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THE SELECTION OF ELECTRIC MOTORS AND CONTROL GEAR FOR INDUSTRIAL USE.

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The paper is confined to motors and control gear from ¼ H. P. up to approximately 250 H. P. output. The selection of a motor and control equipment for a given service requires a knowledege of :

(*i*) The situation.

(*ii*) The duty cycle.

(*iii*) Operating conditions.

(*iv*) Starting conditions.

(*v*) Nature of supply.

(*vi*) Restrictions, if any, of the supply company.

It is seldom that a person has the choice either of A.C. or C.C. supply, so that the selection of a motor in each case depends on the service conditions, and is generally one of the following types :—

CONTINUOUS CURRENT MOTORS.

(1) Shunt wound motors.

(2) Series wound motors.

(3) Compound wound motors.

ALTERNATING CURRENT MOTORS.

Polyphase Motors.—

(1) Squirrel cage motors.

(2) High torque squirrel cage motors.

(3) Slip-ring motors.

(4) Synchronous motors.

(5) Special types commutator, power factor correction,

Single-phase Motors.—

(1) Split-phase induction motors.

(2) Repulsion induction motors.

(3) Capacitor induction motors.

(4) Slip-ring induction motors.

(5) Capacitor slip-ring induction motors.

(*i*) *Situation.*—This has an important bearing on the choice of a motor; for instance, if the motor is required for outdoor use in an exposed place it may be necessary to have a totally enclosed motor; on the other hand it may be cheaper to provide a shelter where dust and rain cannot get in, but where there is a free supply of air, and an ordinary enclosed ventilated motor would be quite suitable. Thus, the cost of the motor together with the shelter may be even cheaper than the cost of a weather-proof motor. In certain situations such as flour and cement mills it is not possible to adopt this method, or perhaps it may not be so convenient, particularly in the smaller sizes of motors.

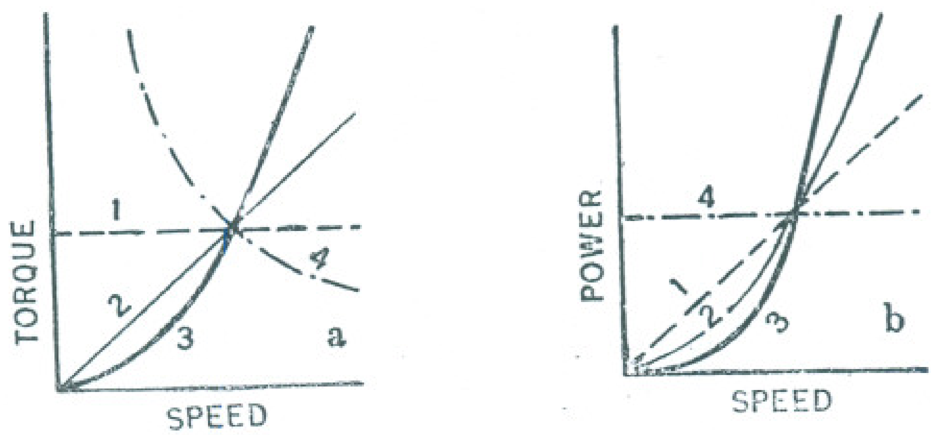
It must be understood that if an enclosure other than the enclosed ventilated type, is required then it is usual for the control gear to be of a similar type. In modern design the tendency is to have the control gear as near to the motor as possible. Then again, the question of suitable cable arises and the same precautions should be taken to ensure that it fulfils similar conditions for protection as the motor. In places where there may be considerable dust, the motor would be affected but the cable would not. Every situation has its own peculiar features, and it is not possible to lay down exact rules to fit each and every case.

(*ii*) *Duty Circle.*—This concerns the frequency of operation and is best illustrated by an example. Take for instance a crane, this duty is comparatively infrequent, it is necessary to lift heavy loads carefully and so a slow speed is quite suitable. When the load has been lifted to its place, and the crane is subjected to no-load, a quick speed of operation is necessary to prepare for the next lift, and a similar type of duty is experienced with machine tools, planers, etc. Certain machines used in rolling mills etc. are subjected to heavy overloads at intermittent times in the process of rolling and the electric motor must be specially designed for this duty. As soon as the overload has disappeared the action of the motor should be quick, and ready to deal with any further rolling required, depending on its design.

(*iii*) *Operating Conditions.*—Let us now take operating conditions. These depend largely on the nature of the drive and in Fig. 1 (*a*) are shown a number of ways in which the load-torque may vary with the speed. Curve 1 represents torque constant at all speeds *as met with* in certain machine tools, reciprocating pumps, etc. Curve 2 represents torque varying directly with speed, as in certain kinds of centrifugal pumps, cranes, etc. Curve 3 shows the torque varying as the square of the speed, as for example in fans ; lastly, Curve 4 shows the torque varying inversely as the speed, as in the case of a lathe designed for constant power. The power speed curves for the different cases are shown in Fig. 1 (*b*). Since power is proportional to the product of torque, and speed, we have in Fig. 1 (*b*)—

Curve 1—power $\propto$ speed
,, 2—power $\propto$ speed^2
,, 3—power $\propto$ speed^3
,, 4—power is constant.

FIG. (1) TYPICAL LOAD CHARACTERISTICS



There are two types of ratings on which motors operate : these are as follows :—

(*a*) Short time rated motors.

(*b*) Continuously rated motors.

(*a*) Comprise crane motors, traction motors, winches, lifts, certain operations on machine tools and of this description, and are estimated to give their full rated output continuously for ½ hour or 1 hour with a maximum increase of temperature of 40° C.

The main limitations to the output of a motor are : (1) Heating and (2) Commutation. In practice, heating is the lower limit, hence it is usual to specify a motor as being of a certain horse power with a given maximum temperature rise.

It is, however, important to appreciate the difference between the rating of a motor, and its ability to perform a certain duty. With a drive whose duty is intermittent like a crane, there is time for the windings of the motor to cool down, and it is not practicable to run motors of this description continuously.

If the temperature rise of the motor does not exceed 40°C on intermittent rating or 40°C on continuous rating for one hour a motor much smaller than a continuously rated machine can be installed, with a large economy in design, resulting in a correspondingly cheaper motor.

(*b*) Motors of this type comprise all other motors in which the duty is continuous or so frequent as to exceed the rated temperature rise of short rated motors. Motors of this description are estimated to give their full rated output continuously with a maximum increase of temperature not exceeding 40° C above the ambient air temperature. In each of the above cases, the temperature rise for totally enclosed machines is 50°C.

TYPES OF ENCLOSURE AND OF MACHINE.

The following standard enclosures for motors are recognized by the British Standards Institution :—

(*a*) An *Open Machine* is a machine in which no mechanical protection is embodied and in which there is no restriction to ventilation other than that necessitated by good mechanical construction.

(*b*) An *Open Pedestal Machine* is an open machine which has pedestal bearings supported independently of the machine frame.

(*c*) An *Open End-Bracket Machine* is an open machine having end-brackets, of which the bearings form an integral part.

PROTECTED MACHINES.

(*d*) A *Protected Machine* is a machine in which the internal rotating parts and live parts are protected mechanically from accidental or careless c ntact while ventilation is not materially obstructed. Unless otherwise specified, a protected machine has end-bracket (end-shield) bearings.

(*e*) A *Screen Protected Machine* is a protected machine in which all the ventilating openings in the frame and end-shields are protected with wire screen, expanded metal or other suitable perforated covers having apertures not exceeding ½ sq. in. (3·2 sq. cm.) in area, but not less than 1/50 sq. in. (0·13 sq. cm.) in area.

(*f*) A *Machine with Fine-mesh Covers* is a machine having protective screens similar to those of the screen-protected machine, but with the openings smaller than 1/50 sq. in. (0·13 cm.).

For the purpose of temperature limits, such a machine shall be regarded as being totally enclosed and shall comply with the limits of temperature-rise when the machine is tested with the openings closed, as such openings frequently become clogged in actual service.

(*g*) A *Drip-proof Machine* is a protected machine in which the frame and end-shields are provided with openings for ventilation so protected as to exclude falling water or dirt.

Pipe or Duct-Ventilated Machines.

(*h*) A *Pipe-ventilated* or *Duct-ventilated Machine* is a machine in which there is continuous supply of fresh ventilating air, the frame being so arranged that the ventilating air may be conveyed to and/or from the machine through pipes or ducts attached to the enclosing case.

A pipe or duct-ventilated machine may be one of three types :—

(*i*) With provision for inlet duct only.

(*ii*) With provision for inlet and outlet ducts.

(*iii*) With provision for outlet duct only.

A pipe or duct-ventilated machine may be cooled by means of

(*a*) self-ventilation.

(*b*) forced draught—air supplied by external pressure.

(*c*) induced draught—air drawn through the machine by external means.

Note.—When necessary, a machine of this type should be described by specifying all these features, *e.g.*, " Duct-ventilated with inlet and outlet ducts self-ventilated."

Totally-Enclosed Machines.

(*i*) A *Totally-enclosed Machine* is a machine so constructed that the enclosed air has no connection with the external air (but not necessarily "air-tight").

(*j*) A *Totally-enclosed Air-blast Self-cooled Machine* is a totally enclosed machine with augmented cooling by means of a fan driven by the motor itself, blowing external air over the cooling surfaces and/or through the cooling passages, if any.

(*k*) A *Totally-enclosed Air-blast Separately-cooled Machine* is a totally enclosed machine with augmented cooling by means of a separately driven fan, blowing external air over the cooling surfaces and/or through the cooling passages, if any.

(*l*) A *Totally-enclosed Water-cooled Machine* is a totally-enclosed machine with augmented cooling by means of water cooled surfaces embodied in the machine itself.

(*m*) A *Totally-enclosed Closed-air-circuit Machine* is a totally-enclosed machine having special provision for cooling the enclosed air by passing it through a cooler external to the machine.

Note.—The cooler may be of any recognised form, using air draught water or other medium as a means of dissipating the heat.

(*n*) A *Flame-proof Machine* (including explosion-proof is a machine, which will withstand without injury, any explosion which may occur in practice within it under the conditions of operation within the rating of the apparatus enclosed by it (and recognised overloads, if any associated therewith), and will prevent the transmission of flame such as will ignite any inflammable mixture, which may be present in the surrounding atmosphere.

(*o*) A *Change Speed Motor* (U. S. A. equivalent : Multi-Speed Motor) is a motor which can be operated at any one of several distinct speeds, practically independent of the load, such as a motor the speed of which is varied by changing the number of its poles.

(*p*) A *Variable Speed Motor* (U.S.A. equivalent : Adjustable Speed Motor) is a motor, the speed of which can be varied gradually over a specified range, but which, when once adjusted, remain practically unaffected by the load ; for example, a shunt motor designed for a range of speed variation.

(*q*) An *Inverse Speed Motor* (U.S.A. equivalent : Varying Speed Motor) is a motor, the speed of which decreases when the load increases as with a series wound or heavily compound wound motor.

In addition to the above, the American Institution of Electrical Engineers recognise the following :—

(*r*) A *Submersible Motor* is one capable of withstanding complete submersion in fresh water or sea water, and may be submerged for four hours without injury.

(*s*) A *Moisture-Resisting Machine* is one in which all parts are treated with moisture-resisting material. Such a machine may be operated continuously or intermittently in a very humid atmosphere such as in mines and the like.

Totally Enclosed Fan Cooled Motors, are motors in which external air is drawn in by a fan at the drving end of the motor and forced through ducts in the stator lamination and out at the other end of the motor, or alternatively by a fan at the non-driving end of the motor. The air within the motor is circulated in a closed circuit through ducts in the rotor and further ducts in the stator, the latter being placed alternately with the corresponding ducts for external air, and the air passing through the separate circuits in opposite directions. By this means the motor is cooled without losing its totally enclosed feature, and this results in a greatly increased output, particularly at the higher speeds. The passage of air to the fan should not be restricted by a solid pulley or coupling.

Output of motors with different types of enclosures and various speeds.

It will be readily appreciated that the output of a totally enclosed motor is not as great as that of a screen protected motor, of the same frame size and correspondingly if the enclosure is such as to reduce or limit the amount of free air which is drawn over the stator and rotor coils, and iron, the output of the motor is reduced proportionally.

This is clearly seen by examination of the attached table which gives the approximate outputs of A.C. and C.C. motors at three speeds, and with five different types of enclosure. T.E.F.C. refers to totally enclosed fan cooled motors and T.E. refers to totally enclosed motors. The higher the speed of a motor the cheaper its cost will be, and that is why a belt drive is preferred to a direct drive; the belt drive permitting the motor to be run at a higher speed than the driven machine and thereby effecting an appreciable reduction in the initial cost of the motor.

Slip-Ring Type (a).

	40° C. rise.				50° C. rise.	
			Pipe-Vent.			
Synchronous speed.	Screen Prot.	Drip Proof.	1 inlet 4 outlet	1 inlet 1 outlet	T.E.F.C.	T.E.
1500 r.p.m. 4 pole ..	75	70	62	57	50	11.5
1000 r.p.m. 6 pole ..	55	50	45	42	40	11
750 r.p.m. 8 pole ..	45	40	37	34	30	10

Squirrel Cage Type (β).

	40° C. rise.				50° C. rise.	
			Pipe-Vent.			
Synchronous speed.	Screen Prot.	Drip Proof.	1 inlet 4 outlet	1 inlet 1 outlet	T.E.F.C.	T.E.
1500 r.p.m. 4 pole ..	80	75	65	62	55	11.5
1000 r.p.m. 6 pole ..	65	60	55	50	42	11
750 r.p.m. 8 pole ..	50	46	42	38	33	10

For D.C. motors on a 440 volt supply—Type γ, similar comparative figures are :—

Speed.	40° C. rise.				50° C rise.	
	Screen Prot.	Drip Proof.	*Pipe-Vent.* 1 inlet 4 outlet	*Pipe-Vent.* 1 inlet 1 outlet	T.E.F.C.	T.E.
1070 r.p.m. ..	77	73	65	54	47	..
760 r.p.m. ..	53	50·5	45	37	33	..
520 r.p.m. ..	54	32	29	24	21	..

CHARACTERISTICS OF VARIOUS TYPES OF MOTORS.

Continuous Current Motors.

The Continuous Current Motor is without a rival in respect of its range and flexibility of speed control. Its wide speed range arises from the fact that the action of a commutator machine is independent of its speed. The magnitude and direction of the torque depend only on the magnitude and direction of the current and the flux, and are not influenced by any particular speed, thus the Continuous Current Motor always develops a starting torque, provided that the field is excited and a current flows in the armature.

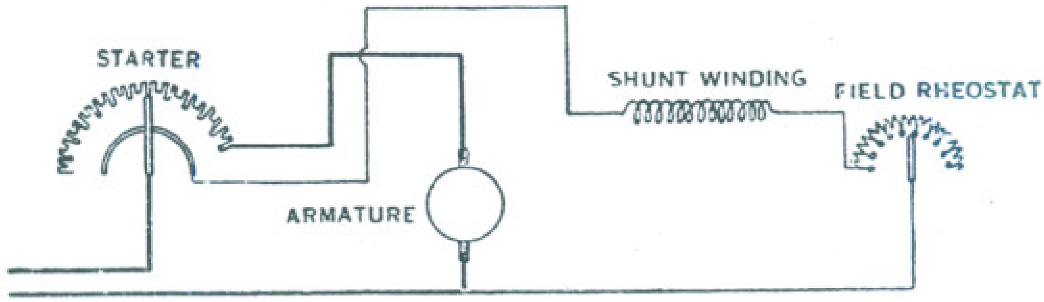
Industrial motors for continuous current circuits are of three classes : Shunt Wound, Series Wound and Compound Wound.

The *Shunt Wound Motor* consists essentially of a rotating armature and a stationary field magnet wound with a number of turns of fine wire which remain connected directly across the supply circuit all the time the motor is working. The field can be separately excited or connected directly across the armature. It is practically a constant speed machine, the speed at full load being only a little less than at no-load, and the larger the motor the closer the speed regulation. There is no tendency for the motor to race when the load is thrown off, and by varying the excitation a variable shunt characteristic can be obtained. The limits of speed variation obtainable in this way are very wide, and with interpoles to take care of commutation and a small series winding to ensure that at small excitation currents the motor does not become unstable on momentary over-load, a speed variation of 1 : 6 is possible. The lower limit is fixed by the maximum flux it is possible to produce in the motor, and by the cooling, especially of the field winding at this low speed. The higher limit is fixed by stability, hunting, commutation, and mechanical stresses. This method of speed control is very economical, since very little power is expended in field excitation.

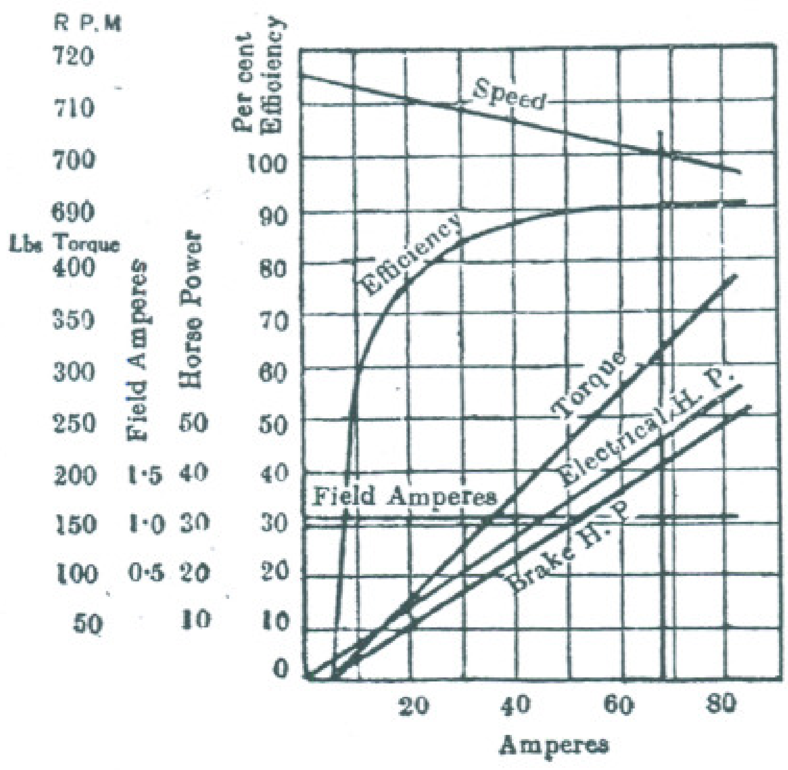
Voltage control.

