anyone.

What are the requirements for a successful operating motor? A motor produces torque and speed, the two elements required to drive any load. The load requirements have certain variations in the relations of torque, speed, and time. Consideration must also be given to the operating temperature. We therefore define a successfully operating motor as one of such size and design as will readily start and accelerate any reasonable load for which the driven machine may be called upon to sustain, carry any reasonable overload that may be imposed on the machine, and be capable of carrying the normal load for the period of time required without exceeding a temperature of 90 deg. C. as measured by thermometer.

The first point to consider in the selection of a motor is the starting and accelerating torque. For convenience the starting torque or turning movement of a motor is frequently spoken of in terms full-load torque. For greater accuracy, it is obviously better to use the actual torque developed by the motor at standstill expressed in pound-feet. After the starting torque requirement of the driven machine has been determined, the ratio of starting torque to normal torque should be noted. The ratio, if relatively large, indicates that a compound or series-wound direct-current motor will be preferable to a shunt-wound machine, or that a slip-ring or high-resistance rotor alternating-current motor should be selected in preference to the standard squirrel-cage motor. Substantially the same method may be used for services requiring very frequent starting. Careful consideration of the starting and accelerating torques frequently permits the selection of a motor of smaller horse-power rating than would otherwise be employed.

The next question is one of peak load. This is usually expressed as a percentage of full-load torque. Here, too, it is better to express this torque in pounds at one-foot radius as this expression eliminates the full-load speed which is a variable. Ample margin must be allowed between the requirements of the driven machine and the maximum torque developed by the motor. The maximum running torque which the motor will deliver without undue drop in speed is usually of greater importance than the maximum horse-power output, because in many applications a slight drop in speed on the peaks is advantageous for the inertia or fly-wheel effect in the driven machines assists in carrying the load over that peak.

Another point of interest in the selection of a motor is the horse-power rating. This will be largely a measure of the motor's ability to do the required work for the specified period without exceeding the safe heating limits or violating other requirements of successful operation, such as good commutation.

Heating in motors is primarily of interest only as it affects the life of insulation. The heating standard must be in the form of a limiting temperature, this limit to be sufficiently low that insulation continuously subjected thereto will not deteriorate, in so far as its insulating qualities are concerned. Evidently the logical upper limit should be based on the ultimate temperature at which the motor is to be operated, since it is above this that the insulation begins to weaken. After careful investigation, supported by tests, and in the light of practical experience, the American Institute of Electrical Engineers has set a temperature 5 deg. C. above that of boiling water, i.e., 105 deg. C., as a conservative and safe limit for the temperature at which treated fibrous insulation can be used without deterioration. The question arises: Would insulation last longer at a lower temperature? Experience indicates a negative answer. This is to be expected, because even the highest permitted temperature is well below the danger zone. The American Institute of Electrical Engineers in its Standardization Rules, Section 302, states:

"There does not appear to be any advantage in operating at lower temperatures than the safe limits, so far as the life of the insulation is concerned. Insulation may break down from various causes, and when these breakdowns occur it is not usually due to the temperature at which the insulation has been operated, provided the safe limits have not been exceeded."

Having established a suitable upper limit, the next step was the selection of a conservative standard for the cooling medium, or surrounding air temperature, or as it is called in the Institute rules, the "ambient temperature." The value settled upon by the Institute is 40 deg. C. In a building this represents an extraordinarily hot day or a very highly heated room for ordinary industrial purposes. It is a temperature approached in all parts of the temperate zone at some time during the year. It is improbable that the average standard motor will normally be required to operate in temperatures as high as 40 deg. C. for any considerable period of time. For all except the hot days of summer, 21 deg. C. very closely represents the average mean room temperature. Therefore, under normal conditions, motors will seldom operate under as high an ambient temperature as has been proposed, and the value selected is consequently very conservative. Incidentally, in the International conferences on standardization previous to 1914, practically all other electrical societies agreed in recommending 40 deg. C. as the ambient temperature, but two countries of Northern Europe held out for the less conservative ambient temperature of 35 deg. C. There are places where conditions are unusual, where the ambient temperature will be higher than 40 deg. C. It is evident that such cases should be treated as out of the ordinary, and special motors designed to meet these conditions. It will be recalled that the former ambient temperature was 25 deg. C., corresponding not to maximum conditions but to average conditions.

