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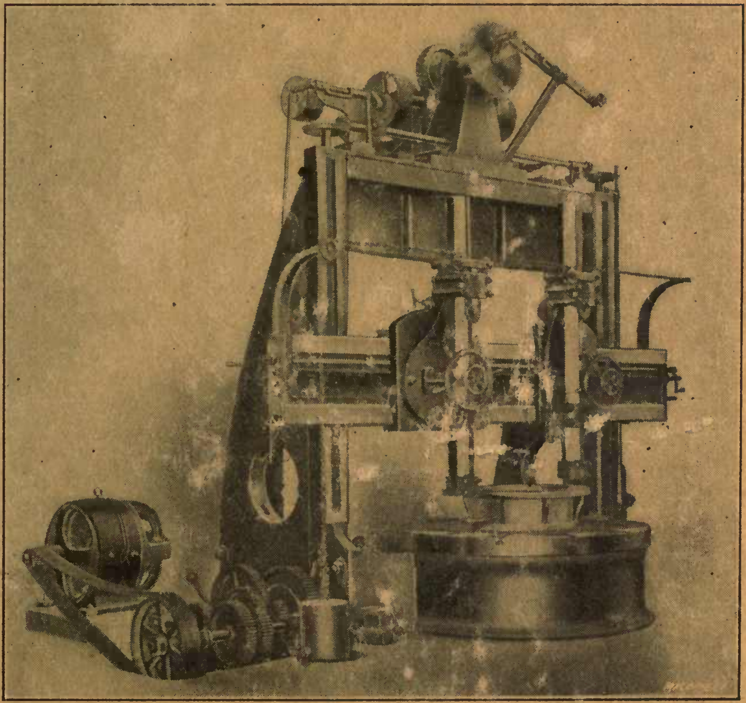
MOTOR DRIVE FOR MACHINE TOOLS

WITH A CHAPTER ON WIRING
FOR MOTOR-DRIVEN MACHINERY



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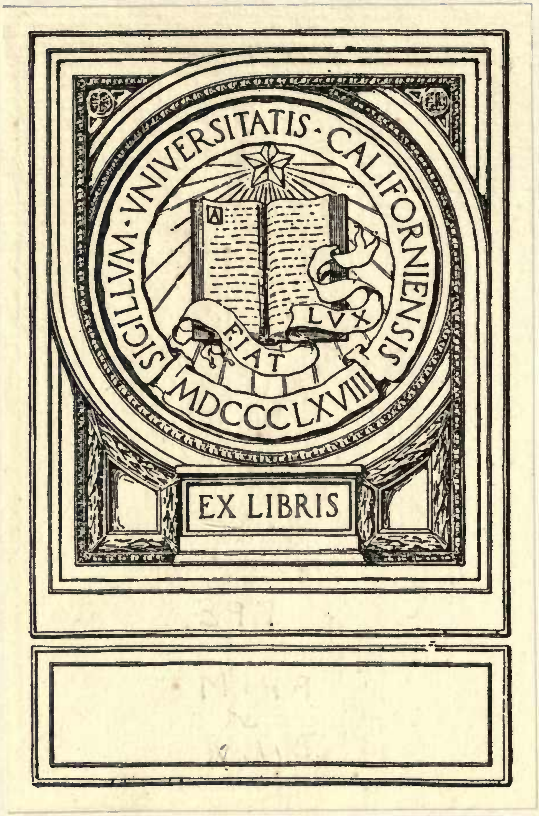
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DESIGN AND SHOP PRACTICE

NUMBER 115

ELECTRIC MOTOR DRIVE FOR MACHINE TOOLS

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CHAPTER I

APPLICATION OF MOTORS TO MACHINE TOOLS*

For the shop where electric power is already installed, all kinds of machine tools may be purchased completely equipped with individual motors. When, however, it is desired to institute a change in a shop that has been employing belts and shafting, and to substitute electric power, it becomes necessary to consider each of the belt-driven tools separately, so as to secure as nearly as possible the same results that are obtained with the tools built for motor drive. At the same time excessive expenditures in the alterations must be avoided. It is the purpose of this article to outline the principles of motor application, and to suggest methods by which the belt-driven tools may be accommodated to motor drive.

The first problem to consider is that of the transmission of the power. In large plants, covering acres of ground, alternating current is employed in order to permit the use of high voltages with the corresponding saving in the copper used for wiring. In plants consisting of but a few buildings, grouped fairly close together, the use of direct current possesses advantages in variable speed possibilities that far outweigh the gain to be secured by the use of the high-voltage alternating current. It is, therefore, the general practice at the present time to use 230-volt direct current for the operation of plants of the nature of machine shops, in which a large part of the load will consist of motors driving tools requiring variable speed. Where long transmissions make the distribution of power by alternating current a necessity, a motor-generator may be installed at the point of distribution for the purpose of supplying direct current to the variable-speed motors. This is often the system employed in the case of railway shops which are spread out over a considerable territory and contain a large proportion of constant-speed tools. Here the transmission current is 440 volts, alternating, and the constant-speed motors are operated on this current, while the motor-generator supplies 230-volt direct current for the operation of the variable-speed motors.

Types of Motors

In the first place the three types of direct-current motors should be thoroughly defined, so that the proper type may be selected for the particular tool to which the motor is to be applied. These three types are series-wound, shunt-wound, and compound-wound motors.

The series-wound motor is one in which the field winding is in series with, or forms a direct continuation of, the armature circuit, so that all of the current that passes through the armature passes

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* Mainly from an article by George H. Hall in MACHINERY, June, 1912.

also through the fields. The amount of current drawn from the line by a motor depends upon the work, or horsepower, which the motor is developing. It therefore follows that in the series motor the strength of the fields will depend upon the load which is placed on the motor, and as the speed of the motor depends inversely upon the field strength, the speed of the series motor will be inversely proportional to the load. Since the speed of a motor also depends upon the voltage that is impressed upon the armature, the speed of a series motor may be controlled by introducing resistance in series with the armature, and this is accomplished by means of a controller which is used also for starting the motor. The use of the controller enables the operator to start the motor slowly under light loads, and also prevents too great a flow of current when starting under heavy loads. The characteristics of the series motor are heavy starting torque and a speed dependent upon the load.

The shunt-wound motor is one in which the field winding is connected across the main lines, or is said to be in shunt with the armature circuit. The amount of current passing through the fields is inversely proportional to their resistance, and, except in the case of the variable-speed motor which will be treated later, remains practically constant under all conditions of load. This results in a constant-speed motor whose output, in horsepower, is dependent upon the current, in amperes, which passes through the armature. The characteristic of the shunt-wound motor is approximately constant speed under all conditions of load.

The compound-wound motor is one having both a shunt and a series field winding. The shunt field is connected to the main line as in a shunt motor, while the series field is in series with the armature and carries all of the current passing through it as in the series motor. The field of an average compound motor is composed of about eighty per cent of shunt winding and twenty per cent of series winding, although this proportion may be varied to suit the class of work for which the motor is to be used. The speed of a compound motor is more nearly constant than that of a series motor, but the drop in speed from no load to full load is considerably more than in a shunt motor, owing to the action of the series part of the winding. The characteristics of the compound motor partake of those of both the series and the shunt motors in about the same degree as the relative proportion of the two windings composing the field.

Selection of Direct-current Motors for Factory Use*

The prospective purchaser should ascertain accurately the desired speed or speeds of the machine to be driven, and the maximum horsepower as well as the average horsepower required to do the work. The speed or speeds of the driven machine may be ascertained by tests conducted with an experimental motor, or from data furnished by the builder of the machine, where such information is available. Often

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* Abstract of an article by Earle D. Jackson in the "Engineering Magazine," September, 1911.

the motor drive is to replace a steam drive, or individual motor drives are to replace an existing motor-driven group drive, in which cases the speeds are easily determined.

Horsepower Required

The horsepower required to do the work should be determined as accurately as possible. The purchaser may rent an experimental motor and ascertain the power required, which is probably the most satisfactory way to solve the problem. The group drive generally requires that this testing be done, as the amount of power required under actual conditions for a group of machines of different kinds and sizes is problematical, and the information cannot be obtained from the machine manufacturers as can often be done in the case of an individually driven machine. It should be remembered in this connection that from the input to the test motor as measured with a wattmeter, or with a voltmeter and ammeter, should be subtracted the test-motor losses, as the motor to be purchased is rated on horsepower output or brake-horsepower. Money spent in the accurate determination of the amount of power required is wisely expended—a fact often overlooked by the factory manager.

Machine-tool builders, motor manufacturers, and central stations are often called upon to supply the information as to how large a motor should be. Without accurate data, the machine-tool builder often overestimates the horsepower required for driving his tools, in order to be on the safe side, with the result that the motors run at one-quarter to one-half load day in and day out, at greatly reduced efficiency. The electrical losses, together with interest and depreciation on the unnecessary extra investment, may amount to a considerable sum in a large installation. It certainly behooves the machine-tool builder to have on hand (and, of course, many of them do) accurate data acquired from carefully conducted tests, covering the performance of his motor-driven machines under all conditions of load and speed.

The motor manufacturer often has in his own establishment individual machine-tool drives and group drives similar to those of the prospective purchaser, in which event he can supply the necessary information as to the size of the motor. Many up-to-date central stations also have a vast amount of data on power required for different motor drives, derived from actual tests under working conditions, which are always available to a prospective power consumer.

The piece-worker requires a relatively larger motor for the same tool than does the operator working by the day. In the former case, heavy cuts at the higher speeds will be the rule, together with quicker starting and more continuous running of the motor, as the piece-worker crowds his machine to the limit, and must be provided with ample motor capacity. Nothing is more discouraging to a workman than to find out that the motor will not perform all the work he requires of it, or is continually giving trouble.

Group Drives*

A few years ago when the electric motor drive began to take a prominent place in manufacturing plants, many factories changed from the old method of belting the engine to a large drive shaft, which was connected by belts to long lines of shafting throughout the plant, to the individual motor drive having a separate motor attached to each machine. The owners soon discovered that this made a very expensive installation, and this form of drive, although the most flexible, is gradually giving way to the group drive for light machine shop work. In the group drive a motor drives a short length of lineshafting which, in turn, drives the machine tools. This arrangement makes the first cost considerably less than that of the individual motor drive, and if planned systematically it is almost as flexible as the latter method.

The best arrangement for the group drive is to divide the machine shop into small units, having a motor for each department or each kind of machines. The lineshafting should be as short as possible and the motors placed in accessible positions, so that they can be watched and easily replaced in case of a breakdown. A small platform makes an excellent mounting for a motor, as it can be easily inspected and removed if found necessary. Experience has proved that motors suspended from the ceiling do not receive as careful attention, and a further disadvantage of this method of mounting lies in the fact that the motors are difficult to replace when set up in this way. With the proper equipment, a motor can be removed from a platform and a new motor installed in less than fifteen minutes. By carefully planning a group drive system, all the lineshafting can be run at the same speed and a standard size motor adopted for the entire shop. This does away with the necessity of carrying a number of different sized motors in stock and standardizes the motor equipment of a factory.

It is often impossible to obtain reliable data for figuring the proper size of motors to drive machine tools. During the installation of mechanical equipment in an automobile engine factory, the machine shop was carefully laid out and a copy of the drawing, together with the sizes of machine tools, kind of work, speed and other technical information were sent to the different machine tool builders with the request that they give the exact power requirements for their machines when operating on the group drive system. The replies were carefully tabulated and after a careful analysis, it was shown that machine tool builders were giving the same results for group drive as for the individual drive, overlooking the fact that some of the machines would be idle and others consuming only a small amount of power at the time when the remaining machines were absorbing the maximum amount of power. These conditions all tend to equalize one another, so that the average power used by each machine would be considerably less for the group drive than the maximum power demanded for the individual drive.

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* From an article by Harry C. Spillman in MACHINERY, June, 1913.

POWER REQUIREMENTS OF MACHINE TOOLS

Kind of Machine	Kind of Work	Per Cent of Machines Running	Floor Area for Machine and Operator in Square Feet	Total Average Power Per Machine in Watts*	Total Average Power Per Machine in Watts†	Friction and Line-shaft Load Per Machine in Watts†	Average Power Used in Doing Actual Work, in Watts*	Total Power Per Square Foot of Floor Area, in Watts
No. 2 Horizontal Rockford Boring Mills	Boring Bearings in Aluminum Cases	85	150	1620	1320	1100	300	8.8
No. 4 Cincinnati Millers	Light Milling on Aluminum	100	120	995	995	830	500	8.3
16-inch Lodge & Shipley Lathes	Turning Small Forgings	60	55	900	555	500	87	10.1
Double Disk Grinders; Double Buffers; Two Wheel Emery Stands	Grinding and Polishing	55	55	1800	1000	300	830	18.2
24-inch Bullard Vertical Lathes	Heavy Cuts on Cast Iron Flywheels	100	100	1350	1350	350	1000	13.5
24-inch Gould & Eberhardt Gear Cutters	Cutting Small Cast Iron Gears	100	65	333	333	250	83	5.5
Four Head Ingersoll Milling Machines	Making Four Cuts on Cast Iron Cylinders	100	300	3550	3550	2300	1250	11.8
Baker Single and Bausch Multi-Spindle Drills	Drilling and Tapping Cast Iron	40	70	1530	637	550	217	9.1
Heald Grinders, No. 60 Internal Grinders ‡	Cylinder Grinding	85	70	2830	2430	1860	500	34.7
No. 6 Whitney Hand Millers	Keyseating Small Cast Iron Gears	60	40	365	220	120	165	5.5
Landis No. 2 Grinders	Grinding Cam Shafts	80	90	1875	1500	1000	625	16.7
Norton 10- by 50-inch Grinders	Grinding Pistons and Small Forgings	70	100	2000	1400	1100	450	14.0
Jones & Lamson Flat Turret Lathes	Machining Small Forgings	85	65	675	560	200	375	8.6
Eight Spindle Cincinnati Gang Drills	Drilling and Reaming Connecting Rods (8 holes)	100	110	2840	2840	2000	840	25.8
Potter & Johnston Automatics	Turning Small Cast Iron Gears	100	75	690	690	440	250	9.2
1⅜-inch Gridley Automatics	Machining Cast Iron Pistons	100	200	1520	1520	1250	270	7.6
No. 4 Warner & Swasey Turret Lathe	Machining Small Forgings	65	55	560	360	310	70	6.5
24-inch Cincinnati Drill Presses	Small Drilling on Forgings	90	40	520	474	345	100	11 8

Machinery

* Deducting Idle Machines. † Including Idle Machines. ‡ Exhaust Fan not considered.