Speed variation by voltage control is the most economical of all, but it requires a variable supply pressure. The variable voltage for the armature circuit being obtained from a motor generator, while the field is separately excited from a constant pressure supply. With this arrangement, it is more convenient to combine voltage and field control—the former for the lower part, and the latter for the upper part of the speed range. Owing to the high capital cost of the plant this method of speed control for shunt motors is only used in special cases, and is limited in application to special drives such as winding engines, haulages, hoists, and rolling mills, etc.

(FIG. 2.) DIAGRAM OF SHUNT WOUND MOTOR WITH STARTER AND FIELD REGULATOR



(FIG. 3.) TYPICAL PERFORMANCE CURVE OF SHUNT WOUND MOTOR



The *Series Wound Motor* consists of a rotating armature and a stationary field magnet wound with comparatively few turns of heavy wire through which the armature current has to pass. As the load increases the field

FIG. 4. DIAGRAM OF SERIES WOUND MOTOR WITH CONTROLLER

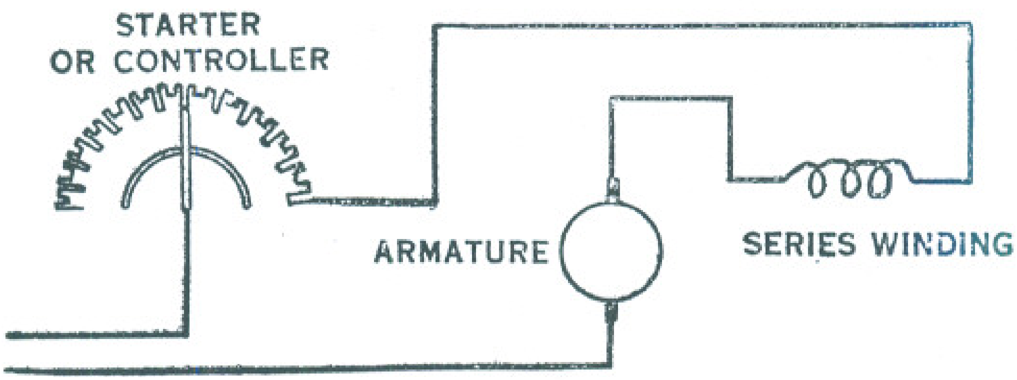
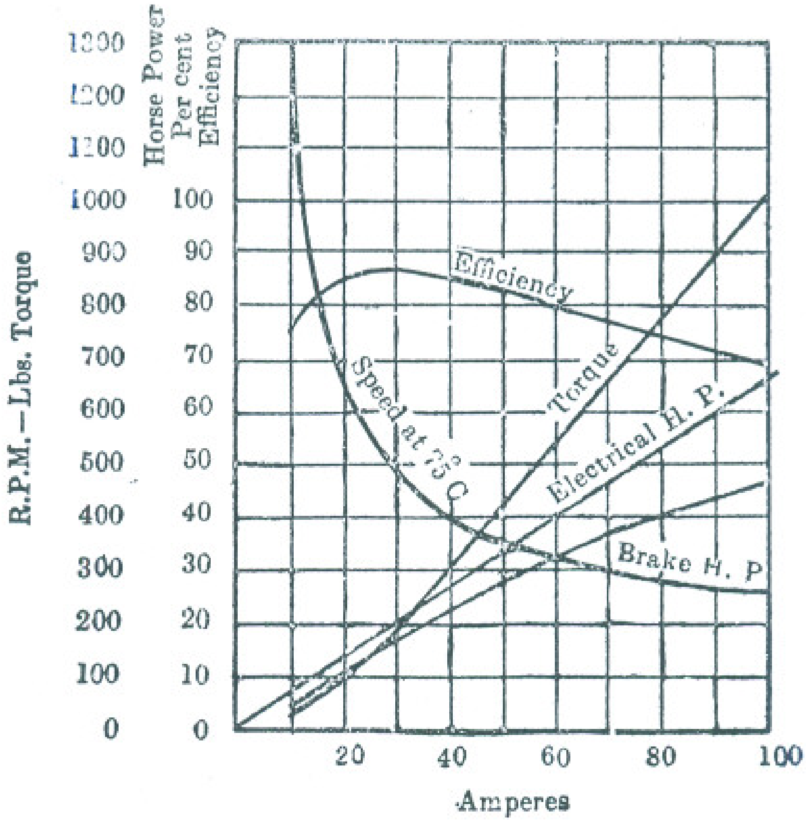


FIG. 5. TYPICAL PERFORMANCE CURVE OF SERIES WOUND MOTOR



is strengthened, and consequently the speed falls, and conversely as the load decreases the speed rises. With all load removed the speed would increase indefinitely, so that series motors should be used against a permanent load, or fitted with a shunt limiting winding or else be constantly under the control of an operator. Series motors offer a very large starting torque and being capable of exerting an enormous torque for short periods can take heavy momentary overloads. The speed adjusts itself to the load, so that a series motor used in a crane will lift a heavy load at a low speed and a light load at a high speed. This automatic adjustment of speed to load makes motors of this type eminently suitable for cranes, derricks, winches, and bending rolls, etc. Series motors should not be used for belt drives, and where the load is liable to fail suddenly, as in a pump losing its water.

Starting and speed regulation are effected by inserting and varying resistances in series with the motor, and further for traction work by connecting two motors, or two pairs of motors alternately in series and parallel.

The *Compound Wound Motor* has a shunt winding wound around its field magnet, and also a few turns of series winding. The speed at no-load is higher than that at full-load, depending on the amount of series winding in circuit ; in industrial motors this varies from 10 to 30%. The series winding enables the motor to exert a larger starting torque than the shunt wound motor, and also to deal with greater momentary over-loads.

Compound wound motors should be used where a large starting effort is required, combined with an approximately constant speed at all loads, such as in driving lifts, haulage gears, etc., to drive machines having very uneven loads, or that are subjected to severe momentary

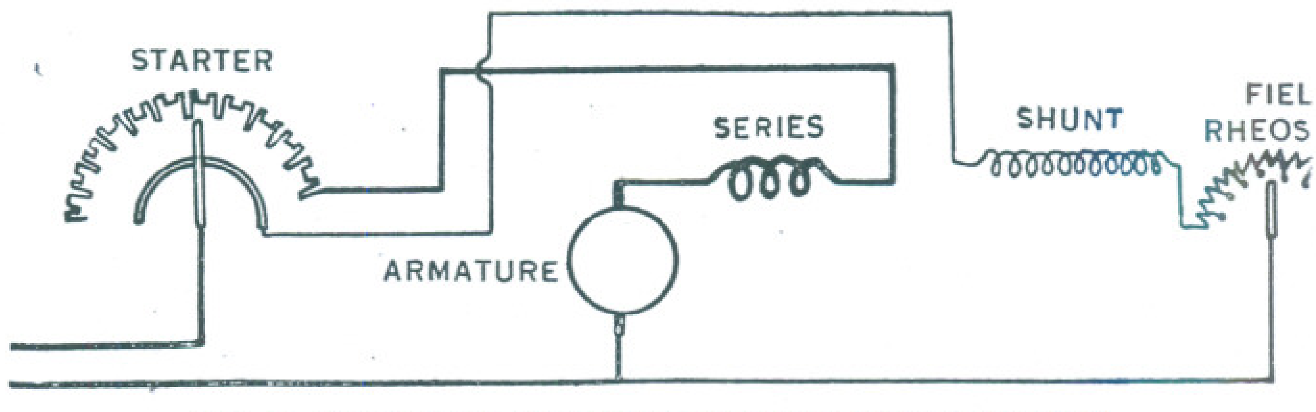


FIG. 6. DIAGRAM OF COMPOUND-WOUND MOTOR WITH STARTER & FIELD REGULATOR

over-load, *e.g.*, punching or shearing machines, small bending rolls, etc., and generally, to drive machines having a reciprocating motion either of work or of the cutting tool. In some cases a flywheel can be fitted with advantage, energy being stored in it during periods of light load, and given up during momentary over-loads when the motor tends to slow down in speed.

Starting and adjustment of speed are effected in the same manner as for shunt motors. The capacity of all three classes of continuous current motors for dealing with momentary over-loads is increased when commutating poles are fitted.

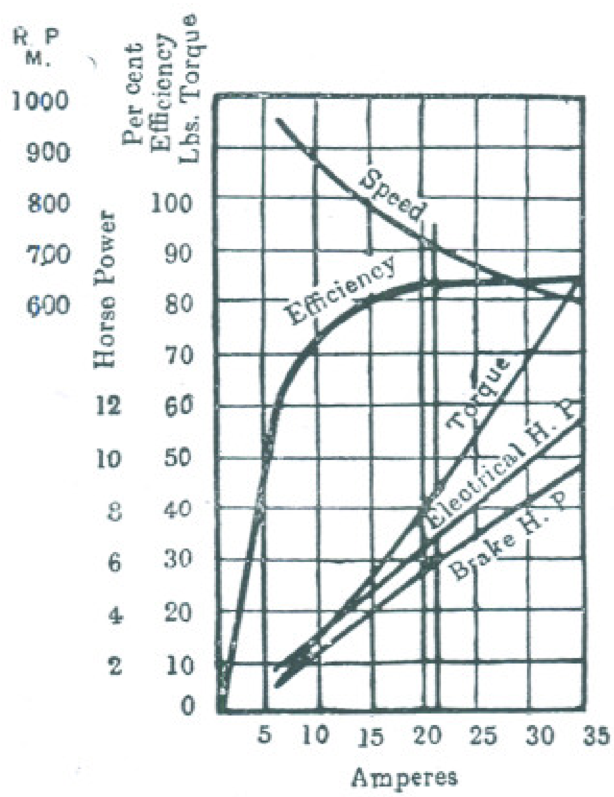


FIG. 7. TYPICAL PERFORMANCE CURVE OF COMPOUND WOUND MOTOR

TYPICAL SPECIFICATION FOR CONSTANT & VARIABLE SPEED C. C. MOTORS.

Yokes.—The yokes are to be of steel castings of high magnetic quality and combine great strength with minimum weight. The feet are to be cast as part of the yoke and both ends of the yokes are to have recessed machined faces to ensure that the end brackets fit concentrically. A fabricated frame will be accepted in lieu of the above provided that it satisfies the requirements as to high magnetic properties.

Poles.—All poles are to be of sheet steel punchings secured in place by tap bolts. Laminated construction is to be used throughout the main poles except for the smaller sizes where drop forgings will be accepted. Interpoles are to be drop forged. Tips to retain the field coils can be punched in one piece with the stampings for the poles.

Field Coils.—The field coils to be former wound. In general, cotton covered wire is to be used except for the smaller shunt coils, which are to be wound with enamelled wire and for heavy series coils which are to be of copper strip. Strip copper coils are to be insulated in the manner used for wire wound coils but before this, the turns are to be thoroughly protected from each other by fullerboard.

Armatures.—The armatures are to be built of annealed high grade sheet steel punchings assembled under pressure between end plates. The punchings are to be directly keyed to the shaft, or in the case of a six-pole machine they can be carried on a spider. Semi-closed slots can be used on the smaller type sizes and in the larger machines open slots can be employed together with axial and radial ventilating ducts to ensure uniform cooling.

Commutators.—The commutators are to be built of hard drawn high conductivity copper bars assembled on a cast iron sleeve which is pressed upon and keyed to the shaft. The segments are to be insulated from each other with specially selected and built up mica which is undercut. Particular attention should be paid to the correct seasoning of the commutators.

Armature coils.—In the smaller type motors the armature coils are to be hand wound and the slot lining to consist of treated press board and empire cloth. The slots can be closed by fibre strips. The ends of the coils are to be insulated from one another and the complete armature is to be thoroughly impregnated with insulating varnish. The larger sizes the coils are to be former wound with either double cotton covered wire or bare copper strip. The slot portions of the formed coils are to be wrapped with mica and a thin paper packing. The whole coils are then to be taken over and subjected to thorough impregnation treatment.

The armature slots are to be lined with treated fullerboard and the coils held in place by bands of steel wire insulated from the armature winding by fullerboard. When completely wound, a second impregnation treatment is to be given to the entire armature.

End Brackets.—The end brackets are to be rigidly constructed of cast iron and can be solid except in the larger sizes in which split brackets are to be used. All brackets to have a machined face having a spigot to ensure a concentric fit with the yoke.

Shaft.—The shaft is to be of high carbon steel and of great stiffness and strength. All fillets are to be turned to large radii and all dimensions ground to limit gauges. Oil throwers are to be turned in the shaft to prevent oil leakage.

Bearings and Lubrication.—All bearings are to be generously designed and in the case of sleeve or split bearings the length must not be less than $2\frac{1}{2}$ times the diameter, and all parts to be proportioned so as to ensure ample lubrication.

Inspection covers, oil overflowers and drain plugs are to be provided on all bearings. In all cases it should be possible to fit ball or roller bearings to each size of motor.

Brushgear.—The brushes are to be of high grade quality with flexible copper tails moulded into the brush and electrically connected to the holder. The brush holders are to be of the box type and carried on rocker rings. The tension spring is to give uniform pressure throughout the life of the brush.

Terminals.—In the smaller sizes terminal boards of moulded insulation can be used. Brass terminals with two pinching screws are to be provided for each connection in the larger sizes rectangular cast iron and moulded composition terminal box to be fitted and covered with a rectangular cast iron hood. Substantial cast brass Admiralty Type terminals are to be provided.

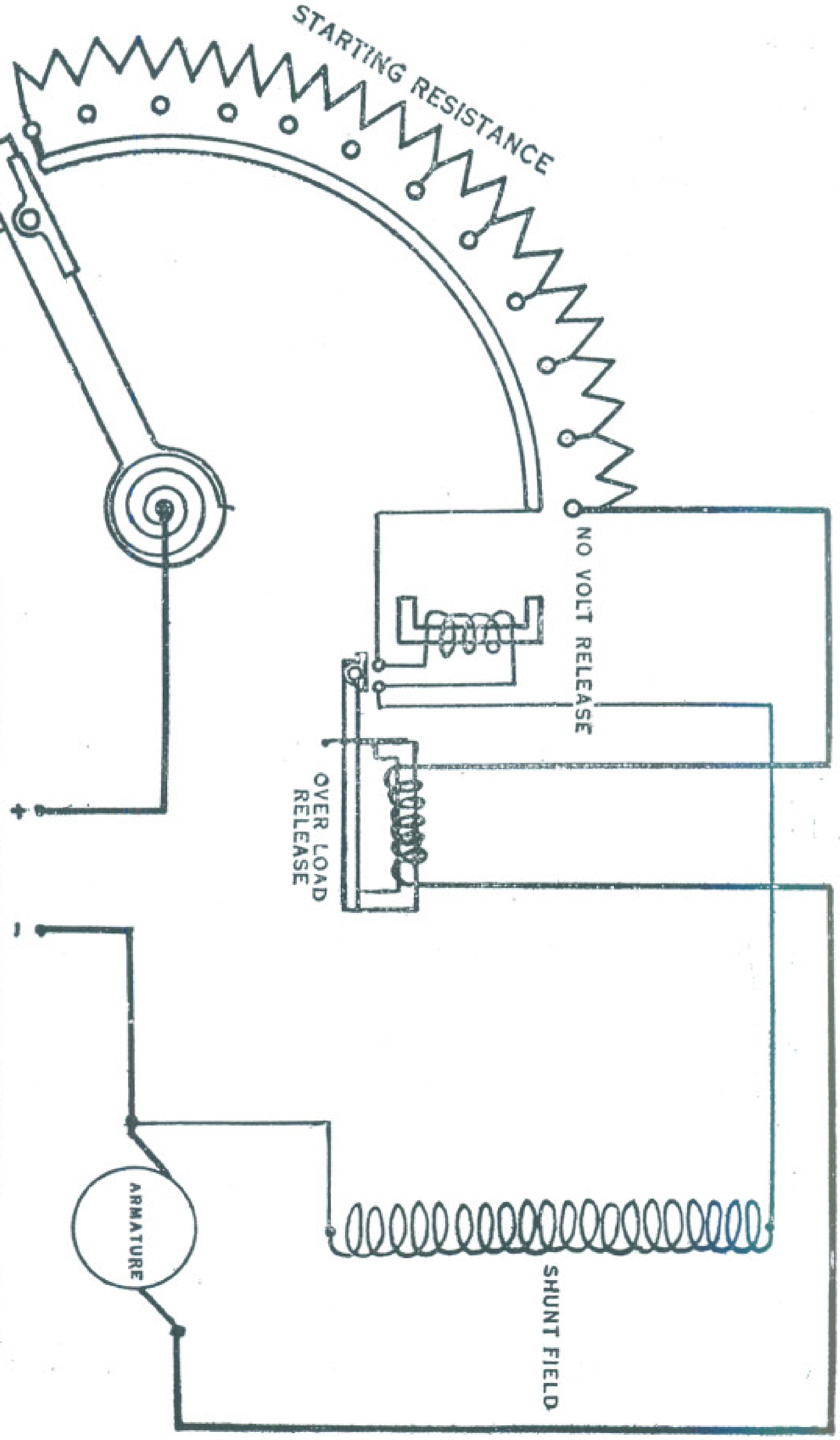
Starting Gear for Continuous Current Motors.

Shunt Wound Motors are started by connecting in the armature circuit a suitable resistance, which is gradually cut-out as the motor attains full speed.

As speed increases a counter electro-motive force or back pressure is generated in the motor which is proportional to the speed, and which largely neutralises the electro-motive force of the supply circuit.

