TITLE:- DIRECT CURRENT GENERATORS

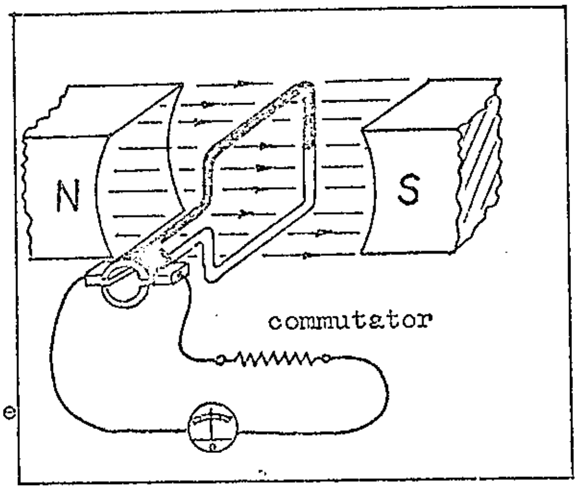
LECTURER:-

DATE:-

EQUIPMENT:-

A generator converts mechanical energy into electrical energy.

A magnetic field is represented by continuous lines of flux, considered to emerge from a north pole and to enter a south pole. When a conductor moves in such a way as to cut magnetic lines of force, there will be an E.M.F. generated in the conductor. Consider an elementary generator. A loop of wire rotating in a magnetic field forms an elementary generator, and is connected to an external circuit through a commutator. The commutator acts as an automatic reversing switch on the generator shaft which switches coil connections to the brushes every half revolution. Its purpose is to provide a d.c. output. Since the e.m.f. and current flow of an elementary generator reverse in polarity every time the armature loop rotates 180°, the output of such a generator would be A.C. if a commutator was not used.



In a practical generator, many coils are used in the armature and more segments are used to form the commutator. This is to smooth out the d.c. taken from the generator. A practical generator has a voltage output which is near maximum at all times, and which has only a slight ripple variation.

Generators can be either separately excited or self excited. Separately excited generators have their fields supplied from either another smaller generator (exciter), batteries etc. and there is no electrical connection between the field and the armature.
Self excited generators use part of the generator's output to supply excitation current to the field. The build up of the field happens as follows:-
When not in operation, the field poles retain a certain amount of "residual magnetism" from a previous run. When started up, this "residual magnetism" provides a very weak field which induces a low e.m.f. in the armature. This low e.m.f. strengthens the field which increases the output voltage. This process continues until the field builds up to full strength.

Construction

The mechanical and electrical design of both D.C. motors and D.C. generators is generally similar, and some machines operate either as a generator or as a motor, therefore the constructional details can be considered for both at once.

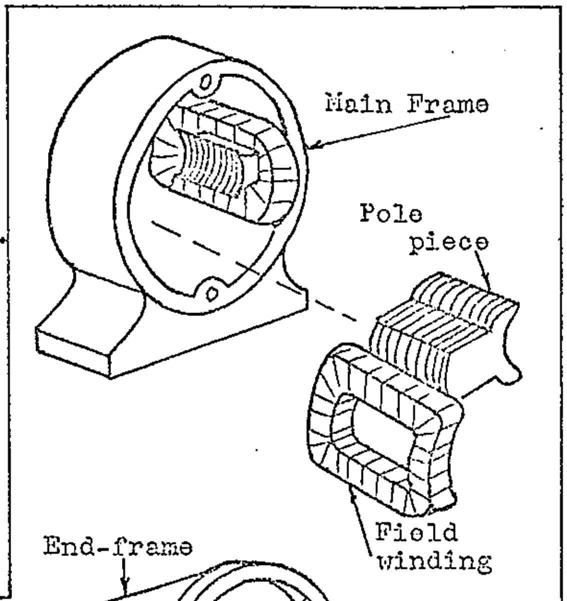
Main Frame Sometimes called the "yoke". It is the foundation of the machine and supports the other components. It also serves to complete the magnetic field between the pole pieces.

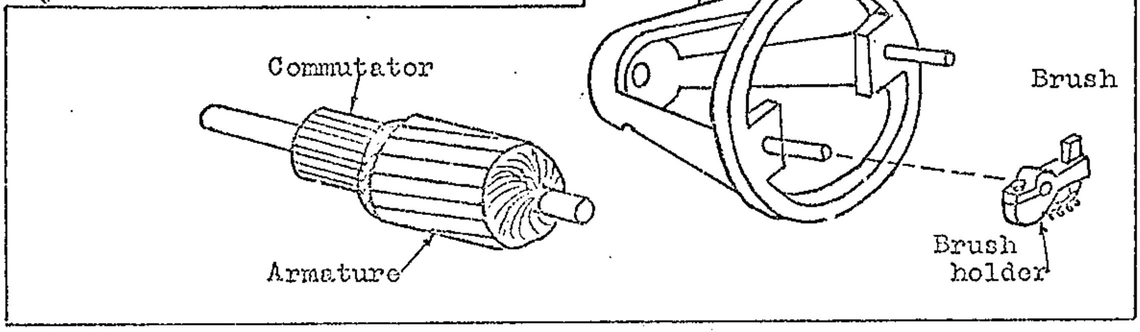
Pole pieces Made of laminations formed together and bolted to the inside of the frame. They provide a support for field coils, and are designed to produce a concentrated field. By laminating the poles, eddy currents are reduced.