Careful tests which have been made since the machine shop was placed in operation show that the shop takes less than one-fifth of the power recommended by the machine tool builders, or in other words, they were figuring over five times too high for the group drive. The accompanying table gives the results of the tests. It also shows that the lineshafting and countershafting consume thirty per cent of the total power, and the total friction losses absorb seventy-two per cent of the total power. This makes a forty-two per cent loss of power from the countershafting to the machine tools, and only twenty per cent of the total power is utilized in doing work. The electrical loss shows eight per cent of the total power. In the table there are two items mentioned as follows: Total average power per machine, deducting idle machines; total average power per machine, including idle machines. These items include all the mechanical power of that department, such as lineshafting, countershafting, machine friction and power consumed in doing work on the machines. In the first case this total power is equally divided among all the machines which are in operation. In the second case it is divided equally among all the machines, both running and idle. The electrical losses are omitted in all cases.

Having determined the speeds of the driven machines and the horsepower required to do the work under all conditions, a knowledge of the various types of direct-current motors is the next essential in order that a motor may be selected which will fulfill the conditions required of it in the most acceptable manner.

Selection of Motors

To determine the type of motor to be employed for the different classes of tools in the machine shop, the character of the power requirements of the tools should be carefully analyzed. In the case of lathes, boring mills, milling machines, etc., in which the work of cutting is continuous, it will be seen that the tool is required to run at a speed which can be adjusted to the character of the work being machined, and when so adjusted will remain practically constant. Also, the tool is usually started before the work of actual cutting begins, so that no excess of power is needed to start. The foregoing requirements correspond to the characteristics of the shunt motor, and for this class of work this motor should invariably be used.

In the case of planers, shapers, slotters, etc., the work is intermittent, being far greater at some portions of the stroke than at others, and for this class of work the compound motor is best suited. The same type of motor is also used for the operation of punches, shears and other tools having heavy flywheels, as the motor will slow down at the period of greatest load, which is just after the completion of the stroke. The actual cut is effected through the inertia of the flywheel, and the maximum load on the motor is that of accelerating the flywheel and bringing it back to normal speed after it has carried the tool through the work.

When operating hoists and cranes, the motor must be started under the full weight of the load to be handled and at the same time slowly enough to prevent the shock of too sudden acceleration. These requirements are best met by the series motor with a controller having a heavy starting resistance, as it provides high torque at low speeds. This type of motor is also used for auxiliary purposes, such as raising the cross-rails of planers and boring mills, traversing the carriages of large lathes, and elevating the tables of horizontal boring mills.

Types of Motors for Different Requirements

The general classification of direct-current motors now included in the standard product of nearly all motor manufacturers is as follows:

Approximately constant speed, no load to full load..............	Shunt motor. Shunt-commutating pole motor.
Semi-constant speed, no load to full load......................	Compound motor.
Adjustable speed, remaining approximately constant for one adjustment, no load to full load	Shunt motor, with adjustable field resistance. Shunt-commutating pole motor with adjustable field resistance.
Adjustable speed, semi-constant for one adjustment, no load to full load.....................	Compound motor, with adjustable shunt field resistance.
Varying speed, varying with the load	Series motor. Series-commutating pole motor.

Constant-speed shunt motors are, of course, used for the operation of groups of machines that are driven by a common countershaft, but for individual drive the constant-speed motor is little used, as one of the greatest advantages of individual drive is the ability to vary the speed of the tool to suit the requirements of each piece being machined. This naturally brings up the question as to where the line should be drawn between tools that should be arranged for group drive and those which may advantageously be equipped with individual motors. No fixed rules can be laid down in answer to this question, but, in general, it is customary to group the smaller tools, as the initial expense of separate equipments for such tools as bench drills, tool grinders, emery wheels, and sensitive drills, often equals or exceeds the cost of the tools themselves. In the tool-room, also, the value of individual equipment is questionable, as the work on each tool is intermittent and there is not the demand for the high efficiency from the tools that obtains in the case of tools used in the manufacturing departments. If the product of a given tool is especially valuable, or forms a very important part of the shop's output, the first cost of the drive is of minor consideration, and an individual equipment which will secure the greatest output is warranted.

Variable-speed Motors

Variable-speed motors, in the generally accepted use of the term, are, strictly speaking, adjustable-speed motors, in that the speed may be adjusted by means of a controller. There are two methods in common practice by which this adjustment of speed may be accomplished. These are known, respectively, as armature regulation and field control.

The first method consists of introducing resistance in series with the armature circuit, thereby reducing the voltage that is impressed on the armature. With constant field strength, as in a shunt motor, the speed of the motor will be directly in proportion to the impressed voltage. If the load on a motor remains constant, the speed will be inversely proportional to the resistance inserted in the circuit, as the torque is in proportion to the current in amperes, and the voltage equals the amperes divided by the resistance. From the foregoing it will be seen that if the motor load varies, the voltage and, therefore, the motor speed will, with a fixed resistance, vary with the load.

Now, consider the output of the motor when armature control is employed; the torque, or turning effort, is proportional to the amperes drawn by the motor, while the horsepower is a function of the product of the volts and the amperes. Thus a motor developing a given horsepower draws from the line a definite amount of current and produces a torque corresponding to that horsepower. If, now, we cut the speed in half, by halving the impressed voltage, while the torque remains the same, the product of the volts by the amperes will be but one-half, and the motor will be delivering but one-half its former horsepower, although it will be drawing just as much current as when delivering the full horsepower. Thus it will be seen that this method of control is uneconomical and gives a speed varying with the load, while the demand of most machine tools is for a drive that will give a desired speed regardless of the load. In employing the method described it is almost impossible to secure slow motor speeds with very light loads. For this reason this method of control is but little used in connection with machine tools.

The second method, that of field control, is most generally used for motors employed in the operation of machine tools. With the voltage impressed on the armature constant, the speed of a motor will be inversely proportional to the strength of the fields. This field strength is directly proportional to the ampere-turns in the field, and as the actual turns of wire must remain constant, the ampere-turns may be easily regulated by inserting resistance in series with the field winding and thus decreasing the current in amperes passing through the field. The torque of the motor is, in this case, proportional to the field strength, and, as the field strength varies inversely as the speed increases, the horsepower of the motor will remain practically constant.

Considering the average class of tools, such as lathes, boring mills, etc., we can readily see that the foregoing motor characteristics correspond to the requirements. When the cutting tool is run at a high speed, the cut taken by the tool is light, and when taking heavy cuts, the speed is slow, thus calling for a practically constant horsepower throughout the working range of the tool.

As the field current is but a small proportion of the total current used by the motor, the total current consumption of motors using this type of control is practically in proportion to the work being done, so that this is an economical method. The speed, also, being regulated by the field strength, is independent of the load, so that for a given controller position it will be practically constant regardless of the power developed. As a matter of fact, the shunt motor with constant field strength will vary about 5 per cent from no load speed to full load speed.

Open or Enclosed Motors

The question whether to employ the open or enclosed motor often arises. The metal covers of closed motors reduce the efficiency and capacity of the motor by preventing free circulation of air around the active elements of the motor. Working conditions will usually decide whether it is possible to use the open motor, which is, of course, the desirable practice, or whether the presence of excessive dust makes it necessary to enclose the moving parts of the motor partially or completely. The partially or semi-enclosed motor should not be placed in a concealed position for the reason that it is then certain to be neglected in an ordinary factory. The perforated covers and wire screens will close up by dust and dirt, and as the result the semi-enclosed motor becomes virtually a totally enclosed motor with a semi-enclosed rating and consequent trouble.

General Considerations

Vertical motors are made in a number of sizes, but are only to be recommended when the nature of the drive makes it apparent that they possess great advantages over the standard or horizontal type, as vertical motors are troublesome to keep in running order and require greater attention. They are not generally kept in stock by local dealers, and the motor, as well as repair parts, must be replaced from the factory stock at the risk of the usual delay in shipment.

Manufacturers' standard sizes and speeds of motors should be chosen wherever possible, in preference to motors of special sizes and speeds, as prices, time of delivery, and general performance of the former will be found to be more favorable than those of special design. In many cases, it will be found impossible to select from the standard sizes and speeds of a single motor manufacturer only, all the motors which are required, and in this case there is no valid reason why the order should not be divided up and the motors purchased from the builders whose standard product meets the required conditions.

The direct-current voltage now practically standardized for factory use is 220 volts. This voltage is both economically and operatively superior for direct-current motor systems to that of 110 volts sometimes employed.

Types of Drives

Having determined the horsepower and selected the type or types of direct-current motors desired, the best means to employ in driving the machines is the next problem that is confronted. In considering a belt drive, a greater pulley reduction than 5 to 1 is not to be recommended. Idlers to increase the arc of contact, or countershafts between the motor and the driven machine to reduce the initial speed of the driver, are doubtful expedients, unless the amount of power used is very small. It is an easy matter to design a belt drive of this kind in which 20 to 30 per cent of the power of the motor is wasted between the motor and the driven machine.

Direct-connected drives, gear drives, and silent chains constitute a list of positive drives from which it should be possible to select a satisfactory method of driving a machine from a motor, in which safety, reliability, and economy of operation are all present. The direct-connected drive is the ideal drive, as it eliminates all intermediate power-absorbing apparatus. In a great many cases, however, the use of the direct-connected drive necessitates the employment of a special motor. It is unfortunate, in this respect, that machine-tool builders and motor manufacturers often disregard each other when it comes to the selection of standard speeds for their respective machines, although they are collaborating more than they did formerly. The silent chain as a means of driving machines is coming into wider use. The early types of silent chains were expensive, rapidly depreciated, and in many installations were far from being "silent." In point of efficiency, the silent-chain drive stands next to the direct-connected drive. The main objection to the gear drive is its excessive noise, but this may be overcome to a large degree by the use of a rawhide pinion.

Specifications

Specifications should be drawn which state in detail the number of motors required, the horsepower of each motor, the desired motor speed or speeds, together with the speed or speeds of the corresponding driven machine, and the name or description of the machine, giving the number of hours of its probable use per day; whether the motor is to be of the open, semi-enclosed, or enclosed type; the line voltage; details of the motor drive, including pulleys, gears, chains and sprockets, of both driver and driven machine; and whether the motor foundations are to be included in the contract price. Specifications should be submitted to at least three reputable motor manufacturers for quotations, giving cost complete in the case of each separate motor, weights and mechanical sizes of motors offered, efficiencies at one-quarter, one-half, three-quarters, and full loads, for all ranges of speed called for, speed regulation from no load to full load, commutation at all loads and speeds, temperature rise, overload capacity, times of delivery, and description of all starting and field or other rheostats to be furnished, as well as complete description of each motor. Each one of the foregoing items should be known, if intelligent comparison and selection are to be made. The specifications may also call for a test of each motor purchased, to be made by the purchaser or his engineer after the motors are in place and before final acceptance, to demonstrate whether or not all of the required conditions have been fulfilled.

TABLE I. TYPICAL LINE OF VARIABLE-SPEED SHUNT MOTOR RATINGS

Frame	2 to 1 Range			3 to 1 Range			4 to 1 Range		
	H. P.	Min. R.P.M.	Max. R.P.M.	H. P.	Min. R.P.M.	Max. R.P.M.	H. P.	Min. R.P.M.	Max. R.P.M.
No. 1	½ ¾	625 800	1250 1600	⅜ ¾	475 800	1425 2400	¼	500	2000
No. 2	¾ 1¼	525 800	1050 1600	¾ 1¼	525 800	1575 2400	⅝	415	1660
No. 3	2 2½	675 900	1350 1800	1½ 2	500 675	1500 2025	¾ 1	450 550	1800 2200
No. 4	2 3½	400 625	800 1250	2 3½	400 625	1200 1875	2	400	1600
No. 5	2½ 3¼	500 725	1000 1450	2½ 3¼	500 725	1500 2175	1½ 1¾	450 550	1800 2200
No. 6	2½ 4	400 550	800 1100	2½ 4	400 550	1200 1650	2½ 3	400 550	1600 2200
No. 7	4 5½	400 525	800 1050	4 5½	400 525	1200 1575	5½	525	2100
No. 8	5½ 7½	650 800	1300 1600	3¾ 5½	450 650	1350 1950	3¾	400	1600
No. 9	5 7½	325 460	650 920	5 7½	325 460	975 1380	6	450	1800
No. 10	10 12	875 1000	1750 2000	7½	625	1875	3 5	300 450	1200 1800
No. 11	15	750	1500	12½	600	1800	5 7½	300 350	1200 1400
No. 12	20	800	1600	15	575	1725	10 12½	375 450	1500 1800
No. 13	25	750	1500	20	600	1800	12½ 15	375 425	1500 1700
No. 14	35	825	1650	20 25	500 600	1500 1800	15	375	1500
No. 15	40	675	1350	25 30	400 525	1200 1575	20	350	1400

The investment in a set of inexpensive but reliable electrical measuring instruments is to be highly recommended in connection with a motor drive. For a small installation, the set should include a portable voltmeter, ammeter, and wattmeter. For a large installation, a considerable investment is sometimes warranted. Thus on important machines, graphic wattmeters can be installed, showing at any time of the day the amount of power used. These instruments, moreover, can be moved from place to place, until every motor in the shop has been included, thus acquiring valuable data for shop records. This is especially valuable immediately after a drive is installed as a means of ascertaining whether or not a motor of proper size and characteristics has been selected.

Application of Motors to Machine Tools

Considering the application of motors to specific tools, we can best divide the problems presented into two classes. The first class comprises those tools in which the removal of metal is continuous, such as lathes and drilling machines. The second class contains those tools in which the removal of metal is intermittent, as with planers, shapers and slotters.

For use with machine tools of the first class, variable-speed shunt motors will be employed, and the next point to be considered is the speed range for which they must be adapted. For a given horsepower the size of the motor will be inversely proportional to the minimum speed, and as the use of gearing or chain drives places a practical limit on the maximum speed, the minimum speed, and consequently the size of the motor, will depend upon the speed range. The best idea of the actual results that can be obtained with field controlled motors may be secured from a table showing the outputs and speed ranges of a standard line of such motors. Although different makes vary somewhat in their ratings from those given in Table I, this gives a correct average of the various lines upon the market.