In accordance with Ohm's well-known law the current in any C.C. circuit is equal to the voltage divided by the resistance. The resistance of the armature circuit is usually very low, and accordingly the current resulting from full supply pressure would exceed considerably the normal working current, which results only from the effective difference between the pressure of the supply, and the full speed back pressure of the motor. But as the windings and other current carrying parts of the motor are designed for economic reasons to carry only the working current, to subject them to an excessively greater current would be to risk a serious burn-out. To avoid this danger a starter is used, to keep the current within safe limits, until the motor has run up to full speed, and developed its full counter electro-motive force. The starter resistance must be cut out gradually, allowing adequate time for the speed (and back pressure) to increase between each step.

The operation of the starter may be followed without difficulty by studying the diagram given in Fig. 8. It will be seen that the movement of the switch arm to the first step allows current to flow into the shunt field winding through the " no-volt " coil, and into the armature winding through the starting resistance. Further motion of the handle gradually reduces the resistance, till all resistance is cut out when the handle has reached the running position.



CONTINUOUS CURRENT MOTOR STARTER FIG. 8.

Round the centre stud about which the starting handle turns is wound a strong spring, which if the handle is released at any intermediate point promptly returns to the "off" position. Under working conditions the handle is held in the running position by the no-volt coil or electro-magnet, but if the supply of energy should cut off or fail or the supply voltage fall to say, 75 per cent of the normal, the no-volt magnet becomes de-energised, and allows the switch arm to be returned by the control spring to the "off" position, when, of course the motor shuts down. Thus, should the supply of energy be resumed from some distant point, all risk is avoided of current being switched on to the motor direct, instead of through the necessary starting resistance.

It is important to note that the winding of the no-volt coil must be suitable for use with the field current of the particular motor with which it is used.

A great advantage in connection with "no-volt" coils is the possibility of stopping a motor from more than one position. This may be done by simply running two wires to push button switches placed in any convenient position, and used to stop the motor by short-circuiting the no-volt coil. This advantage will be readily appreciated when a slight delay may cause loss of life, the value of simple and inexpensive emergency push buttons will then be obvious.

The winding of the over-load release magnet is connected in the armature circuit, as shown in Fig. 8. When the current exceeds the value for which the device is set, the magnet operates to stop the motor by short-circuiting the no-volt coil: A movable calibrated scale is usually provided allowing adjustment from 25 per cent. to 150 per cent. overload.

Where a motor is protected by a separate circuit breaker the over-load release attachment need not be fitted to the starter. Where the motor is protected by fuses the over-load attachment should always be included, and set to trip before the fuses below, thus saving the cost of renewal.

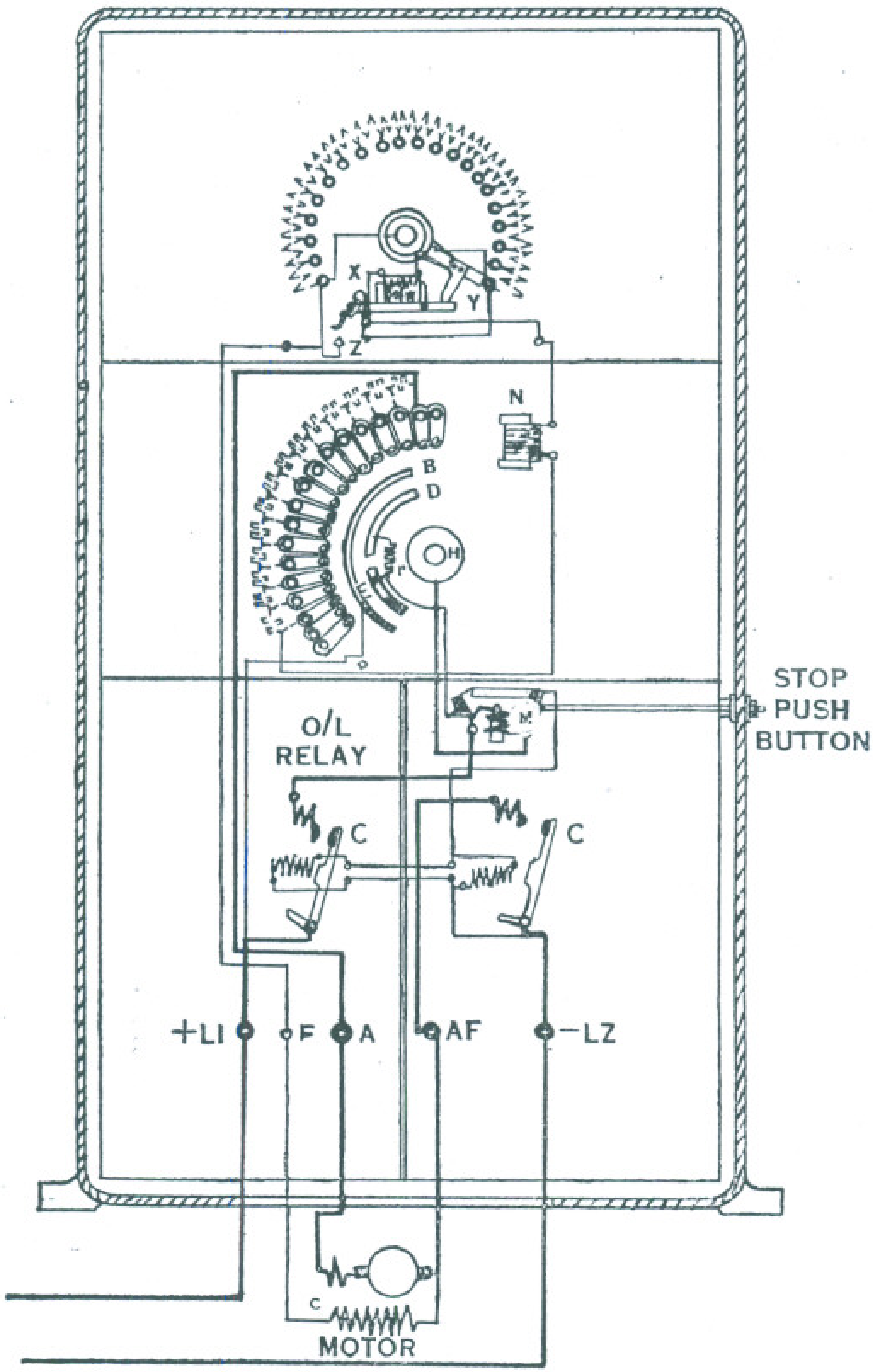
Control Gear for C. C. Motors.

A typical control panel for an adjustable speed compound wound motor is shown in diagrammatic form in Fig. 9. The panel comprises an electrically operated double pole circuit breaker C, a starting rheostat with no-volt release N, an over-load relay M and an inter-locked field rheostat. The starting switch is of the heavy-duty type with a main brush, bridging from centre-plate H to the main contact segments, and an auxiliary brush which bridges segments B, D ; B, E. The first movement of the switch lever to start the motor establishes a connection between B and E and completes the operating-coil circuit of the circuit breaker. Further movement of the lever inserts a resistance *r* in this circuit, in which are also included the auxiliary contacts of the overload relay. The operation

CONNECTION DIAGRAM OF CONTROL PANEL

FOR ADJUSTABLE SPEED CONTINUOUS CURRENT MOTOR

FIG. 9.



of the relay opens the motor circuit at the circuit breaker, and the resistance *r* prevents the circuit breaker re-closing unless the switch lever is returned to the starting position.

The field rheostat is fitted with an interlock which prevents the motor being started with a weak field. The interlock consists of an electro-magnet X, the armature of which, together with contact Z, short-circuits the field rheostat when the motor is stopped. The electro-magnet is connected in series with the shunt field and is designed so that the armature cannot be lifted when the coil is excited by the field current, although, when lifted, the armature will be retained when the minimum field current is passing through the coil. The short-circuit is removed from the rheostat by moving the contact arm to the "all out" position which causes a projection Y, to lift the armature.

When "inching" is required the starter is fitted with an auxiliary switch and two contact studs. These studs are short-circuited when the switch lever is in the "off" position, but are open-circuited when the lever is moved to start the motor. Thus, with the starter in the "off" position, the circuit breaker may be closed by pressing the "inching" push button, but it will open as soon as the button is released or if the switch lever is moved. This particular feature can be fitted if required but is not shown in the diagram.

POLYPHASE MOTORS.

Industrial motors for two-or three-phase alternating current circuits may be divided into the following types :—

(1) Squirrel Cage Induction Motors.

(2) High Torque Squirrel Cage Induction Motors.

(3) Slip-ring Induction Motors.

(4) Synchronous Motors.

(5) Special types, commutator, power factor correction types, etc.

(1) The squirrel cage motor consists of a fixed core named the stator, which carries in slots, a winding known as the stator winding, and a movable core named the rotor which carries the rotor winding in a similar manner. The stator windings of induction motors are essentially single or polyphase windings. The rotor on the other hand may be either of the "wound" or "squirrel cage" type. The wound rotor usually carries a simple three-phase winding in slots, and the ends of the winding are connected to slip-rings. The squirrel cage rotor carries a number of copper bars, each of which fills the slot in which it lies ; the ends of the bars are rivetted, bolted, brazed or welded to two heavy copper rings, alternatively the slots are filled with aluminium, and the ends short-circuited in a patent die-casting method. It will be seen that if the cage winding were removed bodily from the core it would have the appearance of a circular squirrel's cage and from this similarity the name is derived.

The action of a polyphase induction motor may be likened to that of a continuous current motor in which both the fields and the armature are capable of rotation. Supposing the fields of such a motor to be fully excited, and rotate with the armature at rest, and short-circuited, a current of any desired magnitude may be induced in the armature, since the generation of a current depends simply on the relative motion of the fields and the armature. The torque produced by the action of the fields in the induced current will tend to turn the armature, and if the fields be kept rotating at a uniform rate, the armature will speed up until the relative motion of the fields, and the armature is sufficient to generate a current that exactly balances the load ; uniform speed has then been reached. The "slip ", or the difference between the speed of the armature and the speed of the fields, is generally stated in per cent. of the speed that would be reached if the armature were rotating at the same speed as the fields. This speed is spoken of as the speed of synchronism. The speed at no-load is fixed by the frequency of the circuit and the number of poles for which the motor is wound. At full-load the running speed is less than the synchronous speed by an amount which may vary between about 7 per cent. in small motors, and 4 per cent. or even less in larger motors.

In a normal polyphase motor the speed is nearly independent of the load. This is in marked contrast to the C.C. series wound motor, but shows a strong resemblance to the torque speed characteristics of a normal shunt motor. As the load increases the speed slightly decreases, until the maximum load is reached. If the load should be increased beyond this the motor is brought to a stand-still. In practice the working load should not exceed 50 to 60 per cent. above the maximum load. Speed regulation may be obtained by (1), inserting resistance in the rotor ciruit ; (2) changing the number of poles ; (3) cascade connection with one or more motors ; (4) addition of variable speed set.

The first is a common but limited method, the other methods have special applications, that involves expensive equipment and are not frequently met with in ordinary industrial use.

Squirrel cage motors are very simple and robust, and are eminently suitable for service conditions where only unskilled labour is available. They are suitable for use under the same constant speed conditions as continuous current shunt wound motors. They should be installed in situations where the motor is not required to start against full-load. In general practice it will be found that the starting torque exerted by these motors is sufficient for starting direct on to machines, such as Flour Mills, Pumps, Circular Saws, Small Line Shafts, Motor Generator Sets, and similar purposes. When the driven machine requires a greater torque at starting on account of heavy inertia to be overcome such as in the case of Printing Presses, Compressors. Mortar Mills, the motor should be arranged to startlight on a loose pulley, or a centrifugal clutch.

High Torque Squirrel Cage Induction Motors.

In recent years the application of Squirrel Cage Induction Motors has increased considerably, owing to their reliability, and simplicity of construction, low prime cost (both of motor and control gear), and to improved design—the modern Squirrel Cage rotor being virtually indestructible whilst ensuring a high-starting torque comparable to that obtained with a Slip-ring Motor.

For certain requirements, however, it is necessary to have a motor with a *High Starting Torque* and comparatively *Low Starting Current* —the High Torque Motor fulfils these requirements without impairing the full load efficiency. For full voltage starting by direct switching, a starting torque of twice full load running torque is obtained with a starting current of $5\times$ F.L.C. Other starting values are given in the table for starting current and torque.

Applications.—There are many applications for this type of motor, but obviously if gearing, belt, rope or other indirect form of power transmission is used, allowance must be made in designing the transmission for the torque exerted by the motor when starting, as otherwise undue wear may take place.

It should also be appreciated that for centrifugal pumps and fans —unless it is necessary to limit the starting current, and it is intended to start the motor by switching direct on the line—it is better to supply a standard Squirrel Cage Motor, since the torque required with this class of load rises rapidly with the speed, which is approximately equivalent to the speed-torque characteristic of an ordinary Squirrel Cage Motor.

For driving compressors fitted with unloading valves where the torque required is only 15% to 30% of full load torque, it is obviously unnecessary to use a high torque Squirrel Cage Motor, but for compressors which cannot be unloaded, the high torque double Squirrel Cage Motor is most suitable, bearing in mind that the gears, driving chains, etc., must be suitably designed to transmit the torque which it is intended that the motor shall exert depending upon the starting method adopted, as explained above for a high torque motor.

The high torque motor, while having a higher value of torque at starting, has not so high a *maximum* torque as the standard machine. This, however, is often a great advantage as it ensures that any sudden overloads will not pull the motor out of step, but will only have the effect of increasing the "slip."

Construction and principle of operation.—In outward appearance and general mechanical construction these motors except for the rotor, are exactly similar to the ordinary Squirrel Cage

Motors. The rotor, however, has two distinct squirrel cage windings; the outer winding nearer to the air gap is of high resistance, and low reactance, whilst the inner winding nearer the shaft is of low resistance and high reactance. The combined effect of these two windings gives the motor a high starting torque characteristic without excessive starting current and also enables it to operate at high efficiency, the reasons for this being as follows :—

The current in each of the rotor windings is limited by the impedance of that winding, and since the reactance of the individual windings varies with the frequency, it follows that the current in the two windings when starting—the rotor flux being at supply frequency—will be limited mainly by the high resistance in the case of the outer winding and the high reactance in that of the inner winding.

As the rotor accelerates the frequency of the rotor flux decreases proportionately, so that at full speed the reactance of the inner winding becomes neligible, thus allowing a much larger proportion of the rotor current to be carried by this winding. The result is that, whilst at starting, the bigger proportion of the rotor current is carried by the outer squirrel cage winding which has a high resistance, and therefore enables a large starting torque to be exerted without excessive starting current, at full speed the inner winding which has a low resistance carries most of the rotor current, and therefore enables the motor to operate at high efficiency.

General considerations in starting Polyphase Induction Motors.—When an induction motor is switched directly on to the supply, the conditions at the instant of switching in will be similar to the condition of short-circuit, for the rotor has no time to accelerate, and the stator current will be excessive and of poor power factor. The torque produced is small, and is almost always less than the normal full-load torque. Evidently the motor would not start if the load were in excess of the short-circuit torque, even though the stator were switched directly on to the supply. Thus there are two objections to direct starting :—

(*a*) The torque may not be great enough to start the motor.

(*b*) The current is very high, of poor power factor, and if the acceleration is low the excessive current may be prolonged sufficiently to damage the windings of the motor and the line. If the motor is large the very high current would disturb the supply.

Both these objections affect the user and the supply company. The user wants to make sure that the motor will start up against its proper load, and the supply company to ensure that the motor in so doing will not take an excessive current, besides this it affects the regulation of pressure in the system.

TABLE OF AVERAGE VALUES OF STARTING TORQUE AND CURRENT OF POLYPHASE INDUCTION MOTORS.

Method of starting.	*High Torque Squirrel Cage Motor.*		*Ordinary Squirrel Cage Motor.*		*Slip-Ring Motor.*	
	Starting Torque.	Starting Current.	Starting Torque.	Starting Current.	Starting Torque.	Starting Current.
Switching direct on line.	Twice full load	5 times F.L.C.	125% of full load	5 times F.L.C.	Full load torque.	1¼ times F.L.C.
Star-Delta Starting ..	70% of full load	1.85 times F.L.C.	40% of full load	Twice F.L.C.		
Auto-Transformer Starting.	Full load	2¼ times full load				
Ratio $\frac{\text{Starting Current}}{\text{Starting Torque.}}$	$\frac{2\frac{1}{2}}{1}$		$\frac{4\frac{1}{2}}{1}$		$\frac{1}{1}$	

Note.—F.L.C. indicates Full Load Current.

STARTING REGULATION FOR A. C. AND C. C. MOTORS.