From what has preceded it is evident that the motor manufacturer in following the Institute standards can design his motor for any temperature rise which, based on an ambient temperature of 40 deg. C., will not exceed 105 deg. C., i.e., 65 deg. rise. It should be borne in mind, however, that the temperatures so far used are the external or observable temperatures of the motor and no allowance has been made for the greater heating of the interior and inaccessible parts. It is very difficult to measure internal temperature by ordinary thermometers, and thus the ultimate temperature of motors or the actual temperature rise is arrived at by assuming that the hottest spot in any part of a well-designed motor will have a temperature not more than a certain definite number of degrees above that of the observable temperature of the same part. The Institute's allowance for the difference is 15 deg. C. for open-type motors. This would apply to thermometer readings for ultimate as well as for temperature rise. [illegible] ultimate observable temperature [illegible] C. for treated fibrous material [illegible] perature rise of 50 deg. C. above [illegible] temperature. On totally enclosed [illegible] there is less difference between the [illegible] spot and the observable temperature [illegible] 10 deg. C. is a fair allowance for [illegible] motors. Therefore, the observable tem- perature rise permitted for open motors [illegible] 50 deg. C., and for totally enclosed motors 55 deg. C. While in some designs the permissible temperature rise is decidedly the limiting feature, in other designs the requirements of other conditions will result in a lower temperature rise.

It might appear that a motor which has a temperature rise of 40 deg. C. will have a longer life than one designed for 50 deg. C. As previously pointed out, this is not true because the limit adopted by the Institute for the ultimate temperature is well below that point at which deterioration of the insulation will take place. The situation in this case is roughly analogous to the amount of heat required to produce steam. If the quantity of heat is such that the temperature of water never exceeds 90 deg. C. no matter how long it is applied, no steam will result because the water has not reached the boiling point. In a like manner deterioration in insulation will not occur until its critical point, analogous to the 100 deg. C. for boiling water, is reached.

In case the ambient temperature is under 40 deg. C.—say 20 deg.—it might seem that the motor could be operated at a greater temperature rise. This is possible in some cases but a very dangerous policy and the Institute rules do not sanction such loads as shall occasion in the insulation a temperature rise in excess of 50 deg. C. This is a matter of such importance as to justify reproducing from the Institute rules the text of Section 305A, which follows:

"Whatever may be the ambient temperature when the machine is in service, the limits of the maximum observable temperature or of temperature rise specified in the rules should not be exceeded in service; for, if the maximum temperature be exceeded, the insulation may be endangered, and if the rise be exceeded, the excess load may lead to injury, by exceeding limits other than those of temperature; such as commutation, stalling load and mechanical strength. For similar reasons, loads in excess of the rating should not be taken from a machine."

With reference to horse-power rating, the Institute has adopted two distinct ratings—

one a continuous rating,* the other a short-time rating. The meaning of the first is self-evident. The second will be reviewed. It is, briefly, the equivalent output which a motor can deliver for a specified time, such as during 5, 10, 15, 30, 60 or 120 minutes, without exceeding a temperature rise of 50 deg. C. provided that, after each run and before starting on the next run, the motor be allowed to cool to within 5 deg. of the ambient temperature. It is also understood that the motor must operate without violating the requirements of successful operation, such as commutation, sufficient starting and maximum torque, suitable mechanical strength, etc. The short-time rating is primarily a method of expressing a thermal equivalent. For example, motors built to operate valves are frequently given a five-minute short-time horse power rating because the operations are normally intermittent and the principal requirements are with reference to mechanical strength, torque and commutation. Crane motors are similarly rated on an equivalent 30-minute basis—since crane motors are operated for longer periods of time than valve motors, although somewhat similar torque characteristics are required. Machine tools, compressors, etc., are frequently rated on a 60 or 120-minute basis, as the period of operation and the duty cycle of the load is such as to make this a close heating equivalent. A machine tool, for example, might be operated for a longer period than specified, but the periods of heavy load and light load must be such that the ultimate heating of the motor will be closely equivalent to the rated horse power for the time stated.

It sometimes happens that some certain requirements may prove a limiting factor in rating a motor, with the result that all the other factors have an unnecessary margin between these values and those recognized as safe standards. Where heating is the limiting factor in the rating or selection of a motor, the horse power rating may be said to represent simply the equivalent load which produces the same heating as would accrue under full normal load in continuous operation. Under these conditions, a 10-h.p. motor which will develop 10 h.p. for the period of time specified without exceeding the predetermined safe heating limits, or it will carry a varying load which will result in the same or lower ultimate temperature for the period in question. As an example, consider a 10-h.p. continuous-rated motor. Suppose a duty cycle of 9.5 h.p. 90 per cent of the time is to be imposed on this motor; the other ten per cent to consist of momentary loads of 13 h.p. and underloads of 3 to 7 h.p. The heating effect on the motor due to this duty cycle would be about the same as if 10 h.p. was delivered continuously. It should be borne in mind, however, that the variations of current, rather than the actual variations of mechanical load, must be used in determining the heating equivalent. It should also be noted that while a 10-h.p. continuous-rated motor would meet the heating limitations it would not be satisfactory unless the starting and maximum running torque available were ample to meet the starting and running overloads imposed on the motor, and that successful commutation should not be exceeded.