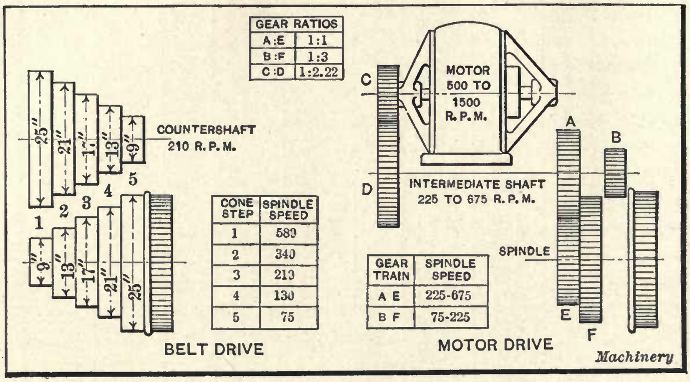


Fig. 1. Comparison of Belt and Motor Drive of Engine Lathe

With a wide motor speed range, a larger part of the working range of the tool is, of course, covered than with a more limited range, but as it is impracticable to cover the entire working range of such a tool as a lathe or boring mill by a corresponding motor range, it is customary to use one or more mechanical speed changes to augment the electrical range. The problem is, therefore, to select a motor speed range that will give satisfactory results without involving too elaborate mechanical changes. Actual experience has shown that, under average conditions, a motor speed range of 2½ to 1, or 3 to 1, together with two mechanical speed changes, will cover practically any range of speed that is obtainable with a cone-pulley drive on any of the ordinary types of machine tools.

To show just how this works out, we will take an actual case of an engine lathe provided with a five-step cone pulley. In making applications to old lathes it is desirable to retain the back-gearing, while the cone is removed from the spindle sleeve and two gears mounted thereon as shown in Fig. 1. The motor is placed above the headstock, on a bracket, and is geared to an intermediate shaft running directly below. This shaft carries two gears, *A* and *B*, either of which may be meshed with its corresponding spindle gear *E* or *F*. The engraving shows a comparison of the spindle speeds obtained with the original belt-drive and those that may be secured by the application of a 3 to 1 motor. Not only is the range of spindle speeds increased, but whereas in the belt range of 75 to 580 revolutions we obtained but five distinct speeds, with the motor and a twenty-step controller we obtain a range of 75 to 675 revolutions with forty different running speeds, varying by about 6 per cent. This calculation considers only the range of speeds obtained without the back-gearing of the lathe and the range is, of course, repeated at correspondingly lower speeds by the introduction of the single or double back-gearing with which the lathe is provided.

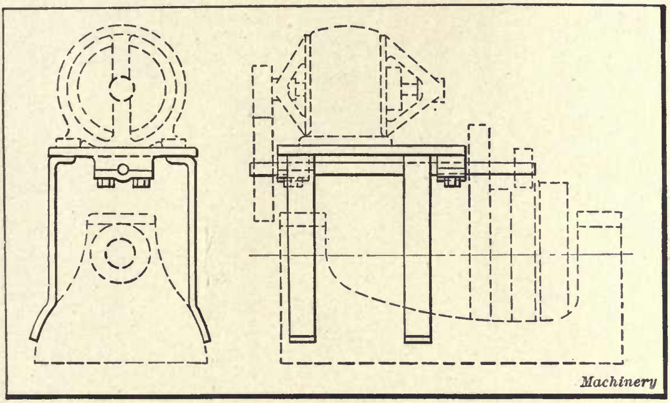


Fig. 2. Plate and Brackets for Supporting Motor

Just here it may be well to point out one of the greatest advantages of the motor drive. It will be noticed that the belt drive, which gave a range of 75 to 580 revolutions, did so in five steps varying by at least 60 per cent per step. If the lathe is running on, let us say, the fourth step it may be found that the cutting speed, owing to the size of the work or the condition of the tool, is not as high as could be used to best advantage. To jump to the next speed, however, increases the cutting speed over 60 per cent, which will be too much, and the work will consequently be done on the fourth step, although this may be 30 or 40 per cent below that at which the best economy would obtain. With a motor drive giving speed increments of 6 per cent or less, the work can at all times be done at practically the best speed, and the increase of output that will be thus secured will be readily appreciated.

Another typical case where the advantage of the motor drive is clearly shown is in the facing of a large surface such as a flange. The ordinary practice is to adjust the speed properly for the cut at the largest diameter and then cover the entire surface at this speed, although, as the tool approaches the center, and the cutting diameter becomes smaller, the cutting speed will be too low. To be sure, an energetic lathe hand can shift his belt from time to time as the work progresses, but this is practicable only after a reduction in speed of the 60 per cent made necessary by the large intervals between the cone steps. With the motor drive, requiring only the slight movement of the controller handle to adjust the speed, the operator will continually "notch-up" his controller, so that the entire surface will be covered at practically maximum speed.

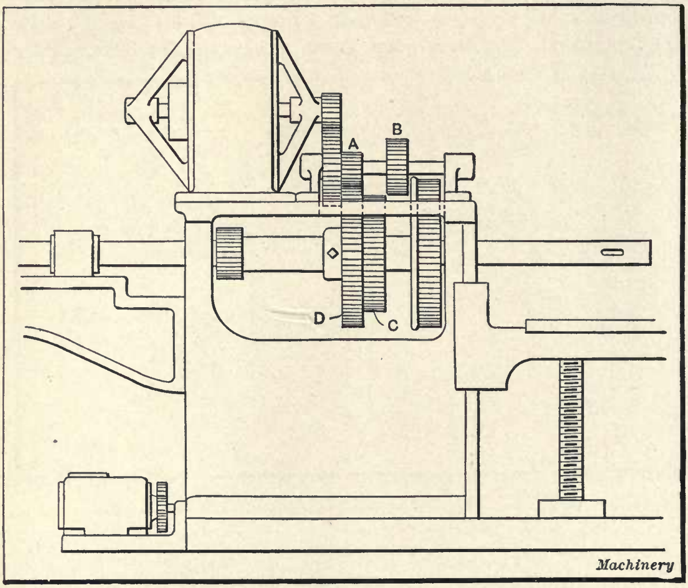


Fig. 3. Motor Equipment of Horizontal Boring Machine

In making this application to belt-driven lathes, if a considerable number are alike, it will be found economical to make a pattern and cast a bracket that can be attached neatly to the headstock. This bracket will be provided with bearings for carrying the intermediate shaft below the motor. As this entails expensive pattern work, it will be cheaper, if the number of similar lathes is small,

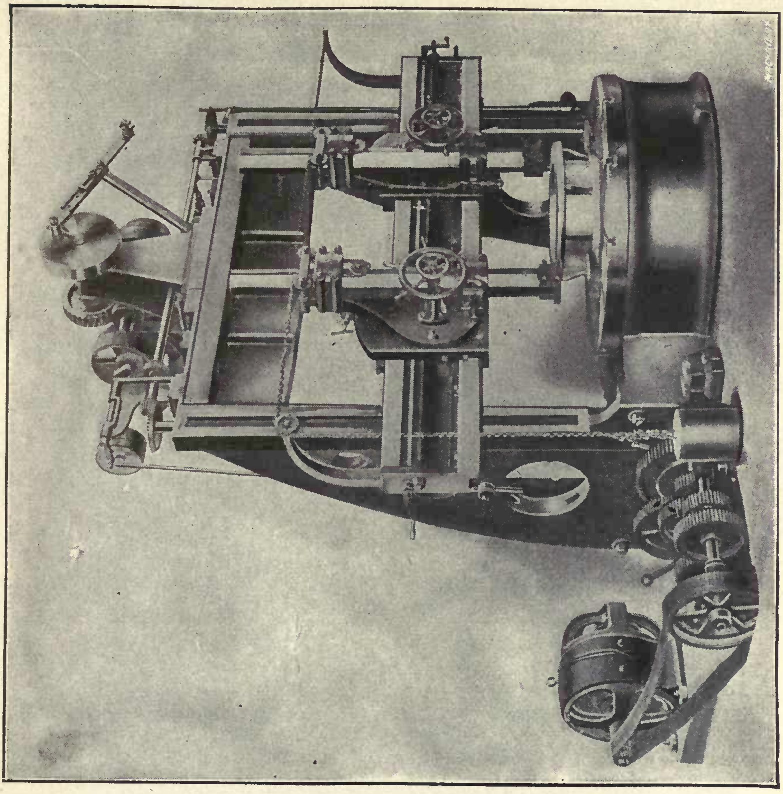


Fig. 5. Motor Equipment of Large Boring Mill

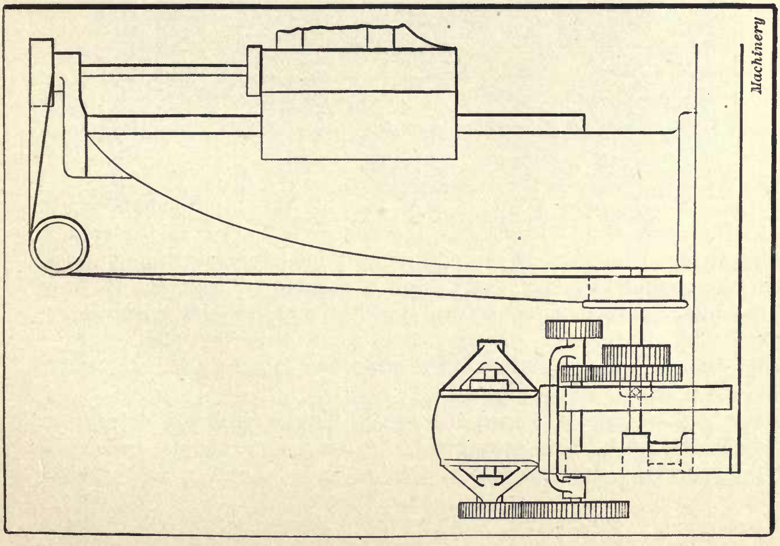


Fig. 4. Motor applied to a Radial Drill

to use wrought-iron brackets to support a plate on which the motor can be placed. This plate will require a very simple pattern which can be readily changed to suit different sizes of motors for various tools with which it can be employed. Fig. 2 gives a general idea of such a bracket, and indicates the method of supporting it over the headstock of a lathe.

The same scheme works out very satisfactorily for applying motors to other types of tools, although certain modifications may be needed in order to obtain the best results. Fig. 3 shows a horizontal boring machine which has been equipped in a manner similar to that of the lathe. The cone is replaced by the two gears *C* and *D*, but in this case the pinions *A* and *B* are fast on the intermediate shaft, while the gears *C* and *D* are free to slide on a feather in the spindle quill, so as to be engaged at will with their corresponding pinions. The intermediate shaft, in this case, is carried in brackets in front of the motor rather than beneath it. Fig. 4 shows how this type of drive, with underneath intermediate shaft, may be applied to a radial drill, and the same arrangement will be found readily applicable to upright drills.

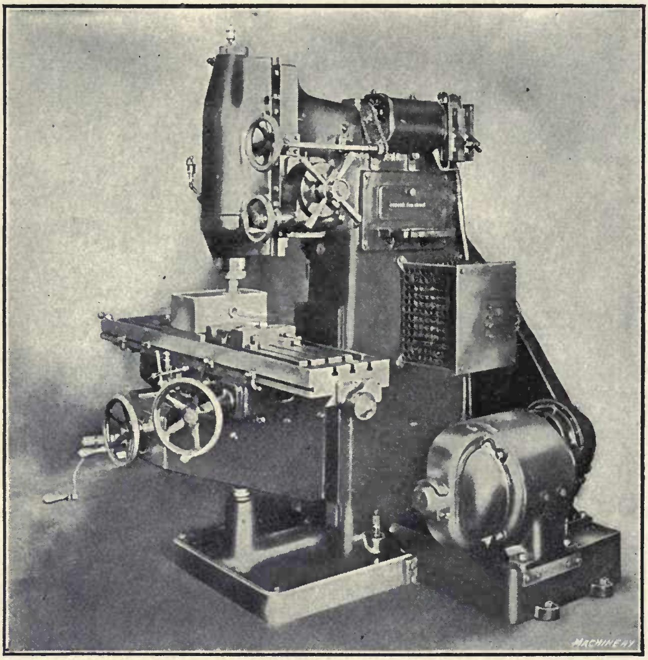


Fig. 6. Motor applied to a Vertical Milling Machine

The halftone Fig. 5 shows the application of a motor drive to a large boring mill. The arrangement is extremely simple, consisting of replacing the driving pulley with a chain sprocket, and driving from the motor which is set at any convenient near-by point. The two pinions for the gear changes are seen in front of the original driving gears of the mill.

For operating milling machines the most successful applications are made with chain drives. The motor may be placed on a floor base attached to the base of the machine, or it may be bracketed onto the top of the machine, illustrations of both of these arrangements being shown in Figs. 6 and 7. The latter motor position is preferable, as the chips from the machine necessitate the use of a fully enclosed motor if it is placed below the table of the machine. The examples shown are offered mainly as suggestions, as the construction and speeds of each particular tool will call for separate consideration.

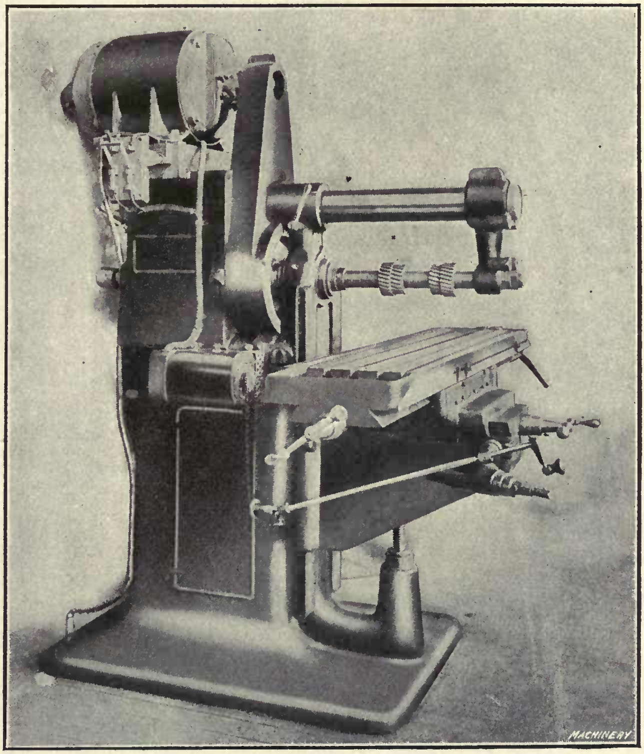


Fig. 7. Motor Equipment of Universal Milling Machine

Horsepower Required

Having decided upon the desirable speed range and the mechanical details of the application, the next problem is the selection of a motor of suitable power. Upon this point no positive rules can be followed, as so many factors enter into the consideration. For the operation of a lathe for general work a 5-horsepower motor might be fully adequate, while for driving the same size of lathe for manufacturing purposes, and using only high-speed steel at maximum cutting speeds, a 10- or even a 15-horsepower motor might be needed. For running a milling machine, for example, it is obvious that a much smaller motor could be employed if the machine were to be used only for finishing work, with light cuts, than would be needed on the same machine if it were to be used for heavy roughing work. Any tabulated data, therefore, based on the size of the tool, must necessarily give averages only, and should be modified by one's best judgment, based on the actual conditions obtaining.