Where alternative starting conditions are given, the smaller *of the two starting currents shall be the limit. "F. L. C." refers to "Full Load Current."*

Supply Company.	C. C. Motors.	A.C. Motors.				Remarks.
		Single Phase.	Poly-phase Motors.			
			Squirrel Cage.	Slip-ring type.	Synchronous Motors.	
1	2	3	4	5	6	7
The Bombay Electric Supply & Tramway Co., Ltd.	A. ..		All motors above 4 H. P. to be wound for 3 phase 400 volt supply.			
Single Motor Installation.	B. All sizes 2½×F.L.C. ..	Upto 1 H. P. . . 6×F.L.C. ..	Upto and including 4 H. P. three phase motors 6 times F.L.C. Above 4 H. P. & upto 10 H.P. „ „ „ 3 „ „ „ 10 „ „ 15 „ „ „ „ 2 „ „ „ 15 „ .. .. „ „ „ 1½ „ „			
Installations of 2 or more motors.	All sizes 2½×F.L.C. ..	Upto & including 4 H.P. 4 times aggregate F.L.C.	Upto & including an aggregate of 8. H.P. .. 5 times F.L.C. Above 8 H. P. upto & including 20 H.P. in the aggregate .. .. 3 „ „ Above 20 H. P. upto & including 30 H.P. in the aggregate. 2 times F.L.C. of largest motor or 1½ times the aggregate F.L.C. Above 30 H. P. in the aggregate .. 1½ times aggregate F.L.C.			
The Calcutta Electric Supply Corporation Ltd.	A. Without apparatus for limiting starting current } Upto 1 K.W. Upto 4 K.W. 225 V. C.C. .. „ 50 „ 450 V. C.C. .. B. Starting current not to exceed 2×F.L.C.	Without apparatus for limiting starting current. } Upto 4 K.W. Upto 4 K.W. 230 V. A.C. ..	Individual motors not to exceed 30 K.W. 15 K.W. 3½×F.L.C. 20 „ 3 × „ 25 „ 2½× „ 30 „ 2 × „	Starting current not to exceed 1½ times full load current.		Individual motors above 50 K.W. will be supplied at high pressures alternating current. A.C. Motors of over 4 K.W. must have a starter with at least 2 over-loads and one no-volt release.
Delhi Electric Supply & Traction Co., Ltd.	Motors requiring more than 10 amperes will only be supplied across outer of a 3-wire system.	Upto 1 Horse Power. ..	Upto 10 H. P. Starting Current not to exceed 2×F.L.C.	Above 10 H. P. and Starting Current not to exceed 1½ times full load current.		Above 30 H. P. the choice of suitable voltage rests with Company. A. C. motors of over 5 H. P. to have no volt release.
The Lahore Electric Supply Co., Ltd.	A. Without starter upto 0·5 H. P. With starter "No Limit" ..	*Split Phase Starting.* Demand not exceeding 4 K.W upto 1. H. P. or less. *Repulsion Start.* With or without starter } Upto 1 H.P.	Without starter up to 3 H. P. with Star Delta starter up to 15 H. P. With Auto-Transformer Starter { Upto 25 H.P.	No limit provided power factor does not fall below 0·85.	No limit. ..	
	B. ¼ to ¾ H.P. . . 8 times F.L.C. 1 „ 3 „ 2 „ „ .. 5 „ 15 „ 1½ „ „ .. 20 „ 25 „ 1¼ „ „ .. Over 25 „ 1¼ „ „ ..		*Maximum starting current permitted.* 5—6 times F.L.C. 4 „ „ 2½ „ „ 2 „ „ Not allowed ..	4 times F.L.C. .. 3 „ „ 2 „ „ 2 „ „ 1½ „ „		
The Madras Electric Supply Corporation.	A. Upto 3 H. P. 225 volt C.C. Supply. B. 15 amperes per step at 450 volts.	Upto 1 H.P. 250 volts. A.C.	Upto 20 H.P. provided they are fitted with light starting gear.	5 amperes per step at 440 V. 3 phase.		
Punjab Public Works Dept., Electricity Branch.			Motors upto 5 H. P. Direct Starting. Above 5 H.P. but not exceeding 65 H.P. starting device so designed so as not to allow the starting current to exceed 2×F.L.C.			Above 5 H. P. motor starters to be provided overload and no-volt release gear.

It is not merely a question of regulating the voltage of supply within a few percentage of normal. Many induction motors work continuously on full load, and frequently have to cope with overloads which approach to the stalling torque of the machine. Should a number of motors be operating at the end of a fairly long line, and the starting of a large machine coincide with an overload period on another, it is quite possible that the combined effects of start and overload currents will so reduce the pressure at the consumer's end that the overloaded motor would fall out. If this mishap occurs, there is a danger of the effect becoming cumulative in the period which elapses between the stalling of the overloaded motor and the operation of its protective gear. If these events take place in the premises of one consumer, it may cause the stalling of motors on premises of other consumers in the neighbourhood.

In order to protect themselves from the effects of excessive starting currents, most supply authorities have special regulations for connecting motors to their mains and the method of starting them. A table is given overleaf of average values of starting torque, and current for industrial motors. Another table is shown giving details of the starting regulations arranged in tabular form obtained from some of the principal supply companies in India.

As can be seen from the list it is usual to permit direct starting on motors upto 5 H. P. and star-delta and auto-transformer starting above this size, but the starting current in each latter case must not exceed twice full load current.

Method of starting Poly-phase Induction Motors.

The direct starting method is adopted in motors of small output, in which full line voltage is applied to the stator, then an ordinary induction motor takes approximately five times full load current and will start against full load torque.

Direct Starting.—This may be accomplished by using an ordinary three-pole switch fuse, with fuse wire inserted in the holders of slightly larger current-carrying capacity than the starting current, or slightly below the stalling current of the motor (which is about seven times full load current). This is a cheap and simple method of starting, but suffers from the inherent feature that protection while running is kept down to a minimum.

A more satisfactory method is to have a direct starter change-over switch, in which the fuses are cut out in the starting position, and are inserted in the second or running position. The fuseholders can then be " fused " or rewired to a safe value; this results in increased cost, but a high degree of protection; overload coils can replace the fuses, at a further additional cost.

Where the motor is liable to be overloaded frequently, and the *mistri* cannot be relied upon to insert the correct fusing wire, overload coils should be used. For ordinary purposes fuses are quite satisfactory.

There is on the market what is called an air break automatic switch, which incorporates the comparative cheapness of the switch fuse, with the protective devices of an automatic starter. The switch is suitable for the direct starting and protection of two- and three-phase Squirrel Cage Motors upto 3 H.P. 550 V.

The switch is compact, mounted on a moulded base, and enclosed in a strong steel case with a removable cover, and moving and fixed contacts are of pure silver, and are replaceable at small cost. Front connecting screw type terminals are fitted, and cable entry is suitable for bushed holes or conduit glands. The under-voltage protection switch has a low current protective device, which prevents automatic re-starting of the motor when the supply is restored after a temporary failure. The device consists of a series magnet, designed to hold on an armature with a current less than the no-load current of the motor, and connected into one phase of the circuit, if the power supply is interrupted the armature is released, and strikes the trip bar, thus opening the switch.

Fault protection.—The switch has an electro-magnet connected into each phase, the electro-magnet on the centre pole acting as the under-voltage release magnet. The armatures of all three magnets have a common tail piece, which is mechanically linked to the trip bar.

Over-current protection.—Thermal over-load protective devices are fitted on two poles of the switch, each consisting of a heating element which carries the main current, and bi-metal strip which acts as a check or restraining device to the trip-gear. The heating elements are so rated that a continuous load of approximately 133% full load current, if maintained for two to three minutes, causes the bi-metal strip to release the trip-gear.

The automatic switch opens the circuit whenever the voltage falls below a pre-determined limit, thus isolating the motor from the mains and so prevent it starting up again when the supply is restored, thereby preventing any harm that might otherwise accrue both to personnel and plant.

Stator resistance starting.—This type of starting is seldom used now-a-days, as the starters are not cheap and where it is not possible to start direct, it will be found cheaper and simpler to use a star-delta starter.

Star-delta starting.—If the motor is wound with a three-phase stator, and designed to run under normal conditions delta connected, it may be started by the star-delta method.

Fig. 10 shows the connections, voltage and current values for direct starting and for star-delta starting.

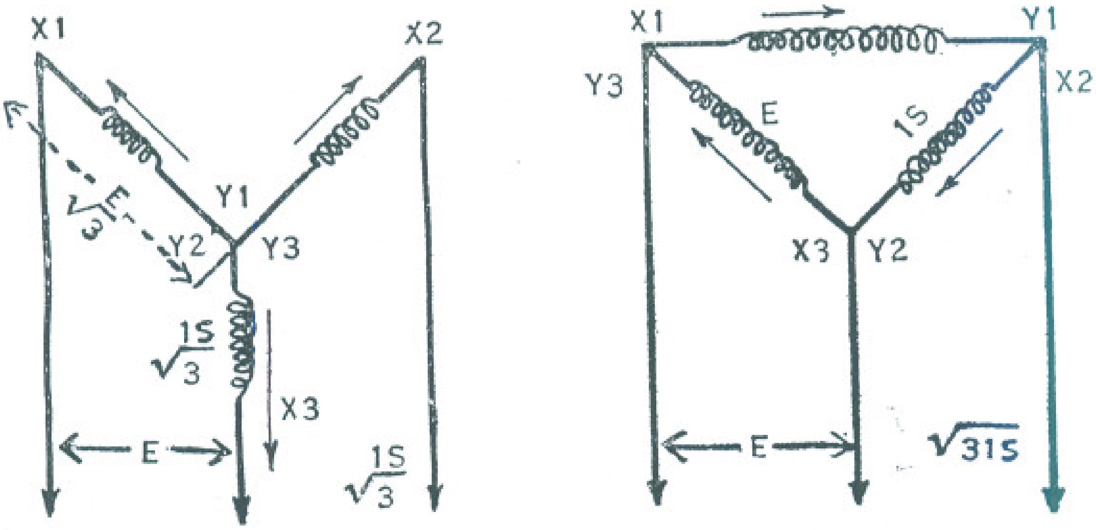
It will be seen that the star connection reduces the phase voltage, and this causes a proportional reduction in phase current.

Starting current.—The re-arrangement of the phases is such as to cause a corresponding reduction in the ratio of line to phase current, with the net result that the line current of the star connected stator is $\frac{1}{3}$ of that of the delta. The torque (which varies as the square of the phase current) is also $\frac{1}{3}$ of that due to the delta connected motor, so that the star-delta arrangement enables us to limit the starting current to $\frac{1}{3}$ normal with a corresponding reduction in torque.

At the instant of switching in, the phase current will be a certain value as a factor of the star voltage and as the rotor accelerates, a stable condition will be reached when motor torque is equal to load torque and the slip say, equal to S.

(FIG. 10.)

STAR & DELTA STARTING CONDITIONS FOR A MACHINE DESIGNED FOR DELTA CONNECTION



When the change to delta connection is made the speed cannot alter instantly, and the slip at the instant of throwing over the starter must still be equal to S. Hence the phase current will be measured to the delta scale, *i.e.*, it will be $\sqrt{3}$ times its original value. In addition to this the stator is now delta connected and the line current is $\sqrt{3}$ times the phase current. Hence when the starter is thrown from "Start" to "Run" the line current is increased to three times the value it had immediately before the change-over.

Star-delta starting is very popular, mainly on account of its cheapness, and robustness of the motor and starter. In starting totally enclosed machines it is worth considering a point which is not always realised. If a certain drive requires, say, a 10 H.P. totally enclosed motor and the starting power required is 7½ H.P. (corresponding to 75% of full load starting) then apparently the use of a star-delta starter is not possible. It must be remembered however, that a 10 H.P. totally enclosed machine corresponds to a 23 H.P. protected machine as far as windings are concerned, the required starting power of 7½ H.P. is actually only 33⅓ per cent. of the capacity of the machine. A star-delta starter is therefore satisfactory.

The starter is usually of the drum controller type, with a mechanical interlock to prevent the motor being switched into the "run" position first, and the over-load protection is generally cut out in the starting position; if not, time lags are incorporated in conjunction with the over-load device. Starters should be capable of being used upto a maximum service of ten starts per hour. For motors upto 30 H.P. air break equipment is quite suitable, from 30 H.P. to 50 H.P. oil immersed starters are recommended. The following features should be necessary or available for use in both types of starters :—

Light weight, convenient shape, small space occupied, no live parts exposed, under-voltage and adjustable over-load protection, cannot be operated in wrong sequence, simple renewable contacts, internal connections and contacts easily accessible, spring return to the 'off' position and suitable for wall or floor mounting. The air break pattern switch usually has a drum rotating switch with controller finger contacts, and two breaks per phase, push button stop should be incorporated in the no-voltage coil circuit, ammeters can be fitted, if required, and cable entry usually consists of wooden bushed holes suitable for V.I.R. cable, other types of cable entry can generally be accommodated at extra cost.

Oil break star-delta starters are of much more substantial manufacture, and briefly have the following additional, or different, features to what the air break type usually have.

Contactor pattern switch contacts, which close with a rolling, and rubbing action that renders them self-cleaning, busbar-chambers can be fitted together with isolating switches that can be mechanically interlocked with starter, cover and oil tank. Standard cable entry consists either of wooden bushed holes, or plates screwed for the reception of conduit. A "loose" handle feature is provided, and is operative usually in the "run" position. The oil tank is detachable, and the contacts can be examined easily. Some makers include time lags whenever overload releases are specified.

It may be pointed out that where the duty is onerous, an oil immersed, direct or star-delta starter can be used for motors whose output is less than 30 H.P. They are more expensive than air break switches, but apart from the testing of the oil, and cleaning where necessary, the maintenance charges are lower.

Auto-transformers Starting.—The connections for an auto-transformer starter for three-phase motors are shown in Fig. 11 together with the combinations for "start" and "run" using "V" connected auto-transformers.

In starting, the motor is first connected to the mains, through the auto-transformers, which reduce the voltage initially impressed upon the motor, and thus cut down the excess of current that otherwise would be drawn from the line; while, owing to the transformer action, the line current is considerably less than the current in the stator windings of the motor.

The transformers are usually provided with a series of taps about four or five in number ranging from 25% to 75% line voltage.

With the use of auto-transformer starters, squirrel cage motors can be started against full load torque taking about three times full load current from the line, or against half full load torque taking about twice full load current.

For motors upto 30 H.P. auto-transformer starters are similar in general construction details to those of star-delta starters, but with the addition of an air cooled transformer. From 30 H. P. upto 50 H.P. oil immersed starters and transformers are used. Some makers employ an air break starter, but the auto-transformer is oil immersed, in sizes upto 30 H.P.

Where Squirrel Cage Induction Motors above 50 H.P. are used, it is usual to have an auto-transformer starter with a separate oil circuit breaker incorporating the necessary protection devices, and including safety interlocks for correct sequence operation.

Poly-phase Slip-ring Induction Motors.

Slip-ring motors differ from the squirrel cage type only in the arrangement of the rotor winding, the ends of which are connected to slip-rings, in order that external resistance may be connected in the rotor circuit.

At no load, slip-ring motors run at practically synchronous speed, and with all external resistance out of circuit the full load speed is almost identical with that of squirrel cage motors. With external resistance in the rotor circuit, a large starting torque can be obtained without excessive current being taken from the line, *e.g.*, full load torque with about $1\frac{1}{4}$ times full load current, or twice full load with about $2\frac{1}{2}$ times full load current. By varying the amount of resistance in the rotor circuit a considerable range of speed may be obtained, the speed automatically adjusting itself to the torque as in the continuous current series wound motor ; in other words the speed varies with the load, and to take an example, a slip-ring motor driving a haulageway, will wind a heavy load at a low speed, and a light load at a high speed.

The insertion of resistance in the rotor circuit increases the slip *i.e.* decreases the speed, but is very objectionable as the percent slip is always equal to the I^2 R losses in rotor circuit, and to drop the speed 30% means 30% of the line energy is wasted in the rotor circuit. This method is therefore costly in power, and requires expensive rheostats and control gear, and it follows that motors of this class are not suitable for running for long periods at less than full-load speed. Most slip-ring motors with small outputs have continuously rated slip-ring brushes, but when large slip-ring motors are required to start up only at long intervals, and to run without stopping for long periods, they can be fitted with brush lifting and short-circuiting gear, but this gear should be accompanied by special interlocks, arranged to make it impossible for current to be switched on to the stator until the starter has been returned to its zero position. The effect of using B.L. & S.C. gear is to save wear of the slip-rings, and brushes, and to eliminate losses which otherwise occur in the cables between the slip rings and the resistance.

Slip-ring motors are generally suitable for use under the same conditions as continuous current compound or series wound motors. A suitable amount of resistance may be left permanently connected in the rotor circuit when a fly wheel is fitted, to allow the speed to fall so that the stored energy may be given up.

Beyond a certain maximum torque, known as the "pull-out" torque, induction motors of either class slow down in speed and rapidly come to a standstill. Thus pull-out torque is usually from 2 to 2½ times full load torque, and consequently the maximum overload capacity is limited within this amount. Special motors can be constructed having a large pull-out torque to suit special cases.

Control gear for Three-phase Slip-ring Motors.

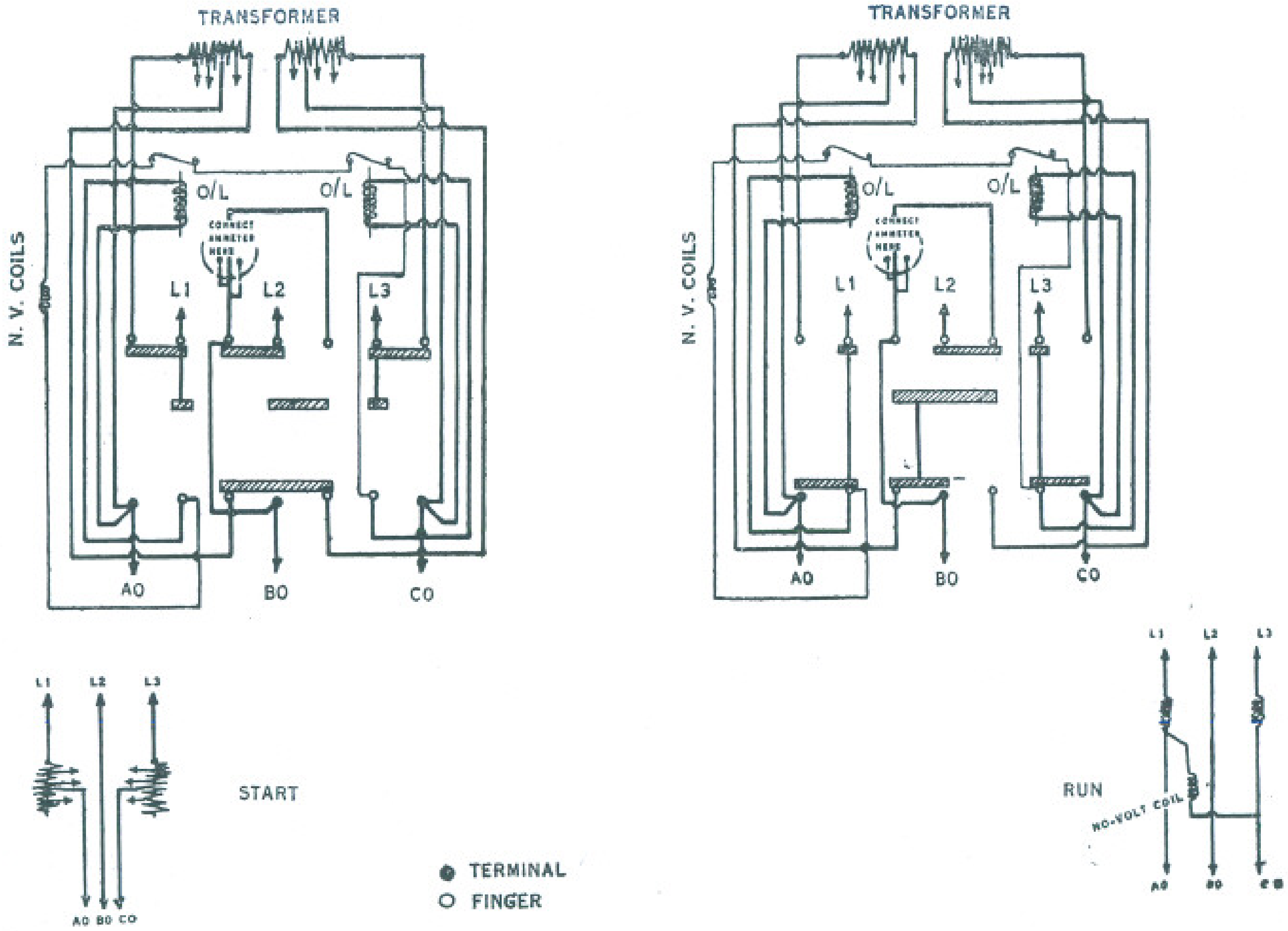
The simplest form of starter consists of a switch having three arms, with a resistance which is gradually cut out of circuit with the rotor winding, as the motor runs up to full load speed.