Field Windings These, when mounted on the pole pieces, form electromagnets which provide the magnetic field necessary for generator action. The windings and pole pieces together are often called the field. The windings are coils of insulated wire wound to fit closely around the pole pieces whose current provides the field..

End Frames These are attached to the end of the main frame and contain the bearings for the armature. The rear housing usually supports the bearing only, while the front housing also supports the brush assemblies.

Brush holder This component supports the brushes and their connecting wires. The brush holders are secured to the front end housing with clamps. On some generators, the brush holders can be rotated around the shaft for adjustment.





Armature assembly In practically all d.c. generators, the armature rotates between the poles of the field. The armature assembly is made up of a shaft, armature core, armature windings and commutator. The core is laminated and is slotted to take the armature windings. The armature windings are usually wound on formers and then placed in the core slots.
The commutator is made up of copper segments, insulated from one another and from the shaft by mica. They are secured by retainer rings to prevent movement due to centrifugal forces. Either small slots or risers are provided at the back of segments for connection to the windings.
The shaft supports the entire assembly and rotates in the end bearings.
A minimum air gap is left between armature and pole pieces in order to keep field strength to a maximum.

Brushes The brushes ride on the commutator, and carry the generated voltage to the load. They are usually made of a high grade of carbon, and are held in place by brush holders. The brushes are able to slide up and down in their holders so as to be able to follow irregularities in the surface of the commutator. A flexible braided conductor called a "pigtail" connects each brush to the external circuit.

M16/2/1

TITLE:- DIRECT CURRENT MOTORS

LECTURER:-

DATE:-

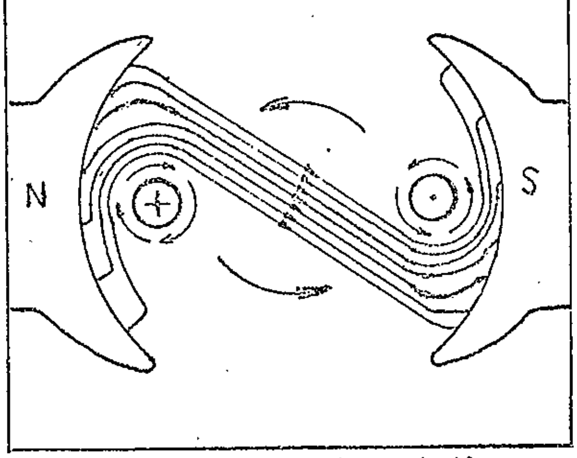
EQUIPMENT:-

Motors are used to convert electrical power to mechanical power.

In spite of the fact that a standard D.C. motor costs more than an induction motor, and that the majority of present day power distribution is by alternating current, the scope for d.c. motors is large, particularly for drives requiring speed control or having some special feature.
D.C. motors can be built in sizes ranging from fractional horsepower up to over 5000 H.P. (used in steelworks).

Principles of D.C. motors Any conductor which carries current is surrounded by a magnetic field. If it lies in the field between the poles of a magnet, the two fields interact. Where the conductors lines of force oppose those of the main field, the main field will be weakened. Where the conductors lines of force assist the main field, it will be strengthened. The result of this interaction as can be seen in the diagram is a distortion of the main field i.e. Field is weakened on top of R.H. conductor and bottom of Left hand conductor, and strengthened at bottom of R.H. conductor and top of L.H. conductor.
The main field, in trying to straighten out, moves the conductor anti-clockwise direction, but then the next armature conductor moves into the main field to take the first one's place and the procedure is repeated. This results in continuous motion of the armature.