TABLE II. AVERAGE POWER REQUIREMENTS OF ENGINE LATHES

	Character of Work			Character of Work	
Swing, Inches	Light, H. P.	Heavy, H. P.	Swing, Inches	Light, H. P.	Heavy, H. P.
12	½	1	30	3	5
16	1½	2	36	5	7½
18	2	2½	42	7½	10
20	2½	3	50	7½	15
24	3	5	60	10	20

TABLE III. AVERAGE POWER REQUIREMENTS OF BORING MILLS

Swing, Inches	Horsepower	Swing, Inches	Horsepower
20	1 to 2	72	10 to 12½
30	3 to 4	84	12½ to 15
40	5 to 6	96	15 to 20
50	5 to 7½	120	20 to 25
60	7½ to 10		

A most excellent plan is to determine the power requirements, by actual test, before purchasing the motors. This can be done, at a comparatively small expense, by belting a test motor to each tool successively, and taking readings with a recording ammeter for a day or two while the tool is running under actual operating conditions. Remember that all good motors have a 25 per cent overload capacity for periods of at least two hours, so that if the day's run on a certain tool shows about 7½ horsepower as the average load, with occasional peaks, for short runs, of 8 or 9 horsepower, a 7½ horsepower motor will be sufficient. The accompanying tables which have been compiled from the recommendations of the tool builders and from actual tests, will, with the modifications mentioned, serve as fairly accurate guides in the selection of proper motors.

As universal milling machines are usually rated by numbers, rather than by any dimension, a tabulation of their requirements is somewhat difficult, but for comparison the figures are given for the Brown & Sharpe machines, and these will serve as a guide for the equipment of machines of other makes.

For horizontal milling machines the power requirements may be based upon the machine capacity as expressed by the width between the housings.

Application of Motors to Planers, Shapers, etc.

The second class of tools comprises those in which the cutting stroke alternates with a non-cutting return stroke, as in the case of planers, shapers and slotters. Here the successive operations of the tool occur in cycles, as shown in Fig. 8. The highest points in the cycle are those which occur when reversing takes place. As the return stroke is taken at two or three times the speed of the cutting stroke, the power required to accelerate the bed of the planer or the head of the slotter to its return speed usually constitutes the greatest power demand, while a somewhat lower point is reached on the reverse to cut. It is not, however, necessary to power the tool to meet the extreme peak, as the overload capacity of the motor will take care of this demand. Instead, the average cutting load represents the desirable nominal rating of the motor.

TABLE IV. AVERAGE POWER REQUIREMENTS OF DRILLING MACHINES

Swing, Inches	Upright, H.P.	Radial, H. P.	Swing, Inches	Upright, H.P.	Radial, H. P.
18	1 to 1½	......	48	2 to 3	3 to 4
24	1 to 1½	......	54	....	3 to 5
36	1½ to 2	2 to 3	60	....	4 to 6
42	2 to 2½	2 to 3	72	....	5 to 6

TABLE V. AVERAGE POWER REQUIREMENTS OF BROWN & SHARPE UNIVERSAL MILLING MACHINES

Machine No.	Horsepower	Machine No.	Horsepower
1	1½ to 2	3	7½ to 10
1½	2 to 3	4	10 to 15
2	5 to 7½		

TABLE VI. AVERAGE POWER REQUIREMENTS OF HORIZONTAL MILLING MACHINES

Width between Housings, Inches	Horsepower	Width between Housings, Inches	Horsepower
12	3 to 3½	36	9 to 10
18	4 to 5	42	12½ to 15
24	7 to 7½	54	15 to 20
30	8 to 9		

In this class of work, a constant speed of the motor is not of as great importance as with constant cutting tools, but it is, rather, desirable that the motor shall be designed to take care of the overloads that occur at the reversals, and for this reason motors for use with tools of this class should be compound-wound. The result is that, as greater demand is made on the motor, the increase of current that passes through the fields strengthens them, and thereby increases the torque of the motor. This also causes the motor to slow down, so that the speed for which the motor should be adjusted is that desired when operating under cutting load. On the return, when the load is light, the motor will consequently run faster than during the cutting stroke.

The average cutting speed of any of this class of tools will be between 25 and 50 feet per minute, so that a 2 to 1 range motor is sufficient for nearly all cases and often a range of 1½ to 1 will be found satisfactory. Compound-wound motors are not used for such wide speed ranges as the shunt-wound motors, since any considerable weakening of the shunt field so changes the relation of the shunt to the series winding as to cause the motor to attain the nature of a series motor, which is undesirable.

In some new planers on the market, pneumatic or magnetic clutches are used for reversing, but in equipping old tools it will be found more practicable to retain the cross-belt drive with belt shipper. A diagram of such an application is shown in Fig. 9. The motor is mounted on the top of the planer housings, and geared to a countershaft which carries the driving pulleys. The use of the flywheel on the motor shaft is most desirable, as it greatly relieves the motor on the peak loads. By mounting it on the motor shaft, instead of on the slower running countershaft, the flywheel effect is much increased. It is also well to provide the driving pulleys with extra heavy rims for the additional flywheel effect that they will produce. On slotters it will usually be found convenient to place the motor on a bracket on the side of the frame, and employ a gear drive, while shapers may be either geared or chain-driven, or belt-driven by using an idler as shown in Fig. 10.

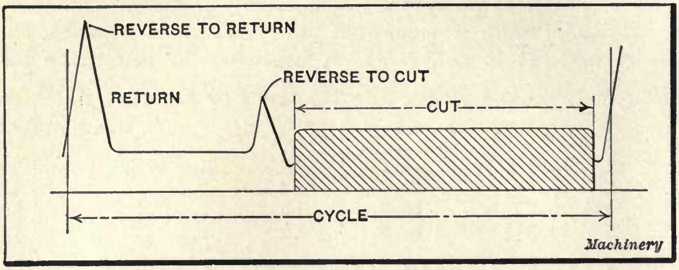


Fig. 8. Cycle of Operations of Planer

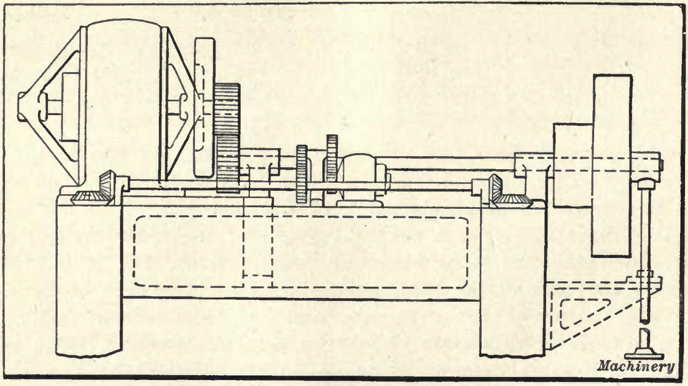


Fig. 9. Motor Equipment of a Planer

The remarks regarding the power requirements for constant-cutting tools apply with equal force to this class of machines.

The figures in Table VII are based on the use of two tool-heads and a return speed having a ratio to the cutting speed of about 3 to 1. If more than two heads are used, or if the planer has a longer bed than that given, the horsepower should be somewhat increased.

In addition to the motors employed for operating the tools of the above classes, there are a number of uses for auxiliary motors as will be noticed in some of the illustrations. In Fig. 3 is shown an auxiliary motor used for raising and lowering the table of a horizontal boring machine, while Figs. 9 and 11 show similar motors employed for elevating and lowering the cross-rails of a large planer and boring mill, respectively. On large lathes auxiliary motors are often used for moving the tailstock along the bed, and they may also be arranged for turning the turret heads on heavy turret lathes.

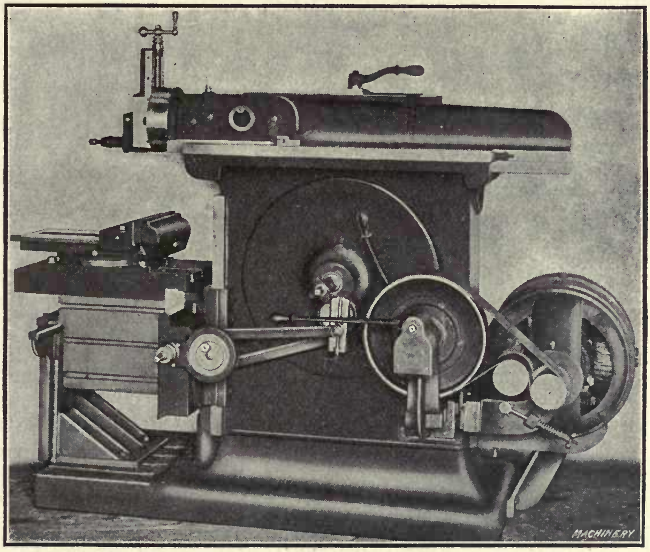


Fig. 10. Motor Equipment of Belt-driven Shaper

Series motors only are used for these purposes, as they are always started under full load, and have their speed regulated by armature control. No rules can be laid down for the power of these auxiliary motors, but the requirements are comparatively small, from 2 to 5 horsepower covering all of the above cases except for the very largest tools. The time of duty is very short. The drives are invariably by means of gearing to the operating shaft, one set of reducing gears frequently being needed to reduce the speed of the motor sufficiently. These motors should never be belted, for if the load should be thrown off, by breaking the belt, they will run up to a dangerously high speed, and may be badly damaged. Another type of auxiliary motor is shown in Fig. 11, where it is used to operate the slotting attachment of a large boring mill. Such a motor should be compound wound and the data relative to slotters are applicable for such motors.

TABLE VII. AVERAGE POWER REQUIREMENTS OF PLANERS

Width between Housings, Inches	Length of Bed, Feet	Horsepower	Width between Housings, Inches	Length of Bed, Feet	Horsepower
84	18	20 to 25	42	10	8 to 10
72	16	15 to 20	30	8	6 to 7½
60	12	10 to 15	20	6	4 to 5

TABLE VIII. AVERAGE POWER REQUIREMENTS OF SHAPERS (SINGLE HEAD)

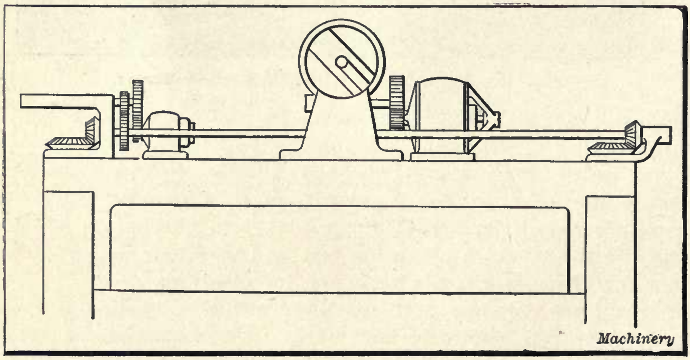
Stroke, Inches	Horsepower	Stroke, Inches	Horsepower
16	3 to 4	24	3 to 5
18	2 to 3	30	5 to 7½

TABLE IX. AVERAGE POWER REQUIREMENTS OF SLOTTERS

Stroke, Inches	Horsepower	Stroke, Inches	Horsepower
10	4 to 5	24	10
12	5 to 6	30	10 to 15
18	7½		

Controllers

For use with motors on machine tools the drum-type controller is most satisfactory, as it has sufficient mechanical strength to withstand the rough usage to which it is liable to be subjected, at the same time being completely enclosed so that all current-carrying parts are fully protected from dirt and chips and from external injury. Drum controllers are built for both armature and field controlled motors as well as for combined control. They may be either reversing or non-reversing, as desired. When used with motors having a 3 to 1 speed range, obtained by field control, they will ordinarily contain about twenty speed steps. In some sizes the necessary resistance is mounted on the back of the drum, while in others it is



Machinery

Fig. 11. Auxiliary Motors on Large Boring Mill

supplied as a separate unit which is connected to the drum by wiring.

The controller should be mounted on the tool at any point to best suit the convenience of the operator. In the case of long lathes a good arrangement is to mount a handle on the lathe apron, and this, by means of gears and shafts can readily be arranged to operate the controller when mounted on the end of the lathe bed.

The resistance, if separate, should be mounted near the controller in order to economize in wiring, but it should be so placed as to be exposed to the air and at the same time protected from dirt and cuttings from the tool. Do not cover up the resistance or place it inside of the tool frame, but select some place above the table of the tool, away from the path of the chips.

Methods of Applying Motors to Machine Tools

In a paper on the Economy of the Electric Drive in the Machine Shop, read at the April, 1910, meeting of the American Society of Mechanical Engineers, Mr. A. L. De Leeuw reviewed the conditions which must be considered in connection with the equipment of a machine shop with electric drive. In conclusion he gave a general idea of the mode of application of motors to machine tools, the selection of motors for different classes of tools, and the lines along which economical results may be expected. The following abstract of these conclusions will undoubtedly be of interest to mechanics in general.

Bench and Speed Lathes

Bench lathes should be driven from a countershaft attached to the wall or bench and driven in turn by a motor. Any kind of motor except a series-wound or heavily compounded motor will do. The object of the motor drive is to get the machine in the best possible location without regard to the location of the lineshafting. A number of these machines may be driven by a common lineshaft, which in turn is driven by a motor.

Speed lathes should be driven from a countershaft located under the lathe, or by a direct-connected motor. In the latter case a variable-speed motor is to be preferred, if direct current is available. Motor drive is recommended when the machine is used in the assembling department, as the machines may then be placed where they are most needed; the crane service would also interfere with countershafts. There will be no material gain, if the machines are to be used for ordinary shop operations.

Engine Lathes

Various methods of driving engine lathes by motors are in use. Some makers furnish motor-driven engine lathes as standard equipment. Some have a headstock with a limited number of speeds, and depend on a variable-speed motor to fill out the speeds of the lathe. Others apply a constant-speed motor, or one with a limited amount of variation, to an all-geared headstock. In general, the use to which this class of machines is put in the shop would naturally lead to group drive. There is no material advantage in the individual motor drive, if the machines are used for regular manufacturing operations, except where the location demands individual drive.

Heavy Engine Lathes, Forge Lathes, Etc.

Heavy engine lathes, and lathes of similar types should be driven by a direct-connected motor. The motor should be direct-current, as these machines are too heavy to permit a convenient all-gear drive. If no direct current is available and there is only one machine of its class in the shop, and this is used for an occasional job only, an alternating-current motor could be used, leaving a wide gap in the speeds. If these machines are used for manufacturing purposes, it would pay to install a small synchronous connector. The speed range in the motor does not need to exceed two to one, though a wider range is better if obtainable without complications or great expense. The position of the motor should be low, as the vibrations in the motor-support have a decided influence on the capacity of the machine, as well as on the repair bill. The output of this class of machines may easily be increased from 20 to 25 per cent by motor drive. Further advantages of the motor drive are the possibility of placing the machine in the line of the routing of heavy work, and of placing it immediately under the traveling crane. This latter object may be reached with a belt-driven machine by placing the headstock under the gallery, if the construction of the shop lends itself to this arrangement, but the same convenience as that of the motor drive cannot be obtained.