The use of a hold-on-coil in conjunction with a strong central spring tending to return the starter to its zero position no-volt protection, and facilitates the stopping of the motor from remote positions by the use of emergency push button switches or interlocks. The starting resistances have to be cut out gradually and take approximately 15 to 45 seconds depending on the size of the motor. If the starting has to be carried out by unskilled labour, it may be necessary to fit a step by step slow motion device so that the operation is carried smoothly and the supply line not

CONNECTION DIAGRAM OF 20 H. P. 400 VOLT—3 PHASE—50 PERIODS

AIR BREAK DRUM TYPE AUTO TRANSFORMER STARTER

(FIG. 11)



subjected to excessive starting current. This type of face plate starter should be capable of a maximum of four starts per hour against full load torque, the total starting period not exceeding five seconds plus half a second per horse power. At least fourteen times the starting period must be allowed between successive starts for cooling. Two starts in quick succession should be able to be made provided that twice the normal cooling period be allowed to follow.

A separate circuit breaker with under voltage, and over current protective devices is required to control the stator circuit. This type of starter is suitable for motors upto 100 H.P. and should incorporate all necessary safety interlocks. For motors upto 200 H.P. an oil immersed rotor starter can be used, these are similar to the face-plate type but are immersed in a tank filled with oil, and are floor mounting, the oil circuit breaker generally being mounted above. The starters should comply with B.S.S. No. 247/1927.

Another type of starter is the liquid starter which can be obtained for use with alternating current Slip-Ring motors up to the largest sizes. Liquid starters have an assured position because of their simple, robust construction, amounting almost to indestructibility, low first cost, easy and safe operation, even by unskilled labour, low maintenance charges, and smooth acceleration in running the motor up to speed. They offer the greatest saving in initial outlay when used with motors that require to be started infrequently, thus allowing ample time between starts for the liquid to cool. A wide field of application for them is found in connection with motors driving generators, compressors, conveyors, screening plant, pumps, fans, textile machinery, etc., and line shafting. Liquid starters should not be installed for use on moving apparatus, such as cranes, where the liquid is liable to be spilled. Also, where frequent starting and stopping is required, a starter with metallic resistances is preferable, unless the liquid starter is specially designed with a cold water circulating system.

Construction.—The starter generally consists of a rectangular metal tank with a semi-circular sheet steel cover, the tank is filled with liquid, the electrolyte, in which dippers termed electrodes are lowered or raised gradually by screw gear. Connections are brought from the slip-rings of the motor to the electrodes, the tank forming a common neutral giving perfectly balanced phases. When the starter is in the full 'on' position, the electrodes are short-circuited by copper to copper contacts to eliminate losses in the starter while the motor is running. The principal parts of the operating gear are mounted outside the tank to protect them from corrosion by the electrolyte. The electrodes should be wrought iron sheet, which give better service than cast iron. When these become seriously reduced by corrosion, new parts can be obtained at a reasonable price. The electrolyte recommended is a 10% solution of washing soda (carbonate of soda) in water. Apart from periodical emptying, cleaning, and refilling with fresh solution, only the addition of fresh water occasionally, to compensate for evaporation, is necessary to maintain the electrolyte. All standard types of cable entry can be fitted.

As this type of starter only controls the rotor circuit, it is necessary to provide a separate switch with overload, and under-voltage protection, together with "off" position, and brush lifting and short-circuiting device safety interlocks. In both cases the protective device prevents unexpected and violent restarting of the motor after an interruption of the supply.

Incidentally it may be mentioned that this type of starter has been developed to control motors upto a maximum of 8000 H.P. These starters should comply with B.S.I. Specification No. 140.

Upto now, separate rotor starters, and oil circuit breakers have been considered, but it is possible to use both equipments mounted in a complete control panel either with floor mounting stands for the O.C.B. with the rotor starter mounted immediately underneath, each starting pillar having the same protective features and safety interlocks as the separate units. In the smaller sizes a mechanical interlock is sometimes provided to ensure that when the circuit breaker trips the rotor starter returns to the 'off' position. This type of pillar can be mounted in switchboards; and arrangements made for fitting bus-bars chambers, and isolating switches. A valuable feature is that with the isolator open, the stator switch can be operated for observation of the contacts.

For non-reversing slip-ring motors upto 50 H.P. a typical panel would comprise the following :—

A totally enclosed, pressed sheet steel case, wall mounting, and fitted with a drum starting switch, having renewable segments and contact finger tips, starting resistances self-contained, wound on bobbins, covered with fire-proof material. Contactor type circuit breaker, with under-voltage, and over-load protection, together with arrangements for electrically interlocking with motor slip-ring short-circuiting, and brush lifting device. Ammeter and special cable entry can be fitted if required.

For motors above 50 H.P. and up to 350 H.P. the stator, starter, and circuit breaker, are so big that it is more convenient to incorporate them in a floor mounting control pillar. Where no excessive dust prevails, an industrial pattern would be suitable with drip proof enclosure, but if the pillar is to be rendered dust proof and splash proof, and thus unaffected by coal or flour dust and the like, a mining type pattern would be necessary. Such a pillar, designed for inching, starting, and protecting non-reversing poly-phase slip-ring induction motors, would comply with the following specification :—

Specification.

The control pillar is to be constructed of sheet steel with base suitable for floor mounting. Back covers with hinged front doors are to be provided so as to render all parts accessible, excepting the isolator. Suitable lifting arrangements to be fitted on the top of the pillar. The pillar is to be equipped with a drum type starter, contactor type circuit breaker (embodying under-voltage and "trip-free" features), over-current relays, and a "stop" push button.

A "dead man's handle" or other suitable gripping device is to be incorporated in the starter so that it is only possible for the operator to leave the starter in the full "on" or "off" position. The pillar is to be provided with a triple pole isolater and a suitable ammeter, together with arrangements for connecting a voltmeter in circuit if required.

Starter.—A starter is to be operated by a lever type handle incorporating a slow motion device, the switch cylinder being rotated by a to-and-fro movement of the handle, and this motion is to be arrested automatically when it reaches the "running" position. The cylinder is to be provided with renewable contact segments and fingers, each division of resistance to be provided with a separate finger, so that any arcing is distributed over a number of fingers. In the smaller sizes, resistances may consist of fire-proof tube elements wound with wire of high resistance alloy and protected by a covering of cement, in the larger sizes cast iron grids mounted on mica insulated steel rods, or unbreakable grid resistances can be supplied.

Circuit breaker.—All three phases of the line circuit to be controlled by a triple pole contactor type circuit breaker (having arc chutes, magnetic blow outs, and renewable arc tips).

Inching may be permitted by alternately depressing and releasing the "dead man's handle," but terminals are to be fitted so that "inching" can be accomplished from points remote from the pillar.

To stop the motor a push button is to be fitted which interrupts the operating circuit of the circuit breakers. Terminals are to be provided so that additional normally closed push-buttons may be used to stop the motor from points remote from the pillar.

Protective devices.—In the event of the "dead man's handle" feature being released before the starting switch has reached the full running position, the line contactor is to open, and not re-close until the switch has been returned to the starting position. This arrangement is to render it impossible to leave any of the resistances in the secondary circuit continuously with consequent risk of burning out. An interlock is to be provided so that the circuit breaker must be opened before the isolator can be operated, thus preventing any arcing on the isolating switch contacts. Three over current relays are to be fitted with time delay adjustable dash pots, calibrated in corresponding percentages of full load current. Operation of any one relay is to interrupt the coil circuit of the breaker.

In the event of failure of voltage the contactors are to open and not to re-close until the starter drum has been returned to the "starting" position.

Terminals are to be provided for connection to the brush-lifting and short-circuiting device to prevent the motor being started whilst the slip-rings are short-circuited.

Isolator.—This is to be of the slow break rotary switch type having two breaks per pole, and operated by an external lever. The line terminals are to be situated in a sealed compartment rendering them inaccessible even when the door of the pillar is open. The isolator is to be mechanically interlocked with the door, so that the latter cannot be opened whilst the equipment is "alive." Arrangements are to be made for fitting an ammeter and voltmeter if required.

Connections and cable entry.—All internal connections are to be complete and cable entry is to consist of conduit glands.

Finish.—The outside of the pillar is to be finished in grey enamel with two undercoatings, internal parts are to be black stove-enamelled, and cadmium plated.

Single-phase Induction Motors.

When a pressure is applied to one phase only of a three-phase induction motor with a closed rotor, no torque is developed if the motor is at rest. But if a three-phase motor is running and one stator phase is disconnected, the machine will develop a torque and continue to run as a single-phase induction motor. When the motor is at rest, the alternating flux merely sets up a current in the rotor winding, the magneto motive force of which acts along the same axis as the stator magneto motive force and consequently no torque is produced. But when a one-phase motor is running, then in addition to the electro-motive force of pulsation which produces the rotor current, an electro-motive force of rotation is also induced in the rotor winding, and this produces a magnetizing current which sets up a cross flux at 90° (electrical) in space to the stator flux, and it is the interaction between the rotor current and this cross flux to which the torque is due.

Thus the single-phase induction motor can develop a torque only when it is running, the direction of the torque depending upon the direction in which the motor is started. Moreover since the cross flux is practically proportional to the speed, only a small torque is developed when the slip is large, and the single-phase motor is not suitable for speed reduction by resistance control. Generally speaking, single-phase induction motors are only used when a three-phase supply is not available, and they are mostly built for small outputs. Both efficiency and power factor are lower than in the three-phase motor, the power factor being low owing to the fact that both stator and rotor have to be excited. Further the output of a given machine is 40% less as a single-phase than as a three-phase motor. There are to-day very few supply systems which work with single phase, and most of these are endeavouring to formulate a programme under which a gradual change to poly-phase supply will be made. Excepting for small motors for drainage pumps, lifts, organ blowers, refrigerators, desk fans, shop signs and for similar work, the single-phase motor has ceased to exist as an important industrial machine. Because of its limited application it is not intended to mention it at length here. Single-phase motors may be divided into five distinct types as follows :—

(1) The split phase induction motor.

(2) The repulsion induction motor.

(3) Capacitor induction motor.

(4) The slip-ring induction motor.

(5) The capacitor slip-ring induction motor.

(1) Split phase induction motor.

This type is similar in construction to an ordinary three-phase squirrel cage induction motor, with the primary wound on the stator and the secondary winding on the rotor.

The stator is composed of two windings : a starting winding, and running winding. The rotor is built up of steel laminations, with copper rods inserted in the slots, and short-circuited at the ends with a copper ring which is spot welded to ensure good conductivity for the rotor currents. Alternatively the rotor bars can be made of cast aluminium, the bars and end rings being centrifugally cast in one piece into the core by a special process. This type is generally not used for outputs exceeding $7\frac{1}{2}$ H. P. Owing to the high starting current and the poor starting torque, these motors will only start on light load, and take approximately four to five times full load current.

The starting winding is connected in series with the "running" winding, and in parallel with these is a resistance and a reactance (choking coil). Though the poly-phase field thus obtained is imperfect, it is possible to obtain about half full load torque when full load current is taken from the line. When the motor has run up to speed, the resistance, and reactance are cut out and the starting winding open-circuited.

In the fractional H.P. motors of this type, one method of starting is by having a high resistance winding on the rotor in parallel with the main winding. This starting winding is cut out by means of an automatic centrifugal switch built into the machine, when the motor has run up to speed. The primary winding is wound on the rotor, and the secondary winding on the stator. This type of motor will develop twice full load torque at starting, and a good class tumbler switch is all that is necessary to switch direct on to the line.

(2) Repulsion induction motors.

These motors are suitable for all single-phase power applications for $\frac{1}{4}$ H.P. upto 10 H.P. They develop a high starting torque and have a constant speed when running. The essentially distinctive feature of the repulsion induction motor lies in the rotor. Makers have various methods of manufacture. Among the best known is the following design: The rotor laminations have two concentric sets of slots, joined by narrow radial slits, in which are placed thin metallic strips. These slots contain two distinct windings, *viz.*, a commutator winding (similar to a C.C. armature winding) in the outer slots and a cast aluminium squirrel cage winding (which clamps the laminations) in the inner slots. This particular construction is patented, and ensures the highest starting torque, and the lowest starting current consistent with good running characteristics.

The stator is similar in construction to the ordinary single-phase induction motor, except that it is generally wound with a simple single-phase winding instead of a three-phase winding.

Operation.—At starting, and during the acceleration period, the magnetic flux produced by the stator winding embraces the outer (commutator) winding only due to the high reactance of the squirrel cage. Under these conditions the motor is virtually a repulsion motor, and as such gives a large starting torque. As the motor accelerates, the reactance of the squirrel cage decreases so that more and more of the flux embraces this winding also. Both windings therefore assist in the acceleration, thereby producing a high torque.

On light loads when synchronous speed is exceeded, the squirrel cage exerts a breaking torque which prevents the speed increasing to more than 2% or 3% above synchronous speed. The squirrel cage, therefore, controls the running speed of the motor.

The type of motor may be switched directly on to the line by a simple switch ; when so started, a torque of $2\frac{1}{2}$ to 3 times full load torque will be developed, with a corresponding initial starting current of from $3\frac{1}{4}$ to $3\frac{3}{4}$ times full load.

If required motors can be wound for reversing service, and a single pole or two pole reversing switch used.

(3) The Capacitor Motor.

Is almost similar in construction to the split-phase induction motor; it has a short-circuited rotor, but the stator has a special auxiliary winding with which is incorporated, a resistance, and a condenser by means of a starter, which permits the motor to both start and run virtually as a two-phase machine. In the running position the condenser is used for raising the power factor, while it also increases the efficiency and overload capacity of the motor. The motor will develop full load torque taking approximately $3\frac{1}{2}$ times full load current. These motors are manufactured in sizes upto 15 H.P.

Control Gear.—The control gear embodies the starting and running condensers, in association with a robust change-over switch and a current-limiting device where necessary in such a way that enables the motor to both start, and run with the good characteristics of a two-phase supply.

(4) Single-phase slip-ring induction motor.

These motors are similar in construction to three-phase slip-ring motors, only they have the stator winding in two parts, like the "split-phase" squirrel cage induction motor. The single-phase slip-ring motor will start against half full load torque taking full load current from the line or alternatively against full load torque with twice full load current.

Various types of standard enclosures are manufactured. The rotor can be of the wire wound type, the coils being former wound and fed into semiclosed slots. Brush lifting and short-circuiting gear can be provided if required.

Starting Gear.—These machines are designed for starting with a combined stator phase-splitting (resistance reactance type) and rotor resistance starter.

(5) Capacitor slip-ring induction motors.

These motors are similar to the above, but their starting arrangements incorporate the resistance and condenser feature that enables the machine to both start and run virtually as a two-phase machine. Motors of this description are made upto 30 H.P. and develop at starting full load torque taking $1\frac{1}{2}$ times full load current or alternatively develop twice full load torque taking $2\frac{1}{4}$ times full load current. An overload torque of at least 150% of full load will be developed.

The starting equipment can be provided with an under-voltage release and two over-current relays.

POWER FACTOR CORRECTION MOTORS.

A number of electric supply companies make special reductions in their tariffs to customers for the improvement of their power factor.

This can be accomplished by a number of ways, such as (1) static condensers, (2) synchronous motors, (3) phase advancers, or (4) special types of motors.

(1) Static Condensers.

These have come into use for improving power factor, especially in those cases, where there are a large number of small induction motors, which are incapable of individual treatment by phase advancers. They require no maintenance, and the switchgear is simple. When any work has to be done on the condenser or its switch the condenser should be short-circuited (after switching off) in order to ensure that it is completely discharged.

(2) Synchronous Motors.

Motors of this description are identical in construction with alternators; any alternator will run as a synchronous motor; the speed at which the motor runs is constant, and is fixed by the number of poles and the frequency of the supply.

If n = No. of revolutions per minute,

p = No. of poles,

$\sim$ = Frequency in cycles per second.

then $n = \dfrac{120\sim}{p}$

When a synchronous motor has been brought up to speed, and synchronised, it will continue to run because the reaction between the armature current and the field will be such as to give a torque in one direction. By adjusting the excitation of a synchronous motor it can be made to take current at leading or lagging power factor, a leading current tends to demagnetise the field of the synchronous motors, and a lagging current tends to magnetize the field.