* Throughout the remainder of this article, "continuous rating" will mean a motor that will operate continuously without exceeding a temperature rise of 50 deg. C.

The capacity and rating of the machine although frequently used interchangeably are not synonymous terms, according to the Institute. The capacity of the machine is the maximum output which it can successfully deliver for a stated period. The rating of the machine is the output stamped on the name plate. The maximum limit for this rating is the capacity of the machine. There is no minimum limit.

The purchaser is usually interested in knowing all the facts about the possibilities of the machine that he is buying; i.e., the capacity of the machine consistent with the requirements of starting torque, maximum running torque, and similar factors. This logically means that the name-plate rating stated in the accepted even ratings should closely correspond with the capacity rating. Such a rating has been referred to as a continuous or 50-deg. rating. Possibly the term capacity rating, within the limits above specified is the most descriptive.

It is obvious that the system which has been widely followed in the past, of giving a normal continuous rating with 25 per cent overload for two hours, is not a capacity but a fractional rating, and that it represents but one form of duty cycle. Under this method of rating, a 10-h.p. motor will carry 10 h.p. continuously with a temperature rise of 40 deg. C., and at any time during such operation will carry $12\frac{1}{2}$ h.p. for two hours with a temperature rise of 55 deg. The temperature rise in these few hours is only a few degrees less than the ultimate temperature which will be attained in eight or ten hours. Consequently, the capacity of such a machine (providing the rating does not under or over state the possibility of the machine) would be about $11\frac{3}{8}$ h.p. continuously or a short-time rating, for 30 minutes, of approximately 15 h.p. This example illustrates that a continuous or capacity rated motor is classed conservatively with reference to heating, since the temperature rise for such an open motor is limited to 50 deg. C. Whereas the temperature rise on a 25 per cent overloaded motor is five degrees higher, i.e., 55 deg. C.

It must not be overlooked, however, that the intent of the Institute rules is not to require a 50-deg. rise but to fix it as a limit for good engineering practice. Designing engineers have long recognized that a temperature rise of 35 deg. in itself was absurdly low, but the object in operating at such low temperature, measured on a part of the motor accessible for the application of a thermometer, was simply to protect the motor in the hot spots where the temperature could not be measured. It had been found by experience that there were hotter parts in the motor than were indicated by thermometer readings. For this reason the exposed parts of the winding not infrequently showed, by thermometer, comparatively small temperature rises of 25 to 35 deg. Therefore, because the temperature rise was so small, it became the fashion to call for 35-deg. rise motors and no doubt the users never knew the real meaning of such low temperatures. Improvements in insulating material, more modern methods of preparing and applying the insulation, together with the knowledge of hot spots gained for tests and experience have contributed to the Institute recognizing 50 deg. as being the safe upper limit. The rules do not, however, require the motors to be so designed as to actually have this temperature rise. Without doubt, designing engineers will retain a safe margin below 50 deg. rise in the continuous-rated motors.

Other factors will also enter to increase this margin of safety. Usually the ambient temperature will be below 40 deg. C. thereby insuring additional safety. Many motors are running today shamefully underloaded and it is to be expected that numerous applications in the future may be at less than the rated load of the motor although it is hoped that the universal disposition to underload will be overcome to a great extent in applying continuous-rated motors. Analyses made by various power companies have indicated that motors are from 20 to 25 per cent larger than necessary causing the installation of excess transformer capacity and running up investment costs. Numerous motors are driving a number of machines each having its own duty cycle such as a machine tool, and investigations have shown that in most applications of group drive, as well as in some cases of individual drive, the demand factor is less than 100 per cent. Evidently such operation will also increase the margin of safety.

Compare the factor of safety of a motor rated in the old way with that of a motor rated in the new. Was the purchaser any better off? No, because the intended margin was not sufficiently definite. A motor of a certain rating with a certain overload guarantee gives much less idea what can be obtained from the machine than a motor rated on the continuous basis. By the old method a motor was capable of carrying 25 per cent overload. If the load is steady and there is no overload, 25 per cent of the possible output of the motor is wasted and the motor is larger than necessary. If it happens that the average load, equal to the rated load, fluctuates up or down ten per cent, there still remains an unnecessary margin of 15 per cent. If the load varies 50 or 100 per cent, the margin of 25 per cent is worthless and the motor would in all probability burn out. To drive a load requires a certain maximum horse-power output. Under the old method of determining the size of a motor, it was customary to deduct 25 per cent from the maximum output required by the machine the motor was to drive and thus arrive at the normal rating of the motor. The new method of rating simplifies the determination by omitting the 25 per cent overload, which is not really overload, and merely stating the maximum load is so much and therefore the motor is rated at that load.