Axle and Wheel Lathes

It is of the greatest importance that axle lathes and car and driving wheel lathes should have the highest possible efficiency, and the most convenient location. These machines are mostly used in locomotive and car repair shops, where time saved does not mean merely the saving of wages, but each day gained means an added day in the earning capacity of the engine or car. It is, therefore, important that these machines be motor-driven whenever installed in a railroad repair shop, though this does not mean that they should not be so driven if used for manufacturing. Direct current should be used. The economy of the motor drive should not be figured in increased output, but in reduction of time required to repair an engine or car.

Chucking Lathes

Generally speaking, there is little reason why a chucking lathe should be motor-driven. Most chucking lathes are provided with the necessary mechanism to shift speeds quickly. A few types handling large work may be motor-driven to advantage, though practically the only advantage lies in the fact that small gradations in speed can be thus obtained. Such machines, therefore, require a variable-speed motor.

Automatic Screw Machines

Small automatic screw machines are generally group-driven. Large machines may be individually motor-driven to good advantage. The larger sizes have generally one or two speeds for one piece of work, though these speeds may be varied when the machine is reset for a new piece of work. The speed given to the machine must naturally be proportional to the largest diameter to be turned, or in other words, to the size of stock used. This will reduce the speed for some of the operations, such as drilling and reaming, far below the economical speed. The amount of time saved by the application of the variable-speed motor may be considerable. Where the construction of the machine permits, two motors, one for feed and one for speed, would give still better results. In all cases variable-speed motors should be used.

Drill Presses and Boring Machines

The only reason why the sensitive drill should be individually motor-driven is that it is often used in an assembling department, where height of ceiling and crane service would make a belt drive awkward or impossible. Most sensitive drills have, in themselves, all the speeds required for their work, so that any type of motor will be adaptable. The motor may either be directly applied to the machine or may drive a countershaft on a stand; or it may be placed on the floor by the side of the machine, in case the machine carries its own set of cones or other variable-speed device.

Generally speaking, the upright drill is used for manufacturing operations and does not require frequent changes of speed. There are, however, many exceptions, for instance, where upright drills are used to do all the operations on a piece by means of a jig. In this case frequent changes of tools, and, therefore, of speeds, are required, and an individual motor drive, whether direct-connected to the machine or operating on the countershaft, is of the greatest benefit. No great benefit can be derived from a constant-speed motor with this type of machine. Radial drills may be considered to present the same requirements as upright drills. There is an additional reason why radial drills should be motor-driven—they are often used in the neighborhood of the assembling floor.

When the work for boring machines is specialized and the machines perform only one operation, there is no good reason why motor drive should be preferred to belt drive. Where, however, the machine is used for a multiplicity of operations, such as drilling, boring, reaming and facing, a motor drive is beneficial if a variable-speed motor is used. The range of speed of the motor should be as wide as possible, so that no gears may have to be shifted for the entire set of operations on a single hole. Especially where a boring machine is used for facing, this variable speed will be found highly economical.

Grinders

Grinders, in general, require so many various movements driven from countershafts that it is hardly possible to apply a single motor directly to the machine; the best that can be done is to attach the countershaft to the machine and drive the former from a motor standing on the floor or on a bracket attached to the machine. In isolated cases it would be well to have one or more motors, each controlling a single operation, attached directly to the machine.

Planers, Shapers, Slotters

Planers in general are not benefited by the application of a motor, as the motor only complicates the difficulties of a planer drive. However, large planers which must be placed under a crane give better results when motor-driven on account of the facility of handling the work. Another possible advantage when using a variable-speed motor and controlling the speed of the motor at the end of the stroke is that much higher return speeds can be obtained in connection with any desired cutting speed. What is true of planers is also true of shapers and slotters. Local conditions may make it advisable to drive them individually by motor, but generally speaking, there are no great advantages to be gained with this drive.

Milling Machines

The larger sizes of knee-and-column type machines, if motor-driven, will give the best results if the motor is of the variable-speed type, especially where these machines are used for gang work. This is due to the fact that the speed of the mills is dependent on the largest cutter in the gang, while the feed is dependent on the smallest cutter, not counting the limitations due to the nature of the work. It is therefore important that the speed should be as close to the permissible limit as possible. When applied to this type of milling machine, the motor should be as low down as possible, as vibrations in the machine have a marked effect on the quality of the finish. In practically all cases the planer type of milling machine should be motor-driven, in order that it may be located under a crane. It is not so very important, however, whether the motor is of the constant-speed or variable-speed type.

Punches, Bending Rolls, Shears, etc.

This class of machinery, used largely for boiler, bridge, structural iron and ship-building work, is generally placed in high shops and under cranes, and in locations and directions most convenient for the routing of the work. The shops in which it is placed are generally large and contain a relatively small amount of machinery, so that the amount of transmission gearing required is large in proportion to the amount of machinery. It is for this reason advisable in almost all cases to drive this class of machinery by an electric motor, which, of course, does not need to be of the variable-speed type.

CHAPTER II

WIRING ON MOTOR-DRIVEN MACHINERY

Electrical wiring on the motor-driven machines furnished by even the best manufacturers is too often poorly arranged and inefficiently installed. This is because the wiring is not considered when the machine is designed. Its installation is usually left to some workman who does the best he can. The wiring and arrangement of the control apparatus should be laid out in the drafting-room. This chapter discusses the best methods of machine wiring, describes the materials used, and gives concrete directions, rules and tables for wiring motor-driven machinery.

One industrial corporation which purchases many motor-driven machines incorporates the following clauses in the specifications for all such equipments:

1. The machine manufacturer shall mount the motor and controlling devices on the machine so that they shall form a part thereof, and shall wire between them as hereinafter noted.
2. The controlling apparatus shall be conveniently arranged for manipulation by the machine operator.
3. All wiring shall be installed in accordance with the regulations of the National Electrical Code.
4. All wiring shall be carried in wrought-iron conduit or in metal conduit fittings. These shall be firmly attached to the frame of the machine.
5. So far as possible, all "live" bare metal parts shall be enclosed with metal covers.

It was found desirable to makes these requirements because of the awkward practice prevailing in this respect among machine builders. Frequently, the builder of the motor-driven machine, although he carefully mounted the motor and arranged the drive between the machine and the motor, would fail to mount the motor-starter or controller on the machine. If he did mount it on the machine, in the great majority of cases he would either provide no wiring between the motor and the controller, or install the wiring in such a careless, unbusinesslike manner that it would have to be reinstalled. Usually, the machine builder makes an extra charge for arranging the wiring in accordance with the above specifications; but it was found that the work was done better and more cheaply by the builder than by the wire-men at the plants where the machines were installed. At the present time, when motor-driven machinery is so generally used, machine builders are paying more attention to the electrical details; but there is still much to be desired. In the following will be given some practical information that may be of value to manufacturers desiring to arrange and install the wiring on their machines as efficiently as possible. It is believed that good wiring will be appreciated by the purchaser.

Rule No. 1 in the specifications given states that when the machine is direct-driven the motor and controller should be considered as a part of the machine. Obviously, they are just as much so as is a gear. If possible, the complete equipment should be shipped so that, after setting up, it will only be necessary for the plant electrician to run a pair of wires to put the machine in service. For large machines, which must be dismantled for transportation, the motor and controlling equipment must be shipped separately, and it may be necessary to dismount the conduit carrying the electrical conductors; but if the wiring has been properly connected and the conduit strapped to the machine in the erecting shop, it can easily be reinstalled. Thus, cranes, which have complicated wiring, can be taken apart, shipped, reerected and rewired with very little difficulty.

The desirability of the requirements of Rule No. 2 is so obvious as to need no discussion.

Rule No. 3 requires that all wiring be installed in accordance with National Electrical Code regulations. Standard fire insurance policies require that the electrical work in all plants having insurance protection be installed in accordance with these regulations. It has taken many years to mold the regulations into their present excellent form, and they are revised constantly to keep abreast with the advances in the art. It is therefore essential that machines which are to be installed in plants carrying fire insurance, be wired in accordance with the Code. Even if insurance is not carried, it is advisable to follow these rules, as they outline a substantial and safe method of wiring. A copy of The National Electrical Code will be supplied free to any one making request to the local Fire Underwriters' Inspection Bureau or to the Underwriters' Laboratories, Chicago, Ill.

Rule No. 4 requires that wiring be installed in wrought-iron conduits or in metal conduit fittings. It costs several times as much to run wiring in metal conduit (the properties of conduit are given in Table XII) as to arrange it without mechanical protection. However, it is only the first cost of conduit wiring that is high. When placed in conduit the wiring is done once for all; there is no future trouble from broken wires, grounds or short circuits, due to abraded insulation. When arranged with conduit wiring, the machine is easier to keep clean and looks neater. The conduit fittings (which will be described later) are used at points where wires issue from the conduit or where a turn in the conduit run is necessary and it is not desired to bend the conduit. In general construction, they somewhat resemble screwed pipe fittings, but they are always arranged with removable covers so that the wire is easily accessible. Conduit and fittings are attached to machine frames with either pipe straps (Table XV) or machine screws, as will be described.

Rule No. 5 requires that all "live" bare metal parts be enclosed within metal covers. It is usually feasible to enclose these parts.

Such enclosure prevents metallic chips from forming grounds or short circuits and renders shock to attendants impossible. With the voltages at which machine motors are usually operated, a shock is not often fatal, but one hears of cases where men have been killed from contact with 220-volt circuits. At any rate, an electrical shock is unpleasant, and if there is a possibility of receiving one the attendant is likely to be cautious and waste time. Fire risk is reduced by enclosing "live" parts. Although the Underwriters do not require enclosure they commend it. The electrical manufacturers appreciate the demand for enclosed apparatus, and it is now possible to buy standard starters and controllers, for nearly all applications, that are well protected and so arranged that conduit wiring can be readily installed.

Wire for Motor Application

The size of wire to use for transmitting electrical energy (in low-voltage work such as that involved in industrial-plant wiring) is determined by two requirements, *viz.*, the cross-sectional area must be large enough to carry the current required without getting too hot, but must not be so large as to cause an excessive drop in voltage—electrical pressure—and consequent energy loss. However, the distances involved in wiring machinery are so short that the latter requirement may be disregarded altogether. The only demand is, then, that the wire be big enough to obviate excessive heating.

The National Electrical Code specifies that all concealed wires shall be rubber-insulated and, in addition, that all wires carried in conduit shall have a double-braid covering. All standard rubber-covered wires used for voltages above 10 and below 600 have the same thickness of insulation. Copper wire is almost universally used for interior wiring. Therefore, if the voltage of the motor is below 600, wire for the installation should be specified, for example, thus: No. 6 National Electrical Code Standard, 0-600 volts, double-braid, stranded, copper wire. The size of wire, and whether it is to be solid or stranded, is determined, as will be explained, by the horsepower output of the motor.

So that wire in service will not be dangerously overheated, the Underwriters have specified a certain safe current-carrying capacity for each size of wire and for wires having different insulating materials. In Table X are given the safe current-carrying capacities for all sizes of rubber-covered wire that the machine builder is likely to use. The sizes listed are all commercial ones and are, as a rule, readily obtainable. When the current or amperes taken by any motor is known, the size of wire to be used can be ascertained from Table X. Although Nos. 18 and 16 wires are listed in the table, the Underwriters do not permit the use, for applications such as herein treated, of any wire smaller than No. 14. It will be noted that the wires between No. 18 and No. 8, inclusive, are tabulated as "solid" and those larger than No. 8 as "stranded." Solid wire is that having a solid conductor, while the conductor in stranded wires is twisted up from several or many wires of relatively small diameter. Stranded wires are sometimes called cables. It is the usual practice in conduit work to specify that wires larger than No. 8 be stranded, because, if solid, they are too stiff to be handled and pulled into the conduit readily. Solid wires can be obtained, if desired, in sizes much larger than No. 8 and these are much used in "open-work" wiring. The numbers of wires in a strand given represent the practice of some manufacturers, but other manufacturers have different standards. They vary little, however, from those shown. As a rule, it is not desirable to specify the "number of wires in strand" when ordering, as the dealer may not be able to furnish just the stranding designated from his stock. Any stranded wire, for conduit work, will answer the purpose, and the use of stock sizes will obviate delay.

TABLE X. SPECIFICATIONS FOR WIRE AND CONDUIT ON MOTOR-DRIVEN MACHINERY

Double-braid, Rubber-covered, 0 to 600 Volts, N. E. C. S. Copper Wire, N. E. C. S. Wrought-iron Conduit

	Number of Wire, B. & S. Gage	Area of Wire, Circular Mills	Number of Wires in Strand	Safe Current-carrying Capacity, Amperes	Size of Conduit, Inches		
					1 Wire in Conduit	2 Wires in Conduit	3 Wires in Conduit
Solid Wire	18	1,624	Solid	3	½	½	½
	16	2,583		6	½	½	½
	14	4,107		12	½	½	¾
	12	6,530		17	½	¾	¾
	10	10,380		24	½	¾	1
	8	16,510		33	½	1	1
Stranded Wire	6	26,250	7	46	¾	1	1¼
	5	33,100	7	54	¾	1¼	1¼
	4	41,740	7	65	¾	1¼	1½
	3	52,630	7	76	¾	1¼	1½
	2	66,370	19	90	¾	1½	2
	1	83,690	19	107	1	1½	2
	0	105,500	19	127	1	2	2
	00	133,100	19	150	1	2	2
	000	167,800	19	177	1¼	2	2½
	0000	211,600	19	210	1¼	2	2½
	....	200,000	19	200	1¼	2	2½
	....	250,000	37	235	1½	2½	2½
	....	300,000	37	270	1½	2½	3
	....	350,000	37	300	1½	2½	3
	....	400,000	37	330	1½	3	3
	....	450,000	37	380	2	3	3½
	....	500,000	61	390	2	3	3½
	....	550,000	61	420	2	3½	4
	....	600,000	61	450	2	3½	4
	....	650.000	61	475	2	3½	4
	....	700,000	61	500	2	3½	4

The size of wire to use for machine wiring is determined by the current (amperes) only. The current taken by any motor may readily be computed from rules given in electrical handbooks. If the motor is available, its exact full-load current is, in accordance with a Code rule, stamped on its name-plate. If the motor is not available, a full-load current value, accurate enough for the present need, can be taken from Table XI. It should be understood that the tabulated values are averages and may vary somewhat from name-plate ratings. Different makes of motors of the same horsepower have different efficiencies and, with alternating-current motors, different power factors, and both these appreciably affect the amount of current taken. The figures given in Table XI indicate the current in each wire. That is, they show the number of amperes flowing through each of the two wires to a direct-current or to a single-phase alternating-current motor, through each of the four wires to a two-phase alternating-current motor, or through each of the three wires to a three-phase alternating-current motor.