There are two types of motor to select from:

(*a*) *Synchronous Induction Motor.*

The synchronous induction motor is started as an ordinary slip-ring motor, and can be built to start against twice full load starting torque. An exciter is provided, usually direct coupled to the motor, which builds up its voltage as the machine accelerates, and, when sufficiently excited, the motor pulls into step and continues to run as a synchronous motor. This type of machine is extremely robust and is made to withstand very heavy loads. If for any reason an overload be experienced strong enough to pull the machine out of step the machine would merely continue to run as a slip-ring machine until the load became normal, when it would automatically pull into step again.

(*b*) *Salient Pole Synchronous Motor.*

This type of motor has starting characteristics similar to, but rather worse than those of ordinary squirrel cage motors, but it is well to remember that as they are built to transmit a certain amount of mechanical horse power in addition to their ability to correct the power factor, their rating is based on the sum of these two operations, and, as in the majority of cases the mechanical horse power is only a fraction of the total rating of the machine, the starting torque seldom prevents this type of motor being adopted.

Starting Gear.

(*a*) This can be of simple construction as in the case of a normal slip-ring induction motor by closing a main switch, and then cutting resistance out of the secondary circuit by means of a liquid starter or other suitable apparatus.

(*b*) Salient pole type of synchronous motors can be started by auto-transformer starters, the pole faces having copper bars inserted in the iron and virtually acting as squirrel cage rotors.

(3) Phase Advancers.

A typical rotary phase advancer comprises an armature having a drum winding, the bars of which lie in slots in an iron case, and are connected to the commutator as in a C.C. armature.

When the rotor current of the main motor flows into the rotor of the phase-advancer, the latter acts as a choking coil, thereby causing reactive drop which gives rise to a lag in the current.

For a given current, this drop depends only on the frequency, that is to say, upon the rate at which the rotating field set up in the phase-advancer cuts the winding. If, however, the rate of cutting is reduced by rotating the winding in the same direction as the field, the reactance and therefore the lag decreases and finally becomes zero at synchronism. Should the speed be increased above synchronism, the reactance attains a negative value (*i.e.*, the phase-advancer acts as a capacity) with the result that the current is advanced, and the leading component of it compensates for the magnetizing current of the induction motor, thereby relieving the system. As no energy need be transmitted to the rotor, or any torque exerted, the stator is usually unnecessary, and all that need be done is to provide a closed path for the magnetic field which is done by embedding the winding a sufficient depth below the rotor surface. The phase advancer is operated usually by a separate motor, or by a chain driven by a sprocket wheel on the main motor shaft.

(4) Special types of motors.

Amongst the best known type is the "No-lag" Compensated Induction Motor. It is comparatively inexpensive in first cost but requires two sets of brush gear so that the maintenance charges are higher than the ordinary type of motor. The "No-Lag" motor provides a simple and comparatively inexpensive method of correcting low power factor on circuits not exceeding 650 volts, and is particularly suitable for cases where the plant is not sufficiently large to justify the expense of installing a synchronous motor or condenser with its attendant switch-gear.

The No-Lag motor is an induction motor with the important difference however, that it operates at unity or leading power factor instead of a lagging power factor less than unity. This characteristic is obtained by means of a commutator and commutator winding with which, in addition to slip-rings, the motor is equipped. Among other advantageous features are the following :—

(1) Comparatively low first cost in comparison with a synchronous motor since the mechanical and wattless power are obtained from a single machine, and no exciter is required.

(2) Operation is as easy as with an ordinary slip-ring induction motor. Starting is effected in the same way, and as great a starting torque is developed.

(3) High efficiency and ability to operate at all loads with a high power factor. Can be designed for any required power factor.

(4) Like a normal slip-ring induction motor, the speed drops slightly as the load is applied, a characteristic that for many applications is more suitable than the constant speed of the synchronous motor.

Power Factor Correction Economies.

The following typical example of a recent installation of No-Lag motors in a factory, will serve to show the economies which can be effected by correcting low power factor. The factory in question had already installed induction motors totalling about 300 H.P., the charge for power being based on maximum K.V.A. demand, which was 176 K.V.A., for the last quarter. Additional motors were required for driving new plant, these motors being of 50 H.P., 15 H.P., and several smaller sizes aggregating 15 H.P., making 80 H.P., of new motors in all.

Squirrel Cage Induction Motors were used for the smaller powers, while the 50 H. P. and 15 H. P. motors were of the No-Lag type designed for 90% leading power factor. In addition, two existing induction motors of 50 H.P. and 15 H.P. were replaced by No-Lag motors of the same ratings, and also designed for 90% leading power factor. After the new motors had been added and the conversions made, the maximum demand for the next four quarters was 176 K.V.A., 170 K.V.A., 176 K.V.A., and 174 K.V.A. respectively. Thus, although the installed H.P. was increased from 300 to 380, the maximum K.V.A. remained approximately the same, although if induction motors had been used instead of the four No-Lag motors, it would have increased by about 50 K.V.A. As the K.V.A. demand is charged at Rs. 13-8 per quarter this factory effects a saving of approximately Rs. 2700 a year in the cost for power.

Arrangements of windings.

The No-Lag motor has the primary winding located on the rotor, and the secondary winding on the stator. The supply is fed to the rotor through the slip-rings. In addition to the primary winding there is a compensating winding on the rotor, wound in the same slots. This winding is provided with a commutator and brushes through which it is connected in series with the stator winding.

The commutator voltage, constant in magnitude, is thus injected into the secondary circuits and produces currents which cause the primary current to alter in phase, thereby improving the power factor of the motor. The phase of the commutator voltage can be altered by varying the brush position, and so the amount of correction can be controlled.

Operation of intermediate speeds.—The No-Lag motor, with slight modifications, can be designed to run at any fixed speed, or at a number of different fixed speeds between normal synchronous speeds. Thus, although 50 cycle speeds of 1200 or 800 R.P.M. are not possible with ordinary induction motors, they could readily be obtained with No-Lag Motors. Motors arranged for operation at intermediate speeds are not intended for power factor correction, although high power factor at full load could still be obtained.

Operation as an asynchronous condenser.—The No-Lag motor can be built to give any desired leading power factor up to practically zero leading. When running at zero leading power factor, it acts as an asynchronous condenser. It naturally draws a small amount of power from the line to supply its own losses as in the case of other types of condensers. The machine runs light on the system, from which it draws leading wattless current. This is adjustable in amount from zero to that corresponding to the full K.V.A. rating of the machine, by moving the brush-rocker.

The No-Lag condenser has an advantage over the synchronous condenser in that it can be started as an ordinary induction motor and synchronizing is not necessary. It is also less sensitive than the synchronous condenser to changes of frequency and voltage.

Operation as asynchronous generator.—In the same way that an induction motor can be driven as an induction generator, the No-Lag motor also can be driven as a generator. The No-Lag generator, however, has a greater maximum overload capacity than the corresponding induction generator, and also possesses the advantage that it can be designed to operate at any required power factor.

The No-Lag generator can also be arranged to be driven independently of any alternator or supply. In this case it operates synchronously, as described below.

Operation at synchronous speeds.—Constant speed at all loads is sometimes essential for certain motor applications, and by re-arrangement of the secondary connections the No-Lag motor can be made to operate at synchronous speed at all loads. Apart from speed, the characteristics of the motor will then be similar to those of a motor arranged for normal asynchronous operation, but the overload capacity in synchronism is reduced to about 130% of full load. Above this load the motor will run as an ordinary induction motor without power factor correction.

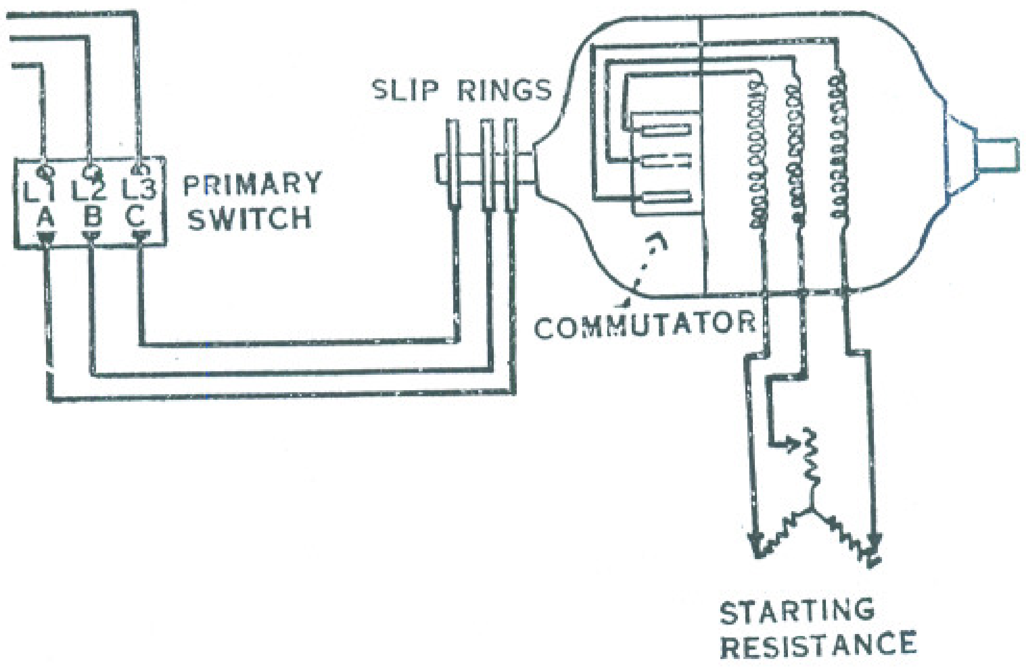
Similarly the No-Lag motor thus connected for synchronous running can be operated as a self-exciting synchronous generator, the stator winding acting as a field winding excited from the commutator winding. Voltage control is obtained by means of a rheostat in the field circuit. Where small outputs are required, the use of a No-Lag generator is often advantageous, since no separate exciter is needed, and there is thus a saving both in cost and floor space.

Construction.—The construction of No-Lag motors, except for the windings is similar to that of standard induction motors and D. C. motors.

In Fig. 12 is a diagram of a three-phase No-Lag motor showing the connections to the rotor and stator, and the starting resistance which is cut out gradually, as in a slip-ring motor.

NO-LAG COMPENSATED INDUCTION MOTOR

(FIG. 12.)



Starting arrangements.—Starting equipment for No-Lag motors is similar to that used with slip-ring motors. It should be borne in mind that the primary (line) circuit is on the rotating element, and the secondary winding on the stationary element of the motor. A typical motor control panel would comprise the following features :—

A totally enclosed sheet steel panel, covering an insulated base fitted with a drum type starting switch, self-contained starting resistances fire-proof pattern, contactor type circuit breaker, embodying under-voltage and "tripfree" features, magnetic blow-outs, controlling all three phases, and having over-load protection, one in each supply line.

SPECIAL OR NON-STANDARD TYPES OF MOTORS.

Alternating current motors.

Amongst the various types of alternating current industrial motors is the VARIABLE SPEED COMMUTATOR TYPE MOTOR. Introduced many years ago this motor has proved an ideal form of drive for numerous industrial purposes. The operating characteristics of motor give results which are not possible to obtain with any other type of self-contained A.C. motor, among the chief of which are the following :—

Speeds unaffected by changes in load.—The speed is adjustable and remains practically constant, as adjusted, irrespective of the load.

Wide speed range.—Normal speed ranges upto 15 to 1 can be obtained.

Uniform and smooth acceleration.—The speed is adjustable by a hand-wheel which acts as a controller with an infinite number of points, and any speed within the range can be obtained. Speed controlled from a distance can be effected either by mechanical or electrical means.

High efficiency.—The speed control does not entail any external loss, so the efficiency of the motor is high over the whole speed range. The power factor throughout the considerable portion of the speed range is higher than that of an induction motor.

These motors are easily started and normally no starting gear is required, the motor being started by setting the brush gear in the minimum speed position and then closing the primary switch. Arrangements are being made to prevent the motor being started unless the brush gear is in the correct position.

These motors consist briefly, of an ordinary slip-ring induction motor with the position of the primary and secondary windings reversed, and the addition of a third winding together with a commutator and brush gear.

The primary winding is located in the rotor and is connected to the supply by means of slip-rings and brushes, while the secondary winding is located on the stator, *i.e.*, inversely to the arrangement of the windings of an ordinary induction motor.

In addition to the primary winding, a regular winding is placed in the rotor slots and connected to a commutator like the armature winding of a direct current motor.

The commutator is provided with two brush rockers, which can be moved relatively to each other either by means of a hand-wheel attached to the motor or from a distance, if required, by mechanical and electrical means. One end of each of the phase windings comprising the stator or secondary winding is connected to a brush stud of one rocker and the other end of the phase to the corresponding brush stud of the opposite rocker. Thus the greater the distance the brushes are moved apart around the commutator, the greater will be the number of commutator bars separating the brushes connected to the ends of each phase of the secondary winding; hence the greater the amount of regulating winding which will be connected in series with the secondary winding. The motor is restricted to low voltages.

Principle of speed regulation.—The voltage induced by the primary in the secondary circuits of an industrial motor is a function of the speed *i.e.*, it is zero at synchronous speed and attains a maximum value when the motor is at standstill ; furthermore if the motor is made to rotate by external means at a speed of twice the synchronous speed, the voltage induced would be equal to that of standstill.

In the case of variable speed motors under consideration, when the brushes connected to the ends of the same phases of secondary winding are in line, and consequently in contact with the same commutator segments, the secondary winding will be short-circuited through the segments. The conditions will then be similar to the ordinary induction motor, and thus the motor will run at slightly less than the synchronous speed, with a small voltage induced in the secondary windings.

If the brushes on the two brush rings are now separated by rotating them relatively to each other around the commutator, then a certain voltage will exist.

Operation.—Motors with the speed range of less than 2—1 may in some cases need to have resistances inserted in the secondary circuit for starting as with the ordinary slip-ring induction motor, in order to limit the starting current and/or provide the necessary starting torque.

Overload protection.—Since the input to the motor is greatly reduced at low speeds ordinary overload protection in the primary circuit is satisfactory, if the output is proportional to the speed. Thermal type relays are recommended for this purpose.

Among the applications for which the motor has been found particularly suitable are as follows :—Calenders, paper and rubber ; Calico printing machines ; Machine tools ; Paper making machines ; Printing presses, rotary and flat ; Pumps ; Mechanical strokers ; and Sugar refining machinery.

INDUSTRIAL ELECTRICAL DRIVES.

Centrifugal Pumps and Fans.

The speed-torque characteristics of these machines vary with the discharge, the torque varying approximately as the square of the speed when the pump, or fan is discharging and as the first power of the speed when the discharge is zero. Hence when a low head pump or a fan is started with the discharge valve open so that delivery commences at a low speed the retarding torque during starting increases rapidly as the speed increases while the initial retarding torque is only about 10% of that corresponding to normal output and speed. These conditions require the use of a C.C. shunt (or compound) motor or an A.C. slip-ring motor.

When automatic control is desired the current limit method of starting should be adopted, and the relays or series contactors, should be so adjusted that the current at which the successive contactors close increases as the speed increases. The number of sections in the starting rheostat will depend on the maximum current peaks permissible during the starting period. With A.C. equipment a separate relay for each contactor will be required. By correctly grading the sections of the starting rheostat, uniform current peaks are obtained on the several notches.

If the delivery valve is closed during starting, the retarding torque varies approximately as the speed (except during the initial starting period) and at full speed is about 40—60% of that corresponding to normal discharge. Similar conditions occur with high lift pumps fitted with automatic foot valves. In this case, the discharge does not commence until the speed reaches about 90% of normal, the actual valve depending on the characteristics of the pump. Hence these conditions correspond to light load starting, and therefore squirrel cage motors may be used. When automatic starting is desired, the best result and minimum voltage disturbance is by using a two-step auto-transformer starter, the first step giving 40% of line voltage which is sufficient for initial acceleration, and the second step giving 85% of the line voltage which is sufficient to accelerate the pump to full speed. With this starter, the contactors are operated by time-limit relays. When a single step auto-transformer is used the voltage impressed on the motor at starting must be from 50 to 80% of normal depending on the characteristics of the pump.

Machine Tools.

Constant speed main drives.—This type of drive is applicable to machine tools where all changes of spindle speed, and feed are effected by mechanical means, i.e., by gears or special all-gear pulleys.

When a continuous current supply is available a shunt or compound wound motor may be used. The former type will suit the majority of cases, but when the machine tool possesses a large flywheel effect, the compound wound motor is preferable as the speed variation with alteration of load is greater than with the shunt wound motor. This enables the flywheel effect to be utilised more efficiently for overcoming sudden and peaky loads. It is also advisable to adopt a compound wound motor in all instances where a heavy starting effort is required.

When an alternating current supply is installed, two types of motors are available, *viz.*, the Squirrel Cage type, and the Slip-ring Rotor type. Before deciding definitely which type of motor is most suitable for the particular machine tool under consideration, the following points should be noted :—

The Squirrel Cage motor is the simplest motor constructed, but generally speaking a squirrel cage motor of the highest efficiency will exert only a starting torque cf from $\frac{1}{2}$ to $\frac{2}{3}$ full load torque with a starting current of from $1\frac{1}{2}$ to twice full load current, whereas the Slip-ring motor is capable of starting against full load torque with full load current, or if necessary, twice full load torque with approximately twice full load current. It will therefore be evident that a Squirrel Cage motor must not be used for the drive of machine tools requiring a heavy starting effort, unless some form of clutch is fitted to enable the motor to start light.

Moreover, it should be remembered that Power Supply Companies limit the use of Squirrel Cage motors, in some cases it is specified that a Squirrel Cage motor must not be used above a certain horse power, and in others that the starting current of such motors must not exceed a certain value, generally $1\frac{1}{4}$ to twice full load current according to the capacity of the power plants, etc. Again, although automatic control can be used with Squirrel Cage motors, such starting equipment is expensive and it is generally preferable to instal a Slip-ring motor than when this type of control is required.

To sum up, therefore, although no hard and fast rule can be laid down, Squirrel Cage motors should be used for the drive of machine tools requiring up to 20 H.P. where hand-operated control is desired, and Slip-ring motors in all other cases.