This new and simplified method of rating places on the purchaser the burden of determining the appropriate margin to be provided. The industry is far enough advanced so that the users are capable of selecting their own margin. The application engineers of today are fully conversant with the diversified requirements of the industry, so that they will have no difficulty in selecting the proper motor for each specific case. There is no excuse for guessing at the duty a motor must fulfill. Twenty years of education should have taught the user how to make allowance for the conditions he has to meet. The new method of rating assists both the seller and the buyer by defining more completely the capability of the motor.

Some confusion exists due to the impression that continuous-rated motors will not stand any overload. The motors are guaranteed to stand 50 per cent momentary overload but they are not guaranteed for any overloads which in heating effect are equivalent to greater than their rated output, i.e., that will cause the motor to exceed a 50-deg. C. rise at any time. In case a motor is subjected to peak loads in excess of the ordinary load and the peak endures for more than a short time, it must be included in the rating. If, however, the peak load lasts for brief periods only, the rating must be sufficiently above the ordinary load to give a continuous thermal equivalent to that required on the brief peak loads without exceeding the permissible temperature limits. From the explanation of the short-time rating it is obvious that the machine will actually carry overloads within the maximum-torque capacity of the machine, but the heating equivalent must be within the limits specified or the motor will not be used within the conditions specified in the guarantees.

It is common practice to rate generators on a continuous basis. During the past ten years such generators, particularly those for connection to steam or water turbines, or gas engines, have been purchased very generally on the basis of a 50-deg. C. rise. The tendency is to rate the machine at the highest point it can be operated at safely in continuous service, thus getting the maximum output possible from the investment. In case a margin for overload is desired, it is necessary to increase the rating of the machine so that the name-plate rating equals the maximum load desired. However, transactions arise where it is necessary to rate the generators on a 40-deg. C. basis and in these instances the rating is taken as $83\frac{1}{3}$ per cent of the rating as a continuous-rated machine.

In this same manner it will be possible to tell the capabilities of a continuous-rated motor operating on a 40-deg. C. basis. For example, a 10-h.p. continuous-rated motor will without change operate successfully as a 8.33-h.p., 40-deg. C. motor and as such will be capable of sustaining an overload up to 10 h.p. with 50-deg. C. rise. This is a scientifically correct method and the only equitable one for obtaining a 40-deg. C. rating from a continuous-rated motor. The objection is that when applied to the continuous-rated motor in standard ratings it gives odd ratings instead of the even ratings to which we are accustomed. However, it is not necessary to place the odd rating on the name plate. All motors sold today have a name plate showing, among other factors, the horse power and corresponding temperature rise. Therefore, mark all name plates with the continuous rating and let it be universally understood that the 40-deg. C. rating is $83\frac{1}{3}$ per cent of the name plate rating of a continuous-rated motor.

Another method of obtaining the 40-deg. C. rating from the continuous-rated motor is to "derate" to the next even rating. This means a 10-h.p. continuous-rated motor becomes a $7\frac{1}{2}$-h.p., 40-deg. C. motor. Following this method through the line of even ratings gives ratios of 66, 75, 80, or 83 per cent. It is quite evident that this is not the right method of procedure, as at a 40-deg. C. rating the motor contains more material than is necessary to justify the designated rating. Such a system of rating is entirely wrong as it is a direct blow at the conservation of material—recently, a very important matter.

Under the new system, the continuous-rating system, the purchaser will know exactly what he is getting and pay for that only. Just a little thought will enable the purchaser, his engineers, or the application engineer to select the proper size and type of motor. In the transition period, however, it should be realized when applying these motors that it is particularly unwise to assume that because a 10-h.p. motor with 25 per cent overload for two hours did the work, a motor of the same continuous capacity will do the same work. It may or may not, depending entirely upon the starting and maximum load requirements and the heating equivalent of the cycle of duty, but it should be fully realized that the motor will carry its rated load continuously with as great a factor of safety as will a motor guaranteed to carry 25 per cent overload for two hours, and it will have equally long life and be equally reliable.

Primarily, the manufacturer must make a safe motor for a specified service. The continuous rating and the 50-deg. C. rise proposed is simply a method of stating more clearly and more definitely than ever before just what the motors will do and giving the purchaser the maximum benefit of the material of which the motor is built. The difficulty which some have experienced in facing this new system is chiefly a mental one, for the same factors as formerly will have to be taken into consideration and the purchaser must place before the manufacturer the conditions under which the motors will be required to operate in the same way that he does at present. After all, the motor and not the name plate is to be operated