Having found the current, in amperes, taken by a motor, the size of wire to be used cannot be selected without first considering another point. National Electrical Code, Rule 8b, reads, in part, as follows: "The motor leads or branch circuits must be designed to carry a current at least 25 per cent greater than that for which the motor is rated. Where wires under this rule would be over-fused in order to provide for the starting current, as in the case of many alternating-current motors, the wires must be of such size as to be properly protected by these larger fuses." The machine builder has no means of knowing what size fuses the purchaser of his appliance will use, so that the best thing he can do, ordinarily, is to provide wires capable of safely carrying 25 per cent more current than the full-load rating of the motor in question. The wire size is, then, selected on this basis.

TABLE XI. APPROXIMATE FULL-LOAD CURRENT (IN AMPERES) TAKEN BY ELECTRIC MOTORS

H.P. of Motor	Direct-current Motors			Alternating-current Motors								
				Single-phase			Two-phase (Four-wire)			Three-phase (Three-wire)		
	110 Volts	220 Volts	500 Volts	110 Volts	220 Volts	500 Volts	110 Volts	220 Volts	500 Volts	110 Volts	220 Volts	500 Volts
1	9	5	2	14	8	3	6	3	2	7	4	2
2	16	9	4	25	13	5	12	6	3	13	7	3
3	27	13	6	34	17	8	17	8	4	19	9	4
5	42	21	9	53	26	12	25	13	6	31	15	6
7½	60	31	13	75	38	16	39	20	8	45	22	9
10	77	37	18	93	49	22	44	23	11	51	25	13
15	111	57	26	....	....	....	66	34	15	77	39	17
20	151	76	34	....	....	....	89	44	20	103	52	23
30	226	114	49	...	....	....	135	68	30	155	78	33
40	303	152	67	....	....	....	179	90	39	205	107	46
50	369	183	83	....	....	....	205	102	44	237	119	52
75	551	277	123	....	....	....	310	155	69	356	179	78
100	737	369	162	....	....	....	409	206	91	473	236	105
150	1114	556	245	....	....	....	618	308	137	711	356	157
200	1475	736	326	....	....	....	820	410	183	940	472	210

For example, assume that a 10-H. P., 220-volt., three-phase motor is to be wired. Referring to Table XI, we find that this motor takes about 25 amperes when operating at full load. To allow for a 25 per cent excess current, in accordance with the Code rule, an estimate is made thus: $25 \times 1.25 = 31$ amperes (about). Referring to Table X, a No. 8 (solid) wire which has a safe carrying capacity of 33 amperes is the smallest that can be used.

The insulation on rubber-covered wire deteriorates very rapidly under the action of heat, so if it is necessary to install conductors where they will be subjected to high temperatures, wire having "slow-burning" insulation should be used. Such wire, if enclosed, must be (according to the Code) in "lined" conduit. This conduit is described under the following heading.

Conduit for Motor Application Wiring

Wrought-iron conduit is merely standard-weight steel, or possibly in some cases wrought-iron pipe, which has been thoroughly cleaned to remove burrs and scale, and then either enameled or coated with zinc. Conduit which meets the requirements of the National Electrical Code and which has been approved by an Underwriters' inspector, is called National Electrical Code standard conduit or N. E. C. S. conduit. In Table XII are given the principal dimensions of commercial N. E. C. S. conduit, elbows and couplings. Conduit is furnished only in lengths of ten feet. Electrical conduit is threaded with standard pipe threads and standard-weight screwed pipe fittings will fit it.

In addition to the "unlined" conduit, described above, a "lined" conduit is manufactured which has a relatively thick insulating lining. The lined conduit is seldom used as it is more expensive than the unlined and the latter has given entire satisfaction. The insulating lining appears to be unnecessary, as the rubber insulation on standard wire provides excellent protection.

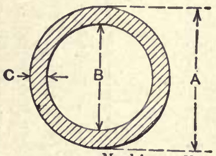
Although its use would be prohibited by the Underwriters, there is really no objection to using commercial wrought-iron pipe instead of conduit for wiring machines. Such pipe should be carefully cleaned inside and out and every precaution taken to make sure that there are no burrs or slivers on the inside of the pipe which might cut insulation on wires. After the pipe is painted, it is almost impossible to distinguish it from conduit.

Conduit elbows are formed from conduit to the dimensions indicated in Table XII. The smaller sizes of conduit can be bent cold to any desired contour, but it requires some skill to do the bending. Conduit-bending machines are obtainable and their installation pays if there is much wiring to be done. Both power- and hand-operated types are manufactured. Couplings for conduit are exactly the same as screwed couplings for standard-weight pipe, except that the former are either enameled or coated with zinc and have a better finish.

After determining the proper size of wire to use for supplying energy to a given motor, the size of conduit to carry it can be selected from Table X. The sizes theretabulated, for the different sizes of wire, have been chosen as the result of much experience with conduit wiring. They are sufficiently large to allow wires to be drawn in or

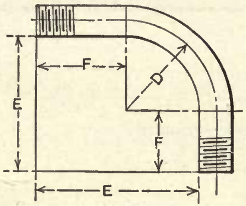
TABLE XII. PROPERTIES OF CONDUIT, ELBOWS AND COUPLINGS

CONDUIT



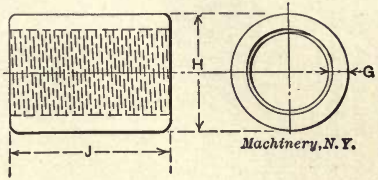
Machinery, N.Y.

ELBOWS



Machinery, N.Y.

COUPLINGS



Machinery, N.Y.

Nominal Size of Conduit	A Outside Diameter		B Inside Diameter		C Thickness of Walls		Nominal Weight, Pounds per Foot	D Radius of Center Line	E Offset	F Length of Str'ght Portion	Weight of 100 in Pounds	G Thick-ness	H Outside Dia-meter	J Length	Weight of 100 in Pounds
	Actual	Fraction to Nearest 64th	Actual	Fraction to Nearest 64th	Actual	Fraction to Nearest 64th									
1/2	0.84	27/32	0.623	5/8	0.109	3/32	0.85	4 1/2	7 1/2	2 9/16	73	1/4	1 3/32	1 5/16	15 1/2
3/4	1.05	1 1/16	0.824	53/64	0.113	7/64	1.12	5 3/8	9 1/4	3 1/4	132	19/64	1 11/32	1 9/16	25 1/2
1	1.315	1 21/64	1.048	1 3/64	0.134	1/8	1.67	5 3/4	10 1/8	4 5/8	200	11/32	1 21/32	1 3/4	40 1/2
1 1/4	1.66	1 21/32	1.380	1 3/8	0.140	9/64	2.24	7 1/4	11 1/2	3 7/16	300	11/32	2	1 15/16	57 1/2
1 1/2	1.90	1 29/32	1.611	1 39/64	0.145	9/64	2 68	8 1/2	12 5/8	3 3/16	415	5/8	2 9/32	2 3/16	71 1/4
2	2.375	2 3/8	2.067	2 1/16	0.154	5/32	3.61	9 1/2	15 1/4	4 9/16	700	1 1/32	2 13/16	2 5/16	132
2 1/2	2.875	2 7/8	2.468	2 15/32	0.204	13/64	5.94	10 1/2	17 3/4	5 13/16	1138	17/32	3 9/32	2 11/16	185
3	3.50	3 1/2	3.067	3 1/16	0.217	7/32	7.54	13	19 3/8	4 5/8	1885	33/64	4 1/64	3	300
3 1/2	4.00	4	3.548	3 35/64	0.226	7/32	9.00	15	21	4	2100	1/2	4 1/2	3 1/8	400
4	4.50	4 1/2	4.026	4 1/32	0.237	15/64	10.66	16	32 1/2	4 1/2	2160	1/2	5 3/32	3 1/8	412

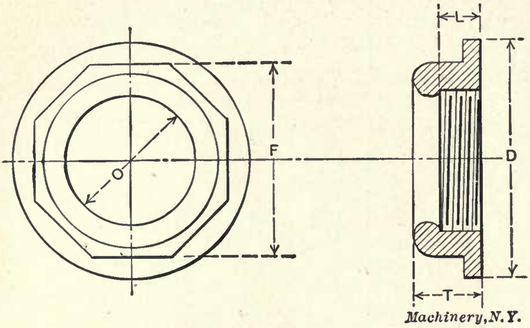
All dimensions in inches. All tubes are 10 feet long, threaded at both ends and furnished with a coupling. These dimensions were taken from manufacturers' tables and from samples.

out without the application of excessive force. It is a common error to choose a conduit size so small that the wires must be pulled in with blocks and tackle. If this is done, the insulation is likely to be injured and withdrawal may be impossible.

Conduit Fittings and Sundries

Where wires emerge from conduit ends, the Code requires that provision be made so that a possible burr on the inside of the conduit will not abrade the insulation on the wires when they are being drawn in or out. Conduit ends may be protected either by a bushing, such as shown in the engraving accompanying Table XIII, or by a fitting, of one of the types shown in Fig. 14, equipped with a porcelain cover, Fig. 12. The bushing should be used when the conduit terminates within an enclosed outlet, junction, or panel box (see Fig. 13) which may be made of either cast or sheet iron. The dimensions given in Table XIII will prove useful in indicating what clearances are required for screwing the bushing on the end of the conduit and will also assist in determining the locations for the conduit holes.

TABLE XIII. DIMENSIONS OF CONDUIT BUSHINGS

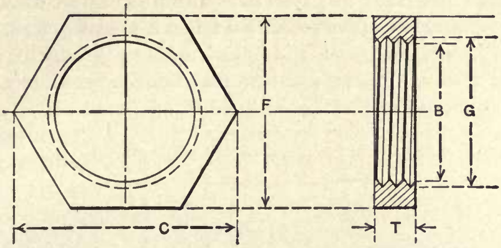


Thomas and Betts Bushings. All Dimensions taken from Samples.
All Dimensions in Inches

Size of Conduit	F	D	O	T	L
$\frac{3}{8}$	$\frac{25}{32}$	$\frac{27}{32}$	$\frac{15}{32}$	$\frac{11}{32}$	$\frac{3}{16}$
$\frac{1}{2}$	$\frac{15}{16}$	$1\frac{1}{32}$	$\frac{19}{32}$	$\frac{13}{32}$	$\frac{1}{4}$
$\frac{3}{4}$	$1\frac{5}{32}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{15}{32}$	$\frac{1}{4}$
1	$1\frac{13}{32}$	$1\frac{17}{32}$	$\frac{31}{32}$	$\frac{17}{32}$	$\frac{5}{16}$
$1\frac{1}{4}$	$1\frac{11}{16}$	$1\frac{29}{32}$	$1\frac{5}{16}$	$\frac{19}{32}$	$\frac{3}{8}$
$1\frac{1}{2}$	$1\frac{31}{32}$	$2\frac{5}{32}$	$1\frac{17}{32}$	$\frac{5}{8}$	$\frac{13}{32}$
2	$2\frac{15}{32}$	$2\frac{11}{16}$	$1\frac{15}{16}$	$\frac{21}{32}$	$\frac{13}{32}$
$2\frac{1}{2}$	$2\frac{7}{8}$	$3\frac{5}{32}$	$2\frac{11}{32}$	$\frac{3}{4}$	$\frac{15}{32}$
3	$3\frac{17}{32}$	$3\frac{25}{32}$	$2\frac{27}{32}$	$\frac{7}{8}$	$\frac{17}{32}$
$3\frac{1}{2}$	$4\frac{1}{8}$	$4\frac{7}{16}$	$3\frac{5}{16}$	1	$\frac{19}{32}$
4	$4\frac{5}{8}$	$5\frac{1}{16}$	$3\frac{13}{16}$	$1\frac{1}{16}$	$\frac{21}{32}$

Outlet boxes usually have unthreaded holes for the conduit, as indicated in Fig. 13, but where a waterproof installation is essential,

TABLE XIV. DIMENSIONS OF CONDUIT LOCK-NUTS

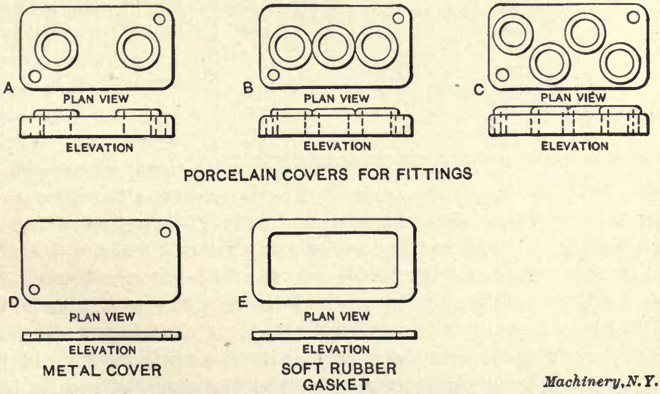


Machinery, N.Y.

Thomas and Betts Lock-nuts. All Dimensions taken from Samples. All Dimensions in Inches

Size of Conduit	Threads per Inch	B	G	F	C	T
$\frac{3}{8}$	18	0.568	0.658	1	$1\frac{1}{8}$	$\frac{3}{16}$
$\frac{1}{2}$	14	0.701	0.815	$1\frac{1}{16}$	$1\frac{7}{32}$	$\frac{5}{32}$
$\frac{3}{4}$	14	0.911	1.025	$1\frac{1}{4}$	$1\frac{7}{16}$	$\frac{5}{32}$
1	$11\frac{1}{2}$	1.144	1.283	$1\frac{1}{2}$	$1\frac{23}{32}$	$\frac{3}{16}$
$1\frac{1}{4}$	$11\frac{1}{2}$	1.488	1.627	$2\frac{1}{32}$	$2\frac{5}{16}$	$\frac{3}{16}$
$1\frac{1}{2}$	$11\frac{1}{2}$	1.727	1.866	$2\frac{1}{4}$	$2\frac{9}{16}$	$\frac{3}{16}$
2	$11\frac{1}{2}$	2.223	2.339	$2\frac{23}{32}$	$3\frac{1}{8}$	$\frac{7}{32}$
$2\frac{1}{2}$	8	2.620	2.820	$3\frac{1}{4}$	$3\frac{3}{4}$	$\frac{1}{4}$
3*	8	3.241	3.441	$4\frac{11}{32}$	$4\frac{11}{16}$	$\frac{11}{32}$
$3\frac{1}{2}$	8	3.738	3.938	$4\frac{3}{4}$	$5\frac{1}{16}$	$\frac{3}{8}$
4	8	4.234	4.434	$5\frac{1}{2}$	$5\frac{7}{8}$	$\frac{5}{16}$

* This size is octagonal.