2. *Variable speed main drives.*—This drive can be used only where a continuous current supply is available. It is usual to standardize these equipments and motors can be adopted for speed ranges of 4 : 1 and 3 : 1 and 2 : 1.

There are advantages in adopting a variable speed motor in preference to a constant speed motor for most machine tools, notwithstanding the fact that the variable speed motor costs more than the equivalent constant speed motor which would be used for the same machine tool.

The extra cost, when taken as a percentage of the complete cost of the machine tool equipment would, however, be small. The speed range obtainable on the motor itself enables the machine tool maker to dispense with a gear box altogether in some instances, and reduce the number of gear ratios in others. The wearing parts of the machine tool are therefore reduced. In addition very fine speed increments over a wide range can be obtained, as against the definite number of fixed speeds obtained with mechanical change gear. A variable speed motor, geared direct to the machine tool, enables the highest economical cutting speed to be easily and quickly found by the operator. The screen protected shunt wound continuous current motor is ideal for this drive.

3. *Constant speed auxiliary drives.*—This type of drive is required for operating the quick traverse motion of tool slides, tailstocks, and saddles, in cases where it is preferable to use a separate motor for the duty, and the motor only operates at its normal load for short periods.

For continuous current use, the adoption of half-hour rated screen protected compound wound motor is recommended and A.C. supply a slip-ring screen protected, half-hour rated induction motor. A Squirrel Cage motor is often used for this alternating current drive, but as the motor is required to reverse, and as this operation is more satisfactorily accomplished from the point of view of the control gear with a Slip-ring motor, the adoption of a motor of the latter type is recommended. Where the motor may be situated, and the expanded metal grids of the enclosure would not prevent the entrance of chippings to the interior of the motor, pipe-ventilated or drip-proof motors should be used.

Control Gear.

The starting, stopping, and speed control of a motor driving a machine tool are very important factors in its operation and can be accomplished by :—

(*a*) *Hand operated Control Gear.*—In this instance the control of the motor and tool is in the hands of the operator, and the human element with its inherent liability to error cannot be eliminated entirely.

(*b*) *Automatic contactor or remote control gear.*—In this instance the workman may obtain complete control of the tool and the motor by simply operating a push button or small master switch fixed at some convenient place near his working position, the main control gear being fixed some distance away.

With this type of control gear, the responsibility for cutting out the starting resistance correctly does not rest with the operator, but is done for him automatically by current limiting devices that prevent any dangerous rush of current when starting up, and correctly and smoothly accelerate the motor up to speed in the shortest safe time. It is impossible, therefore, for a careless operator to damage the motor when starting up.

There are many advantages to be gained by the adoption of automatic contactor control, with push button operation, and the following are the most important points :—

(A) By supplying an automatic control set and providing for its operation by means of " start " and " stop " push buttons fixed at the working position on the machine tool, the operator can automatically control the motor with certainty and without mental or physical strain. Furthermore, he cannot possibly damage the motor by starting up too quickly.

(B) With many machine tools the inertia load is extremely heavy, and to start such machines satisfactorily by a hand operator or controller requires considerable time and a careful operator.

The stopping of the machine in the ordinary way takes a long time, but by the adoption of automatic control arranged for dynamic braking, this time can be much reduced, and the machine stopped, and re-started repeatedly in the shortest safe time. Idle and non-productive time can therefore be reduced to a minimum, and the production per unit machine increased.

The Dynamic Brake is an automatic electrical device which operates smoothly and stops the machine in the shortest possible time with the minimum of strain on the mechanism. In any form of brake, mechanical or electrical, the energy represented by the inertia of the moving parts must be dissipated at the brake shoe. In the dynamic brake the energy is transferred into heat by causing the motor to generator current, and dissipate this energy in a resistance. There is no contact of metal to metal, or any frictional contact whatever when the dynamic brake operates ; it is undeniably superior to any mechanical brake. It should be noted however, that dynamic braking can only be adopted in connection with automatically controlled equipments operating from a continuous current supply.

(C) It is an advantage, and increases the production of machine tools, such as lathes with long beds if the operator is able to stop, and start from various positions. With automatic control this can be accomplished by the use of additional interlocked push button stations.

(D) Production time is often wasted with machine tools such as wheel lathes, etc., by the destruction of the cutting edge of the tool through encountering " hard spots " in the work, and it is therefore an advantage to be able to slow down before the tool meets these spots. Again if the work does not give a continuous cut but has gaps between the portions to be machined, it is useful to have an easy means of " slowing down " while the tool enters the work. The operation of " slowing down " can be easily arranged with automatic control gear by the addition of a "slow" push button.

(E) By providing an "inch" button the motor can be made to revolve at a creeping speed as long as this button is pressed down. This feature is particularly useful to enable accurate setting up to be done with quickness and facility.

From the above remarks it will be realised that the maximum output will be obtained from any particular motor driven machine tool only by installing AUTOMATIC CONTROL GEAR for the main drive. The extra cost will be quickly repaid by increased output.

With certain machine tool drives, apart from planer and similar drives it is necessary to make arrangement for reversing the motor; this can be accomplished by a hand-operated switch, by a drum type controller, or by a separate contactor switch, according to the frequency of reversal and duty of the motor.

For the control of auxiliary motors required with certain machine tools for the quick traverse motions of Tool Slides, Tailstocks, or Saddles, a hand-operated drum type reversing controller and resistance, together with an isolating switch, and fuse will be found a satisfactory arrangement.

It is preferable with alternating current motors when used for auxiliary drives to adopt a reversing controller, and a Slip-ring motor, rather than a Squirrel Cage motor with star-delta or auto-transformer starter and separate reversing switch. This latter method also necessitates the fitting of a clutch by the machine tool makers. The adoption of a Slip-ring motor therefore simplifies the control gear, and makes the use of the clutch unnecessary, as the motor will start satisfactorily against the load.

A mechanical brake is sometimes used by machine tool makers for the quick stopping of the auxiliary motors, and in this case standard brake solenoids (A. C. and C. C.) are suitable for operating mechanical brakes. Automatic equipments are strongly recommended for main drives, and they should always be used with Heavy Machine Tool drives and for machines where frequent starts are necessary.

FLOUR MILLS.—In large mills the cleaning plant is generally quite separate from the actual grinding, sifting, etc., the machines being of light construction and including aspirators for extracting the dust from the wheat, separators and graders, scourers, cockle cylinders for extracting seeds, oats, etc., from the wheat; wheat washers, stoners, and whizzers for drying the wheat. The average power for each of these cleaning machines, when dealing with about 1000 lbs. of wheat per hour, varies from one to three B.H.P.

In connection with the grinding plant, there are rotary plane scalpers, centrifugal dressing machines, and plansifters, each absorbing from two to five B.H.P. depending upon the size of the machine.

Combination Machines.—Including aspirators, separators and cockle cylinder.

Duty.	Approx. Power.	Duty.	Approx. Power.
500 lbs. per hour	1 B.H.P.	2500 lbs. (or 10 sacks per hour.)	2½ B.H.P.
900 ,, ,, ,,	1½ ,,	3750 lb. (or 15 sacks per hour.)	3 ,,

Stone Corn Grinders (Wheatmeal).—

Diam. of stones.	Fine Wheatmeal.	Coarse Wheatmeal.	Approx. Power.
15 in.	120 lb. per hour	220 lbs. per hour	3 B.H.P.
20 ,,	150 ,, ,,	280 ,, ,,	4½ ,,
25 ,,	180 ,, ,,	350 ,, ,,	6 ,,
30 ,,	200 ,, ,,	400 ,, ,,	7 ,,
36 ,,	225 ,, ,,	450 ,, ,,	8½ ,,
42 ,,	275 ,, ,,	550 ,, ,,	10 ,,
48 ,,	350 ,, ,,	700 ,, ,,	12 ,,
54 ,,	450 ,, ,,	900 ,, ,,	14 ,,

Stone Corn Grinders (Fine Flour).—

Diam. of stones.	Fine flour.	Approx. Power.
36 in.	325 lb. per hour	17 B.H.P.
42 ,,	425 ,, ,,	20 ,,
48 ,,	500 ,, ,,	25 ,,

Three-Pair Roller Flour Mills.—

Coarse Wheatmeal.	Approx. Power.	Coarse Wheatmeal.	Approx. Power
500 lbs. per hour.	6 B.H.P.	1,200 lbs. per hour	14 B.H.P.
700 ,, ,,	8 ,,	1,500 ,, ,,	17 ,,
900 ,, ,,	10 ,,	1,800 ,, ,,	20 ,,

The powers mentioned for the three-pair roller mills are grinding the average class of wheat. If required for the hardest classes of wheat, the powers mentioned should be increased by 10 per cent. to 15 per cent.

Combined Roller Plant.

Single machines, consisting of three pairs of grinding rolls, scalpers, bran duster, offal dividers, centrifugal dresser, sieve purifier, and exhaust system.

Size of rolls.	Fine Flour.	Approx. power.	Size of rolls.	Fine Flour.	Approx. power.
12 in. × 6 in.	200 lbs. per hour.	10 B.H.P.	15 in. × 6 in.	300 lbs. per hour.	12 B.H.P.

The power required for driving small complete mills from a single motor unit, such as are installed by many inland mills and including cleaning plant, stone grinders, conveyor or elevator, flour dressers and separators :—

Fine Flour.	Approx. Power.	Fine Flour.	Approx. Power.
200 lbs. per hour.	15 B.H.P.	400 lbs per hr.	25 B.H.P.
250 ,, ,, ,,	18 ,,	500 ,, ,,	30 ,,

In making a general estimate of the power for a complete model mill plant of small size, say, up to five to ten sacks per hour (each sack 280 lbs.) it may be assumed that 14 B.H.P. per sack output per hour may be taken as a reliable figure for up-to-date machines which are installed under the best running conditions.

The plant comprises the mill proper, the unloading, cleaning and storage plant. The mill proper comprises groups of machines which require to be operated 24 hours a day. It is possible to arrange for a group drive for roller mills, purifiers and grindstones, also plansifters, conveyers and elevators.

Individual drive should be used for intake, wheat mixers, screen room, break rolls, smooth rolls, automatic packers, provender plant, and water pump.

So far as possible squirrel cage motors, with oil immersed auto-transformer starters should be used, if this is not possible owing to the high torque necessary to be developed, slip-ring motors with brushgear encased in flame-proof cover should be used, as flour dust is very explosive.

With regard to the temperature rise and ventilation of the motor, if should be noted that it is of great importance in producing good quality flour to keep the temperature in the vicinity of the machinery as low as possible. It is therefore desirable to have the motors designed for a low temperature rise and in order to reduce this rise to a minimum, pipe ventilated motors should be installed.

Control gear should be of the totally enclosed oil immersed type, except for the larger size drives, such as purifiers, break and smooth rolls, and screen room which can be of the liquid starter type. Electrical interlocks should be provided to make sure that the mill machinery is started in such a way that no congestion of produce can take place anywhere in the process. This interlock can be arranged so that if any individual motor shuts down, the remainder likely to cause congestion will also stop.

Bakeries.—An electric drive is very advantageous in this instance. Whether individual or group drive is used depends on the arrangement of the plant. The power requirements are small, and very seldom exceed 10 h.p.

The plant comprises sifters, conveyors, dough kneaders, dough divider and hander-up, cake mixers, bread mixers, sponge mixers and fans. For individual drives these machines can be driven by protected type squirrel cage induction motors using star-delta starters. For group drive the sifters, and conveyors, lend themselves better, but other machines can be group driven, but they should be fitted with a loose pulley, and a change gear where a speed range is required.

The machines for preparing mixers for cakes etc., can be fitted with two speed gears, and chain driven through a dog clutch adapted with interlocking gear.

For preparing batter and beating eggs etc., a variable speed drive is necessary, and this can be arranged by a sliding gear transmission, in conjunction with a pole changing motor. Control of the motor can be operated by a push button contactor starting panel.

Continuous current motors should be totally enclosed.

Kitchen equipment.—For large kitchens a number of power machines can be used for potato peelers, vegetable cutters, pastry mixing, meat cutting and mixing, and meat slicing equipment. For small kitchens a refrigerator and a fan are useful acquisitions.

Power machines are usually driven by totally enclosed, or drip proof motors from $\frac{1}{4}$ upto $7\frac{1}{2}$ h.p. Motors up to 1 h.p. can be of the single phase repulsion type, above this size and upto 3 h.p. they should be of the polyphase squirrel cage induction motor type, and direct started. Motors of larger size than this can be of the squirrel cage type but arranged for star-delta starting.

Small refrigerators and fans are driven by split-phase squirrel cage induction or repulsion induction fractional horse power motors, and these can be used on single-phase circuits.

Garages.—The plant to be driven comprises small lathes, drilling machines, small boring machines, pumping machines, paint spraying equipment, grease compressor, and motor generator or rectifier for battery charging.

A group drive by means of a squirrel cage induction motor with star-delta starting is quite suitable for the machine tools. The paint sprayer, and grease compressor should have individual drives, with squirrel cage induction motors, and either a direct, or star-delta starter used depending on the size of the equipment.

The motor-generator should be separately driven by a star-delta squirrel cage induction motor, and a shunt wound generator used, alternatively a tungar rectifier can be installed.

Laundries.—The machines to be driven comprise washing machines, drying machines, ironing, and finishing machines, hydro-extractors, collar ironers, body ironers, and wringing machines. Many of the smaller machines (*e.g.*, hand-ironers, starchers, gcfferers) can be group driven.

Hydro-extractors must be driven by a compound wound C.C. motor or a slip-ring induction motor, with liberally rated starters, in view of the heavy starting torque, and the time taken for the machine to accelerate. Electrical interlocks are used with washing machines to ensure that the lid is automatically locked until the rotation of the cage ceases when the lock releases itself. Similarly the machine cannot be started up to work until the lid has been closed, and automatically re-locked. Interlocks are also provided in ironing machines to prevent the operator from trapping his fingers when the ironing plate is brought to bear on the cloth. There is a great tendency for the worker to put one hand on the table, and operate the ironing plate with the other. By means of the electrical interlock this is nct possible.

Ironing machines to take up to 300 sheets per hour can be driven by a 6 h.p. motor which can be of the squirrel cage induction motor type. The windings of all motors should be specially impregnated against moisture. Totally enclosed or drip-proof motors should be used, where any excessive moisture is present.

Ice Factories.—The motors required for ice factories fall into the following classifications :—

(*a*) Main compressor motors for freezing cycle.

(*b*) Centrifugal Pumps for fresh water, brine, condenser water and thawing tanks.

(*c*) Crushing Plant for reducing ice from blocks to small pieces suitable for ship's holds, etc.

(*d*) Conveyors and elevators at various points throughout the process.

(*e*) Applications to be found in most factories such as fitting shop, welders' shop, capstan, smithy and cranes.

(*f*) Special applications peculiar to the ice industry such as pushing gear for ice tanks during freezing process, agitators for brine tanks, positive delivery gear pumps for liquid ammonia.

Given below is a table setting out the approximate starting torques required for the above drives.

Ammonia Reciprocating Compressors	..1·5 times full load torque,
Centrifugal Pumps	.. ·40 ,, ,, ,,
Crushing Plant (Starting with spiked rollers clear of ice).	.. ·60 ,, ,, ,,

If there is a liability for jamming to occur, the starting torque may increase upto 200%.

Conveyors	..1·5 times full load torque.
Elevators	..2·0 ,, ,, ,, ,,
Fitting Shop (assuming lineshaft drive).	..*Welding M. G. set. Capstans.*
Smithy Blower, etc.	..All light starting not in excess of 40% of full load torque.
Pushing Gear for Ice Tanks	..2·0 times full load torque.
Agitators for Brine Tanks	.. ·30 ,, ,, ,, ,,
Ammonia Gear Pumps	..1·25 ,, ,, ,, ,,

The above figures must be regarded as approximate only, as, in many cases, the friction of the machines may considerably affect the figures particularly with old machines.

The motors should generally be of the drip proof squirrel cage induction type, suitable for star-delta starting, as there are not many high starting torques.

For the crushing plant if there is a liability of the machinery to jamb, drip-proof slip-ring induction motors should be used, and the same type of motor is desirable in the case of conveyors and elevators.

The compressor may be driven by a slip-ring induction motor, with liquid starter, or if there is any saving to be obtained by improving the power factor, a synchronous induction motor can be used with suitable gear.

All motors should have their windings impregnated against moisture, and terminal arrangements should be suitable for lead covered with single wire armoured, served cable.

Coal and ore handling plant.—This plant consists of a travelling gantry, or bridge on which runs a traversing crab, carrying the bucket. The hoisting and traversing motions have to be performed at high speed, necessitating rapid acceleration and retardation. C.C. series, or heavily compounded, motors are usually adopted ; but when only poly-phase A.C. supply is available, slip-ring induction motors are employed, and special provision is made for dynamic braking, the stator winding being excited from low voltage C.C. supply (obtained from a motor-generator set). Current limit control, in conjunction with a master-controller, is adopted.

Mine hoists and reversing rolling mill equipments.—The duty cycles for these services are similar. Both require large outputs for short periods, rapid and smooth acceleration and retardation in both directions of motion. The frequency of the cycle is higher for the rolling mill than the mine hoist.

Small equipments are usually operated by either a C.C. compound motor or a slip-ring induction motor. Current limit control, in conjunction with a master-controller, is usually adopted, but with A.C. equipments a special form of hand operated liquid rheostat is frequently used.

Large equipments are usually arranged on the Ilgner regenerative equalizer system, with a separately excited shunt for compound C.C. motor and a flywheel motor-generator set (consisting of a slip-ring induction motor, with automatic slip regulator, and a compensated separately excited C.C. generator). The entire speed control is effected by regulating the generator field (Ward-Leonard System) which is controlled by means of a reversing potentionmeter connected rheostat, with a small controller. Thus any desired voltage, plus or minus, will be produced by the generator armature and the torque, and speed of the driving motor will be directly proportional to this.

Lifts.—This duty is essentially suitable for C.C. series wound motors, with contactors starters working in conjunction with a current limiting device.