Machinery, N.Y.

Fig. 12. Covers and Gasket for Conduit Fittings

the holes should be threaded. When the holes are unthreaded, a lock-nut (shown with Table XIV) is run on the end of the conduit and, after the bushing is screwed to position, the lock-nut is turned up snugly against the side of the box, binding the conduit firmly in position. It should be understood that the dimensions given in Tables XIII and XIV for bushings and lock-nuts are accurate for only one manufacturer's line. There are several different makes available, but all will measure approximately the same as those shown.

The application of conduit fittings can best be shown by an example. In Fig. 15 is illustrated a motor-driven open-side planer with the wiring between the starter and the motor neatly carried in conduit. At the motor terminal the conductors issue through a fitting, which is of the type shown in Fig. 14 at *C*, equipped with the cover shown in Fig. 12 at *B*. The conduit fittings are so made that any style of cover of a given pipe size will fit any cast-iron fitting of corresponding pipe size. The covers are held on with brass screws. In Fig. 17 is shown an arrangement of fittings that might be used with the type of starting panel shown in Fig. 15, if the motor were located below instead of above the panel. It will be noted that where "elbow" fittings (*G* and *H*, Fig. 14) are arranged with metal covers, they are effectively used at turns in the conduit run, instead of bends or wrought-iron elbows. Fig. 18 illustrates further applications of conduit-fitting elbows.

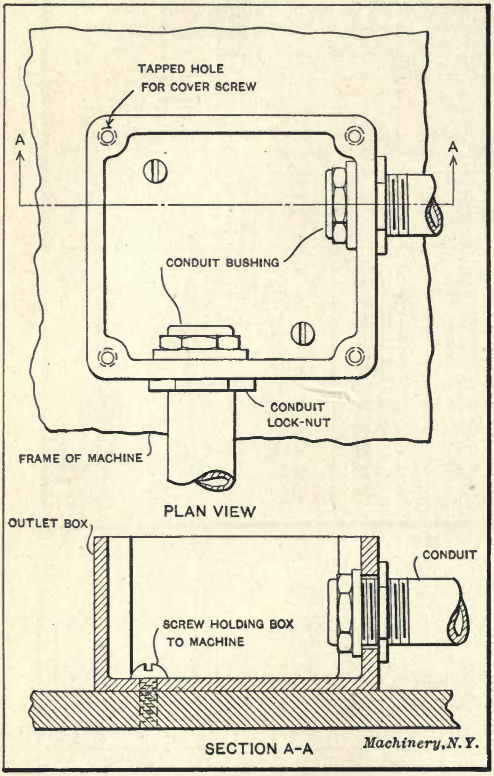


Fig. 13. Outlet Box Mounted on Machine

A very convenient feature of the fittings shown in Fig. 14 is the provision of a headless set-screw in the throat. By means of this set-screw it is possible to secure a conduit end firmly in a fitting even if the threading on the conduit is faulty or if, because of a bend in the conduit, it does not set up tightly in the fitting, when in its proper position. In this type of fitting, conduit can be secured without being threaded at all. The set-screw provides ample attachment, if conduit and fittings are firmly fastened to a supporting surface, as they usually are on machinery. Nor is it necessary to thread conduit running into fittings like that in Fig. 16. An unthreaded end of a conduit length is inserted in the nipple, the nut is tightened, and the conduit is secured. The threaded portion of the nipple is split and tapered. These fittings possess several advantageous points. Being of sheet-steel, they are unbreakable. The fact that each fitting has several "knock-out" holes makes possible a great number of combinations from a comparatively small stock of fittings and covers.

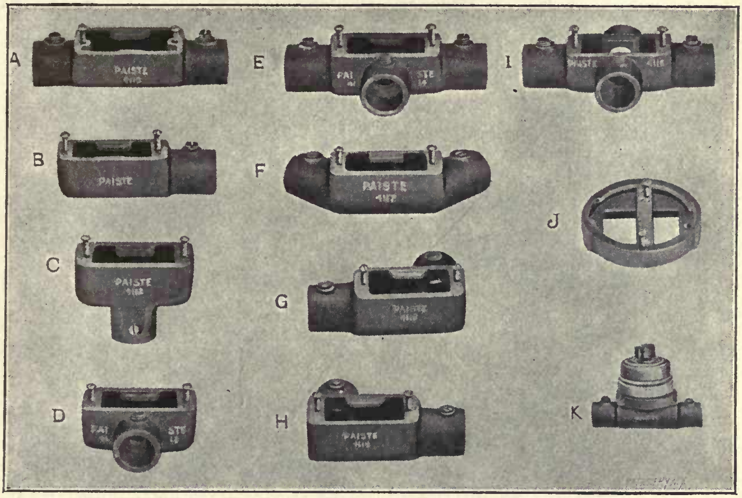


Fig. 14. Types of Cast-iron Conduit Fittings

Supporting Conduit Wiring

Obviously, conduit carrying conductors should be so securely supported that there can be no chance of its being displaced under reasonable conditions. Pipe straps, formed from sheet-steel and then galvanized, such as those shown with Table XV, are most frequently used for supporting conduit, as shown in Figs. 15, 17 and 18. The dimensions given in Table XV will be found useful in making clearance allowances and in determining the locations for the tapped holes for the round headed machine screws, with which the straps are fastened. The dimensions in Table XV are accurate only for the lines of certain manufacturers, but will be approximately correct for all makes.

Another good method of supporting conduit runs is by fastening the fitting to the machine frame with machine screws, as shown in Figs. 13 and 19. The screws pass through a hole drilled in the bottom of the fitting and down into a hole tapped in the machine frame.

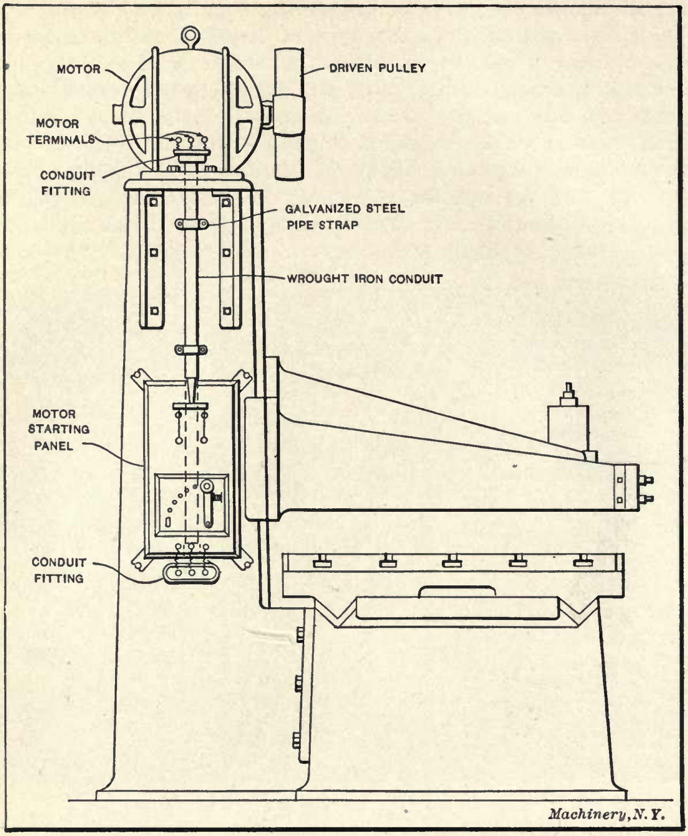


Fig. 15. Open-side Planer with Well-arranged Wiring

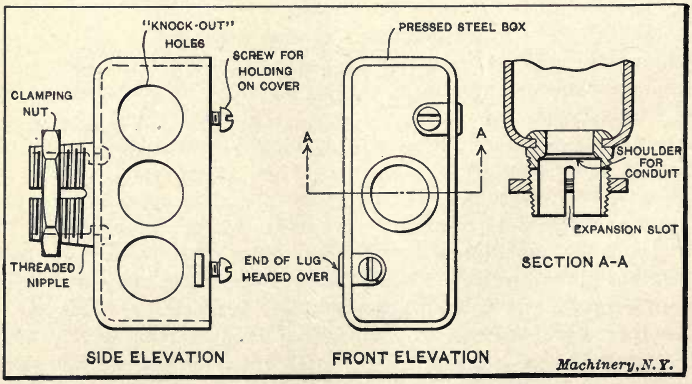


Fig. 16. Details of Typical Pressed-steel Fitting

It is often feasible to support a complete conduit installation by this method and thereby entirely avoid the use of pipe straps. This sort of a job presents a neat appearance.

Motors Arranged for Conduit Wiring

When it is specified that the "motor shall be arranged for conduit wiring," certain motor manufacturers will provide, without extra charge, a metal terminal box, with a removable cover, around the motor terminals. A motor so arranged is shown in Fig. 18. Such a terminal box permits of the best possible installation, and through its presence a conduit fitting, like that at the motor in Fig. 15, can be dispensed with. A hole is provided in the terminal box and the conduit is terminated with a bushing in the hole.

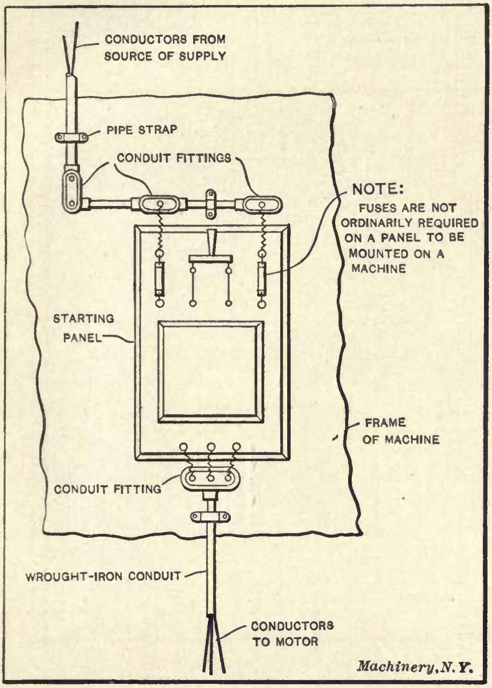


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Fig. 17. A Neatly Wired Starting Panel

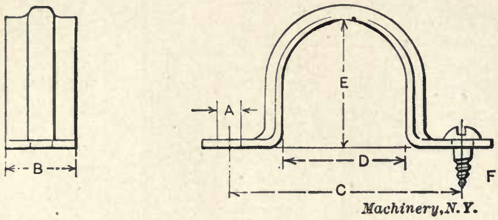
Switches

It is required by the National Electrical Code that every motor and starting box be protected by a double-pole cut-out (fuses or circuit breaker) and controlled by an indicating switch that plainly indicates whether the circuit is open or closed. For motors exceeding in capacity ¼ horsepower, a double-pole switch is required, but a single-pole switch may be used for smaller ones. It is always advisable, however, to use the double-pole type, as through its use both sides of a circuit are rendered dead when the switch is open.

For handling currents up to 20 amperes, or thereabout, the best switch to use is of the indicating-snap type, shown in Fig. 20. This type can readily be obtained as either single-pole, for direct-current and single-phase alternating-current motors, or triple-pole for three-phase motors. All "live" parts are effectively enclosed in a formed sheet-metal cover (Fig. 20) which is lined with an insulating material. By unscrewing the composition handle, the cover can be quickly removed for making connections. Wires enter the switch through holes in the back of the porcelain base. A revolving dial, bearing the legends "On" and "Off," indicates whether the switch is open or closed.

An indicating-snap switch mounted on a conduit fitting as shown in Fig. 21 makes a rugged and safe switching combination. All wires and "live" parts are completely enclosed. Some manufacturers make conduit fittings especially designed for carrying switches; but an equivalent fitting may be assembled, as shown in Fig. 14 at *K*, with the components *A* and *J*, or with *J* and any other piece shown in Fig. 14.

TABLE XV. DIMENSIONS OF PIPE STRAPS



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All Dimensions taken from Samples. All Dimensions in Inches

Nominal Size of Pipe	A Diameter of Screw Hole	B Width of Strap	C Distance between Centers of Screw Holes	D Width of Opening	E Height of Opening	F Size of Wood Screw to Use No. in.	Approximate Cost per 100	Approximate Number per Pound
1/4	0.20	5/8	1 9/16	9/16	17/32	8× 5/8	$0.40	75
3/8	0.20	5/8	1 3/8	11/16	21/32	8× 3/4	0.45	72
1/2	0.20	5/8	1 5/8	7/8	25/32	8× 3/4	0.50	40
3/4	0.22	3/4	2 1/8	1 1/8	1	10× 3/4	0.75	29
1	0.22	3/4	2 3/8	1 3/8	1 1/32	10× 7/8	1.00	21
1 1/4	0.22	13/16	2 3/4	1 3/4	1 5/8	10×1	1.25	18
1 1/2	0.22	13/16	3	2	1 7/8	10×1	1.50	14
2	0.22	1	3 3/4	2 1/2	2 5/16	10×1 1/4	2.00	12
2 1/2	0.25	7/8	4 3/8	2 3/4	2 15/16	11×1 1/4	2.75	6

For handling currents above 20 amperes, open-knife switches are commonly used. The open type is used because (so far as the writer is aware) no enclosed knife switch is regularly manufactured. These open switches are best mounted close to the motor starter. Controllers and starters, as will be outlined later, can be purchased with the line switches mounted directly on them, as indicated in Figs. 15 and 17. Such combinations are called starting or controlling panels.

In all of these examples of knife-line-switch and controller applications, it was evidently deemed unnecessary by the designer to enclose the switches and controllers. If enclosure is desirable (and as many view it, there are few cases where it is not) a cover for a knife-switch can readily be constructed from sheet or cast metal as suggested in Fig. 22. As will be described subsequently, circuit-breakers are often used on motor-driven machines, making switches unnecessary.