For A. C. supply several methods are available, the lifts may be driven by single- or three-phase commutator motors, or by double wound high torque squirrel cage motors. In this case the lift is started by switching the motor direct to the line on the higher speed winding, and after the travel is nearly completed, the low speed winding is switched into circuit. The motor will thus first act as a brake until the slower speed is reached, after which correct decking is ensured.

Textile mills.—Belt driving from individual motors has been applied to light high speed looms giving very successful operation, and notably increased production. A special form of spring suspension is provided whereby the short driving belt to the loom is maintained at constant tension by the weight of the motor. Good starting is ensured by specially designed high starting torque squirrel cage induction motors, and the shock that occurs when the motor starts up is taken up by allowing the belt to slip. In some weaving sheds a single continuously running motor is installed for each pair of looms, belts being taken from double width pulleys at both ends of the motor to fast and loose pulleys arranged on each loom so that the belts are nearest the motor bearings when on the fast pulleys. Compared with the individual drive this arrangement requires a smaller capital outlay, but involves greater losses because of the continuous running, and less even loading of the motor, and does not give the maximum output obtainable with the individual high speed clutch drive, using either chain or gears. In certain cases a group drive is more economical, particularly in the conversion of some mills from steam to electric drive, when the individual drive would necessitate expensive re-arrangement of existing looms. Various types of motors can be supplied for group driving, the types most commonly used being either ordinary, or high torque high efficiency squirrel cage motors, or slip-ring motors and arranged either as enclosed ventilated or pipe-ventilated machines according to circumstances. In some instances, however, it may be possible to use either slip-ring motors in conjunction with phase advancers or alternatively, synchronous induction motors, in order to obtain reduced charges for giving an improved power factor.

Cement Works.—The electrical drive is an ideal one for use with the plant in a cement works, and the whole process of manufacture can be rendered automatic.

There are two processes by which Portland Cement may be manufactured, and these are known as the " dry " process and the " wet " process, the two methods differing essentially in the treatment of the raw material. The raw materials (limestone and clay, shale, slag or marble) are ground together, either as a dry powder, or mixed with water, the mixture being called "slurry."

The slurry is then fed into the upper end of the kilns and is carried along continuously by the inclination and rotation of the kilns so that it slowly gravitates to the lower end. As the material approaches the lower end its temperature is increased until it reaches the burning zone, where it becomes converted into clinker. This resulting cement clinker drops through outlets at the bottom end of the kiln into coolers and from there it falls into a chute, and thence on to a shaker conveyor, which discharges into a series of crushing rolls. From there this clinker is conveyed to a mill where it is mixed with gypsum, the two materials are ground together forming cement. The cement is then conveyed to storage silos, after which it is weighed and packed.

Ordinary protected type squirrel cage induction motors can be used if provision can be made to blow out the cement dust by compressed air, otherwise totally-enclosed or pipe-ventilated motors should be used. Squirrel cage motors can be used up to 30 h.p., motors over 10 h.p. require auto-transformer starters, while smaller motors should be started direct. Motors above 30 h.p. can be of the slip-ring induction motor type with the collector rings totally enclosed in a dust proof enclosure.

Many of the machines employed are of a very heavy nature, representing large masses to be accelerated, and in addition the static friction of the bearings of these machines is considerable, therefore it is essential to choose carefully the most suitable type of motor, and starter for each individual drive.

Given below is a list of machines used in a cement works with details of suggested electrical equipment.

Wash mills	40 H. P.	Belt drive.	Slip-ring induction motor.
Water pumps	15 H. P.	Direct drive.	High torque squirrel cage induction motor.
Crushers	60 H. P.	Belt drive.	Slip-ring induction motor.
Elevators and conveyors.	15 H. P.	Gear drive.	High torque squirrel cage induction motor.
Air agitator	75 H. P.	Direct drive.	Slip-ring induction motor
Kilns	60 H. P.	Gear drive.	Slip-ring variable speed induction motor.
Coal mills	150 H. P.	Gear drive.	Slip-ring induction motor.
Firing fans	35-60 H. P.	Direct drive.	Slip-ring variable speed induction motor.
Ball & tube mills.	475 H. P.	Gear drive.	Synchronous induction motor.

The use of a synchronous induction motor is suggested for the purpose of raising the power factor of the works supply, alternatively a slip-ring induction motor may be used.

Colleries.—Electricity is practically in universal use in all colleries, at the present time. Power is used for winding, haulage, pumping, driving the washing and screening plant, coal cutters and battery charging.

Winding requires high power for acceleration, and to prevent heavy peak demands on the power-house, a special load-equalizing equipment is necessary. Ward-Leonard, and Ilgner system of control are the most suitable for the winding motors.

Conveyors, and loaders require to be driven by specially designed, totally-enclosed-flame proof squirrel cage induction motors. The motors should have liberal air gaps, and all joints to be metal-to-metal, with carefully machined surfaces. Bearings can be provided with dustproof cartridge housings, and ball and roller bearings, so that the rotor can be removed without exposing the bearing to the dust laden atmosphere.

It is an advantage if the motors are designed with a welded steel cylindrical frame, as they can then be easily transportable, and on mining motors, the larger machines can be rolled along to the coal face. Motors should be of the high starting torque type and capable of exerting 2¼ to 2½ times full load torque when started direct. Motors should comply with B.S.I. Specifications Nos. 168 and 270 (Flame-proof enclosure).

Switchgear should be of the flame-proof pattern, designed with broad well machined flanges (free from bolt holes), and the operating spindle, and cables should pass through well bushed glands. It is impossible to prevent an explosion taking place in the interior, but the gases are cooled in passing through the wide joint.

Continuous current is only used in colleries in isolated cases owing to the danger of the gases being ignited from the sparking of the brushes on the commutator.

Tanneries.—The machines to be driven are of great variety, and include fleshing machines, bark mills, chemical mixers, disintegrators, hide rollers, pumps and cranes.

A.C. motors should be totally-enclosed or drip-proof, as there is much moisture present near the tanning pits, and washing machines owing to the high starting torque slip-ring motors are generally used especially for the larger machines such as rollers, pumps and cranes.

C.C. motors should be of the shunt wound type, totally-enclosed, and compound wound for rollers, and pumps series wound motors should be used with cranes.

Water-tight terminal arrangements should be provided on all types of motors situated near the tanning pits.

Quarries.—The machines to be driven comprised cranes, cutting machines, carborundrum and diamond circular saws, swing frame saws, and planing machines.

Slip-ring induction or series wound motors can be used for driving the cranes, but they require to have a very high overload capacity in torque.

The stone working machines are group driven by a slip-ring or shunt wound induction motor, which should be either totally-enclosed fan cooled or else of the pipe-ventilated type. All motors have to stand up against very severe conditions, since stone dust has remarkable power of penetration and the jets of water playing on the cuts being made on the circular saws produce a profusion of fine abrasive spray. So, that it is necessary for motors driving these machines to be water proof, and the windings of the motor should be specially impregnated against moisture.

Cranes.—It is advisable to instal a power driven crane, even for a few hundredweights, as the saving in time and labour soon pays the difference in initial cost compared to a manually operated crane.

The electric crane has the following points in its favour :—

1. Simplicity of operation.
2. No power consumed whilst crane is standing.
3. Power used varies in proportion to the load.
4. Always ready for starting up.

Overhead cranes have usually three motors : one for operating the hoist, one for travelling, and one for traversing. Gantry cranes sometimes have instead of an overhead runway, a bridge member supported by structural legs which are propelled by wheels and gearing, the crane travelling along rails on the ground. Jib cranes have a jib or boom, provided with a motor driven hoisting device ; in addition, a motor is often provided for slewing the jib.

For cranes drives continuous current series wound motors are best. If only alternating current supply be available, motors should be of the slip-ring induction type, and must be liberally rated for hoisting. For an engineering shop or other establishment where operation is more or less continuous, continuously rated motors will be used. For very intermittent use, as in power-houses, short rated motors can be employed.

Cranes are equipped with a magnetic brake on the hoisting motor to ensure that the hoisting mechanism is locked when power is off the motor. Limit switches should be fitted in every case, where it is necessary to prevent over-travel.

Brickfields and Sand Pits.—It is not often that electric drive can be adopted for use in this industry, but in districts where mains can be laid without excessive cost and the load reasonable, electrification is justified.

Pumps, sand cutters, screeners, conveyors, and in certain cases, crane driven grabs are used. The slip-ring induction motor is the type generally used, with protected type enclosure, but in exposed situations the motor should be totally enclosed or drip proof.

Electricity in Agriculture.—In a farm of average size would require about four motors of the following ratings, $\frac{1}{4}$ h.p. for the house, $\frac{1}{2}$ h.p. for the small farm machines, 5 h.p. for the larger machines, and 15 or 20 h.p. for the heaviest machinery split up as follows :—

Refrigerator	.. $\frac{1}{4}$	h.p.
Milking	..5—10	h.p.
Pumping	.. 5	h.p.
Sawing	.. 5	h.p.
Thrashing	.. 25	h.p.

A motor of 5 h.p. could be mounted together with its control gear, on a portable frame and when required it could be carried into the farm buildings. The motor could drive on to a countershaft fitted with a number of pulleys of different sizes, to suit the driven machines. If it is necessary to take the motor into the yard, as a rule no special means of anchoring the frame is required, the weight of the motor and frame being sufficient to prevent the belt from slipping. If the motor is mounted on a truck, chock stones should be placed under the wheels.

The eclectrical equipment should be weatherproof or protected by a suitable covering, and the switchgear as simple as possible.

The most suitable type of motor is the 3-phase squirrel cage induction motor, which is simplest in construction, best adopted for rough work or usage, and safest in point of fire risk. Numerous installations in Europe are running quite successfully on single-phase repulsion induction and continuous current shunt wound motors.

General remarks.

The design of motors should be as simple as possible. Nothing in the nature of a very elaborate machine should be looked upon as a sound proposition without going very carefully into the matter. People who are in the market for buying electric motors and control gear are usually in a hurry and more often than not, they are not absolutely certain in their mind as to what type of motor would suit their particular requirements. Some makers of plant make general recommendations as to the type of electric motor that should be used with their machine, but they are not conversant with the starting regulations of the supply company, and their remarks cannot be treated as being the final and best decision in the matter.

The appearance of the motor should be of a solid but pleasing nature and the following points require careful consideration :—

Terminal Box.—A considerable amount of the trouble caused to a maintenance engineer, is largely due to insufficient room in the Terminal Box or else faulty design. In this connection it might be pointed out that there should be easy access to the terminal leads and the lugs should be of solid construction. Admiralty type pattern should be used except in the very small type of motors in which copper tube terminals will be quite satisfactory. The leads coming from the stator should be carefully bushed either with hard wood or else a strong insulating material. Each terminal should be clearly stamped with a distinctive mark. In the case of the stator it should be arranged that the cable entry can be given either from the top or bottom of a motor. Certain makers cast their terminal box integral with the motor and personally I regard this as a definite limiting feature in design, as it is only conveniently possible for cable to enter at one side of the terminal box; furthermore if the box is damaged in any way, it is not an easy matter to repair it, as patching would not be neat and welding the box may entail sending the motor away. In the case of small motors, this feature is not of such vital importance as the cable is light and the wiring is usually carried out in conduit.

Bearing arrangements.—It has been proved for a number of years past that ball and roller bearings are as good as and in some cases superior to oil ring bearings and from a maintenance point of view the comparison is without question. However careful a person is in maintaining a motor, dirt is always liable to get into the bearing casing and foul the bushing and there is the disadvantage that the rings are required to be examined when starting up and at other times, to ensure that they are revolving. In addition ball and roller bearings occupy less space than oil ring bearings, and so enable a shorter overall length of motor to be obtained as well as an improved, and easily maintained performance. One important advantage of ball and roller bearings is that they permit the use of grease as a lubricant. Maximum reliability can consequently be secured with a minimum of maintenance. With ball and roller bearings there is a remarkable absence of friction, and the rotor remains dead central in the axis of the stator core, thereby eliminating the trouble of rubbing of the rotor on the stator, a frequent cause of breakdown of motors with oil ring bearings. A certain amount of objection was raised in connection with ball and roller bearings that the shaft was unable to give any play on a direct drive. This can be obtained by means of flexible couplings, which, as a result of the demand due to ball and roller bearings motors, have gone down considerably in price, and therefore this objection is ruled out.

Shaft.—Most motors are provided with standard shaft extension and these are quite suitable for a pulley drive or fitting to a coupling, if, however, other arrangements have to be made such as carrying a fan runner or for use with a very heavy sprocket or pulley which requires an out-board pedestal bearing ; full information should be given to the manufacturer in order that he may offer a suitable type of motor. As an item in the cost of a motor a shaft is not expensive and most manufacturers will supply any ordinary length provided it is not of a very special design, without extra cost, the only extra being in the case of delivery which is generally increased by one week.

Pulleys.—These should be slightly crowned, in the smaller sizes they are of cast iron and in the large sizes, steel pulleys are used with light rims and strong spokes. Care should be taken that the pulleys are accurately balanced.

Rating.—All motors should comply with the latest British Standard Specification No. 168 (1926).

Efficiency and power factor should be high, the power factor in the slower speed motors being lower than in the higher speed motors. Windings should be specially impregnated for tropical use.

Guarantee.—People must not be led astray by misleading guarantees. Most reliable manufacturers will guarantee their motors for a period of about one to two years, during which time they will service their machines, after that, they will replace anything which has not given satisfaction due to faulty design or material. It has been found that motors, after they have run for a period of four to six months on continuous duty, will most certainly show up any fault in design or workmanship and the fact of guaranteeing them for a period of one to two years is purely nominal. Persons who use any extravagant promises of their machines are usually attempting to get a cheap advertisement because nothing can last for ever and it was never intended that electric motors should be the exception.

Delivery.—The question of delivery is a very important one. In cases where motor and control gear only form a small part of the whole engineering equipment of the order it is not quite so important, as the motor can be manufactured while the other plant is being made and fitted to the machine in a very short time. A number of plant manufacturers will send their half coupling or sprocket wheel to the motor manufacturers for fitting to the motors so that there may be no delay when the motor has to be incorporated in the machine tool or other equipment. If, however, the customer has a belt drive and requires a motor for the purpose it is usual for the customer to expect immediate delivery no matter as to what size the motor may be. This is a most unreasonable attitude and one which, unfortunately, is adopted quite frequently. Some buyers will be led into dealing with firms who will accept a "cut" delivery. This is a risky business for if a manufacturer alters his production programme to suit individual requirements some other person's order must be retarded in order that delivery may be expedited. It is quite possible due to the zealousness of the manufacturer's salesmen, that they accept on some particular occasion, a number of "cut" deliveries. If that is the case, then, it is a serious thing for it is quite possible that orders will be considerably delayed. Manufacturers' production programmes are cut to such a fine limit that it is definitely a most difficult thing to shorten delivery; if this does happen it causes considerable expense, such as working overtime and disorganising routine production of stock motors. If it is essential that delivery should be cut and the motor manufacturers ask for a small extra in price it should not be refused.

Given below is a table giving approximate delivery dates ex-maker's works for standard C.C. and A.C. Motors; also bearing arrangements, etc. and control gear. These delivery dates are for standard apparatus which is manufactured from raw material or composite parts drawn from the stores. In the smaller sizes of motors and control gear, a number of motors are built for stock and in this case delivery can be cut, but in the larger size of motors it is seldom that these can be delivered immediately and the full period of time should be allowed.

Inspection by Customer's Representative at maker's works.—This includes for test, and although one week may appear to be somewhat lengthy for those who have had experience on the test beds of large engineering works this is considered by no means a lengthy period. There is only a limited amount of room on the test bed and it is necessary to mount the motor for a preliminary test after which a motor must not be dismantled but left as it is, together with wiring connections for a period of time, depending as to how soon a customer can conveniently call for the test, during which period a section of the test-bed is out of commission and thereby causes delay in works production. It should be explained that when a motor and control gear can be built together, the delivery will depend on the maximum period, whichever is most, e.g., the motor or the control gear.

Delivery dates for standard C. C. & A. C. Motors. Ex-maker's works.

C. C.			A. C.		
Shunt series and compound.			Squirrel Cage Motors. (For slip ring motors, *i.e.*, approx. 3 H.P. and above, add one week.)		
½ H. P.	5 H.P.	3 weeks	½ H.P.	2 H. P.	2 weeks.
6 ,,	10 ,,	4 ,,	3 ,,	15 ,,	3 ,,
11 ,,	30 ,,	5 ,,	16 ,,	75 ,,	4 ,,
31 ,,	90 ,,	7 ,,	76 ,,	120 ,,	5 ,,
91 ,,	100 ,,	8 ,,	121 ,,	200 ,,	6 ,,

For variation from standard add the following time :—

	C.C. Motors. Weeks.	A.C. Motors. Weeks.
Vertical Motors	4	2
Back geared motors	3	3
Admiralty type motors	6	6
Third pedestal bearing and bed-plates ..	2	2
Third pedestal bearing only	2	2
Motor generator sets...	2	2
Trifurcating boxes	1	1
Shaft extension longer than standard ..	1	1
Inspection by customer	1	1

Delivery dates for control gear for C. C. Motors. Ex-maker's works.

	Weeks.
Industrial type drum operated controller	2—4
Contactor type crane protective panel	4
Hand-operated type crane protective panel	3
Limit switches	3

	Weeks.
Unit and Grid type resistances with plain bushed or cored holes as cable entry.	2—3
Open type contactor gear	6
Enclosed type contactor gear	8
Brake solenoids	4
Faceplate starters	2
Field rheostats, hand-operated	2—3
,, ,, motor ,, ...	10
Motor starting pillar panels	3—4
Extra for conduit glands or armour clamps to the above ..	1

Delivery dates for control gear for alternating current motors. Ex-maker's works.

	Weeks.
Direct starters	1
Rotor starting panel	2—4
Auto-transformer pillars L. T.	4—6
,, ,, ,, H. T.	8
Open contactor panels	6
Enclosed ,, ,, ...	8
Machine tool contactor equipment	8
Industrial drum controllers	4
Watertight	4—6
Contactor & hand-operated crane protective panels ..	4
A.C. brake solenoids	4
Large earthing resistances	8
H. T. Air brake contactors	12