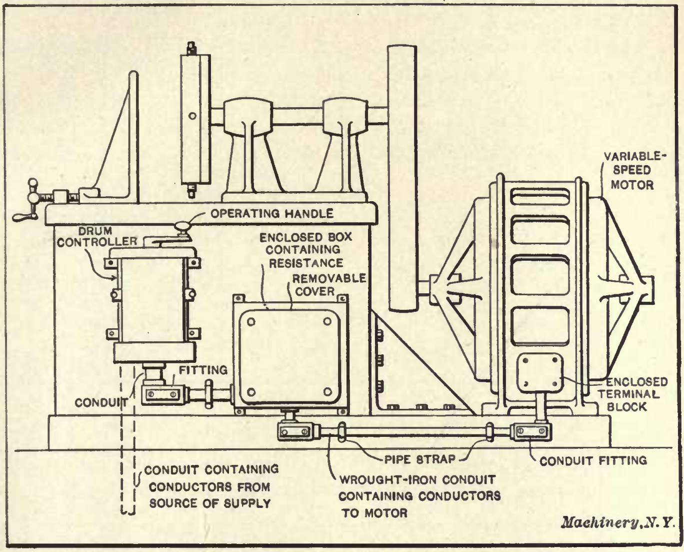

Fig. 18. Machine Equipped with Drum Controller

While a cut-out is required by the Code to protect every motor-controller combination, it is not advisable to mount this on the machine. As a rule, it is best located at the point where the branch-circuit to the machine taps from the main supply circuit, as shown at *A* in Fig. 23. Hence the machine manufacturer should not be expected to provide a cut-out. A cut-out is ordinarily required at *A*

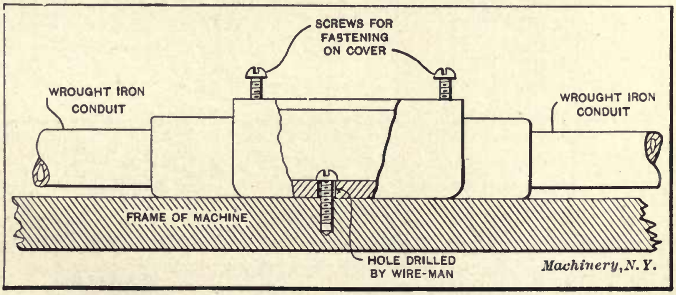

Fig. 19. Satisfactory Method of Supporting Fittings

inasmuch as the branch wires are usually smaller than the main wires and the Code requires the installation of a cut-out wherever there is a decrease in wire size.

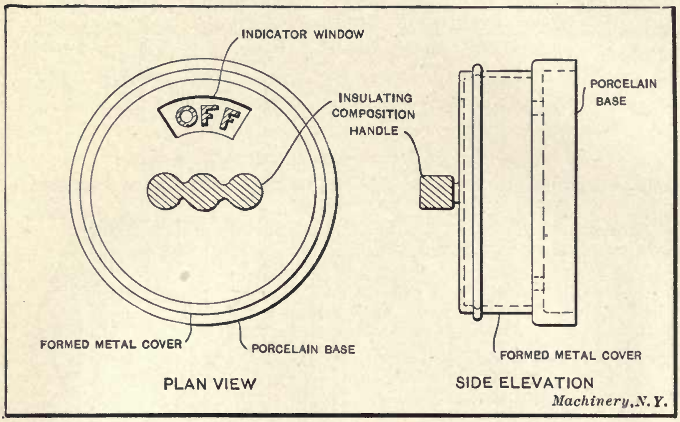

Fig. 20. Indicating Snap Switch

Motor Controllers and Starters

Motor starters as regularly furnished by the motor manufacturers are of the open type shown in line-cut Fig. 15. By "open type" is meant a type which does not have its "live" parts protected by a cover. These open starters have given and will give entire satis-

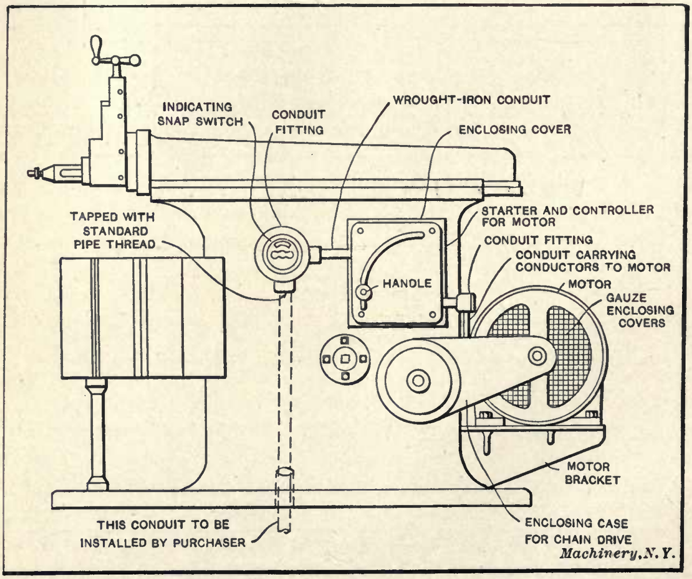

Fig. 21. A Motor-driven Shaper with Completely Enclosed Wiring

faction in places where it is reasonably clean. But some purchasing concerns prefer to have, in so far as possible, all electrical apparatus enclosed, and it is believed that, all things considered, this is usually the most economical method, although the first cost of enclosed equipment is a trifle higher. An enclosed starter is shown in Fig. 21. It consists merely of a standard open starter fitted with a cover which encloses all "live" parts, and has a semi-circular slot for the operating handle. Most of the electrical manufacturing concerns have standardized and are prepared to furnish enclosing covers for their control equipment. Such a cover makes it difficult for the unauthorized to tamper with the adjustment of the starter, keeps it clean, eliminates liability to shock and prevents grounds or short circuits due to flying metal chips.

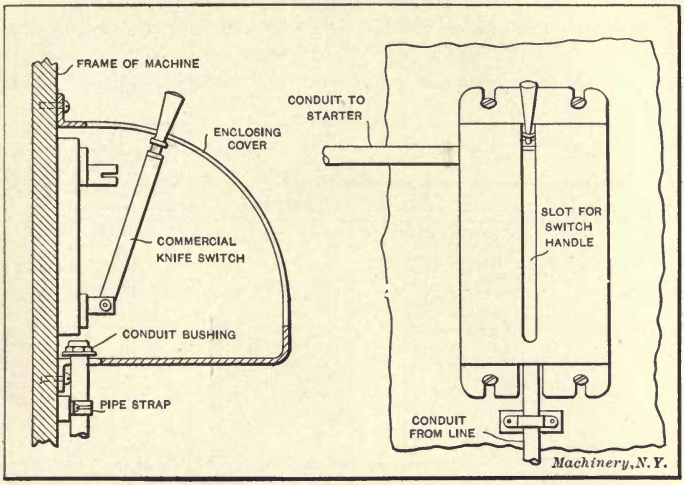

Fig. 22. Enclosing Cover for Knife-switch

The purchaser of an enclosing cover for a starter should insist that it enclose not only the dial-contacts, but also the terminals on the starter. Certain manufacturers will furnish a cover that will shroud the dial and not the terminals, unless specifically directed as above; *all* bare current-carrying parts should be enclosed.

In Fig. 24 is detailed an excellent enclosing cover that can be applied to standard starters. Instead of being slotted for the operating handle as is the one shown in Fig. 21, a better construction is used. An auxiliary operating handle and arm is mounted on the cover; on the end of this arm is an insulating fork which engages the controller arm when the cover is in its normal position, and thus transmits the movements of the operating handle to the controller arm. The absence of a slot in the cover makes the starter dust-proof. The terminals are completely enclosed and a removable piece that can be taken out altogether, for the admittance of wires, or drilled for conduit, is provided above the terminals. When this cover is applied to the standard controller the old controller handle is removed.

Sometimes a circuit-breaker is substituted for the switch on a starting panel, as shown in Fig. 25. A circuit-breaker is one type of cut-out. It opens a circuit automatically when a current, of a value for which it is set, flows through it. It can also be opened manually by releasing a catch. Circuit-breakers, of reliable types, are considerably higher in first cost than a switch-fuse combination, but in the long run they are more economical. The reasons for this are: First, fuse renewals, which are relatively expensive, are not required; and second, the cost of labor wasted while fuses are being replaced, is saved.

The panel in Fig. 25 is shown without enclosing covers so that its construction will be apparent; but it is made with covers which expose only the circuit-breaker and starting-rheostat operating handles.

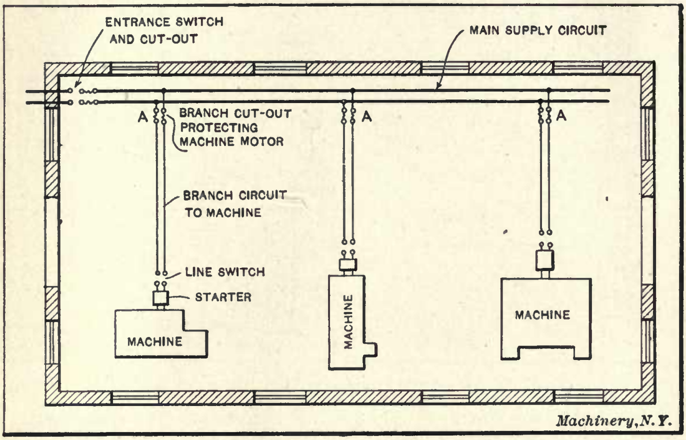

Fig. 23. Wiring Diagram for Motor-driven Machines

Some manufacturers enclose panels like that of Fig. 25 in sheet-metal steel boxes having hinged doors, but this is not a satisfactory arrangement for machinery applications, because, to operate the starter or manipulate the switch, the attendant must open the door. This is awkward and, in case of accidents, when the motor should be stopped without delay, prevents quick action. The consequence is that the door is usually left open or is taken off altogether.

As previously mentioned, motors on machines are frequently protected by branch-fuses located at the supply circuit as shown at *A* in Fig. 23, and a circuit-breaker or a starting panel provides additional protection. However, the circuit-breaker should be set to trip on a smaller current than will rupture the fuses. The circuit-breaker takes the brunt of an overload and operates instantaneously, saving the cost of fuse renewals. As the economies of circuit-breaker applications are becoming better understood they are becoming more popular. Some large industrial corporations specify them on every motor starting or controlling panel.

Drum controllers with external resistances are deservedly becoming very popular, particularly for variable-speed control. In Fig. 18 is shown drum-controller applications. The drum controller receives its name from the fact that contact is made between stationary fingers and rotating segments mounted on a drum. All the parts can be made very rugged and can be so arranged as to be readily removable for renewal and repair. The resistance is arranged in a separate frame which can be provided with an enclosing cover and arranged for conduit wiring as shown in Fig. 18. The drum usually contains only the contact-making mechanism. It is believed that a drum controller is preferable in every way to one of the dial type, which has contact buttons arranged on the face of an insulating panel and a swinging arm to make electrical contact with them.

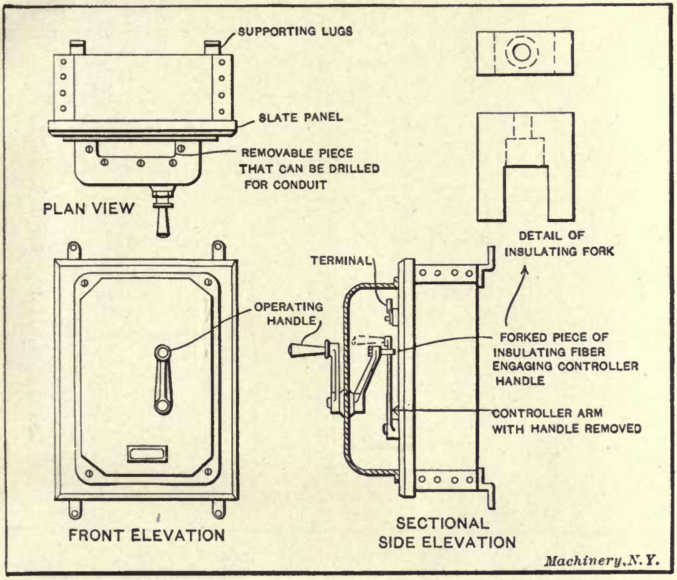

Fig. 24. A Good Enclosing Cover Design

Often the drum controller is mounted conveniently near the motor at the head of the lathe. The controlling handle, whereby the lathe is started, stopped, or has its speed varied, is attached to and travels with the apron, and hence is always handily located for operation. The handle engages with a longitudinally slotted shaft so arranged that when the handle is turned the shaft turns. The shaft extends nearly the entire length of the lathe and motion is transmitted from it to the controller drum by means of sprockets and a chain. It will be noted that the cover of the drum controller can be easily removed by unscrewing a couple of swing nuts.

Enclosing Motors

Motors can be furnished either open, semi-enclosed or fully enclosed. A fully enclosed motor of a given horsepower and speed costs more than a semi-enclosed or an open one, because a large frame is needed for the enclosed type. The power capacity of a motor depends largely on its ability to dissipate the heat generated within it, and if it is enclosed, the heat is dissipated with difficulty. To reduce the quantity of heat generated, the parts must be proportioned more generously; hence the necessity for larger frames for enclosed motors. Motors seldom need to be fully enclosed unless they are to operate in very dirty places, or in other special cases. A gauze enclosure such as that indicated in Fig. 21 is satisfactory for most machinery applications.

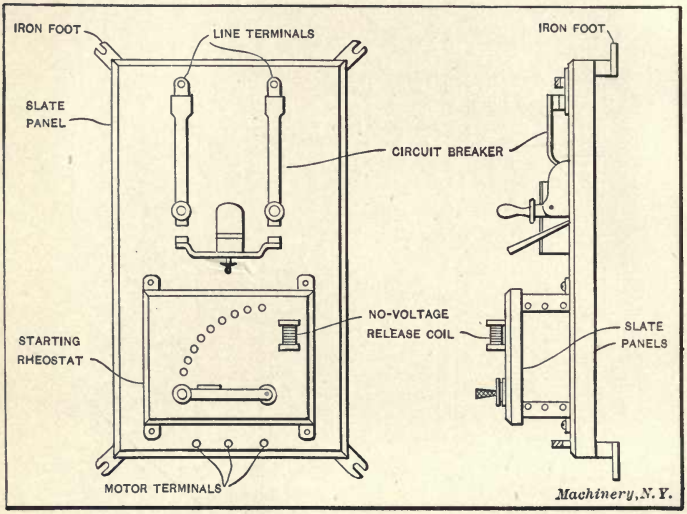

Fig. 25. A Circuit-breaker Starting Panel

Gauze or wire-netting enclosing covers reduce the rating of a motor very little, if any. The use of such covers is advocated on motors for nearly all machine drives.

The Code specifies that the frames of all motors operating at potentials in excess of 550 volts shall be either permanently grounded or else insulated by wooden frames or otherwise. The use of a wooden frame or any other insulating arrangement is not usually feasible, so the almost universal practice is to bolt the motor frame into good electrical contact with the frame of the machine. It devolves upon the purchaser of the machine to see that it is well grounded, either through the conduit conveying the conductors to the machine (the Code requires that the conduit of all conduit wiring systems be grounded) or through a specially provided ground wire connected to the machine. The Underwriters require that special permission be obtained before motors with grounded frames are installed.

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