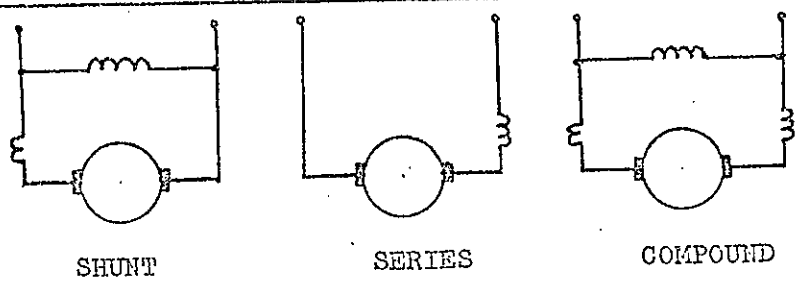
MOTOR ACTION



This continuous motion causes the armature conductors to cut the magnetic field of the main poles. All three conditions for generation of an e.m.f. are now present, i.e. conductors, motion, flux. An e.m.f. is therefore induced in the conductors which, by Lenz's law, opposes the applied voltage. It is therefore called the "back E.M.F." The back E.M.F. is never as great as the applied e.m.f.: the difference between the applied e.m.f. and back e.m.f. is always such that current can flow in the conductor and produce motion.
D.C. motors are classified according to their method of field excitation, i.e. shunt, series compound.
Shunt motors are classed as constant speed machines. The field winding has a constant voltage applied to it so that the flux will be constant at all loads and the torque will be proportional to armature current.
Series motors Whereas the shunt motor is essentially a constant flux machine, the series motor is a variable flux machine. The armature and field windings are connected in series.
Since there is only one circuit through the motor, any change in the load causes a change in the current and the working flux. Neglecting motor resistance, the speed is inversely proportional to the flux if the supply voltage is constant.
At light loads, the current is small and hence the flux is small as the field coils are energised by the main current.
As the load is increased, the current increases and the consequent increase in the magnetic field results in a reduction in the speed.

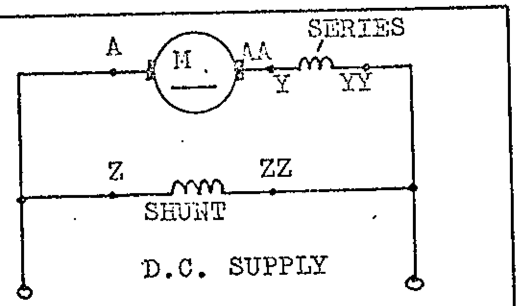
Series motors are not used in cases where light load running is possible such as belt drives, which could break or slip the pulley. The reason for this is that under light or no load conditions, the motor could build up to a self-destructing speed. They are suitable for hoists, cranes etc.

Compound motors The speed of a shunt motor is seen to be almost constant at all loads and the speed of a series motor is seen to vary considerably, falling in a marked manner as the load is increased.
By using both shunt and series coils so that the series winding assists the shunt, the motor characteristic can be made intermediate between them.
The chief application of the compound motor is when used in conjunction with a flywheel to give up its stored energy when a sudden load comes on such as with presses etc. Also used for driving pumps and other heavy duty machinery.



D.C. MOTORS OR GENERATORS

Compounding a d.c. motor A compound motor must be connected in the proper manner to ensure that it rotates in the proper direction, and also to prevent damage.
6 leads are brought out to the terminal block of the motor and should be labelled as follows -
A - AA is the armature
Y - YY is the series field
Z - ZZ is the shunt field



Connect the motor as shown in the diagram.

Follow these steps to check direction -

(1) Disconnect the motor from drive if reversal will cause damage.
(2) Short out series field Y-YY.
(3) Inch motor and note direction.
(4) Remove short from series field Y-YY.
(5) Disconnect shunt field terminal Z. If a field failure relay is fitted in the control circuit, this will have to be wedged in.
(6) Inch the motor and note direction. DO NOT ALLOW THE MOTOR TO ACCELERATE.
If the motor is controlled by a reversing drive, put the controller in the same direction as in step 3 and operate the same pushbutton.
(7) Interchange the leads A-AA or Z-ZZ to allow the motor to run in the correct direction with respect to the controller or pushbutton as follows:-
Step 2 correct, step 5 correct - do not interchange any leads
Step 2 correct, step 5 incorrect - interchange Y-YY (series)
Step 2 incorrect, step 5 correct - interchange Z-ZZ (shunt)
Step 2 incorrect, step 5 incorrect - interchange A-AA (armature)

TITLE:- D.C. MOTOR STARTING & SPEED CONTROL

LECTURER:-

DATE:-

EQUIPMENT:-

All D.C. motors are simultaneously generators while they are motoring. Obviously, motor action predominates under this condition because electrical energy drives the armature, and this means that armature current is delivered by the source.
The generated e.m.f., which results from the conductors in the armature cutting the field as they revolve, is a back e.m.f. (Lenz Law) therefore the magnitude of armature current depends upon the difference between the Applied e.m.f. and the back e.m.f.
In fact, it is the back e.m.f. which exercises a limiting effect upon armature current and causes the motor to adjust its speed and torque automatically to suit varying demands of the load.
At the instant a motor is started, the back e.m.f. is zero because the armature is not revolving. This means that some external resistance must be inserted in series with the low armature-winding resistance to offset the lack of back e.m.f. if excessive values of armature current are to be avoided. As the motor accelerates, and more back e.m.f. becomes available, the accelerating resistance can be cut out or short circuited in steps and when it is entirely removed, the armature is connected directly across the line and is running at full speed.

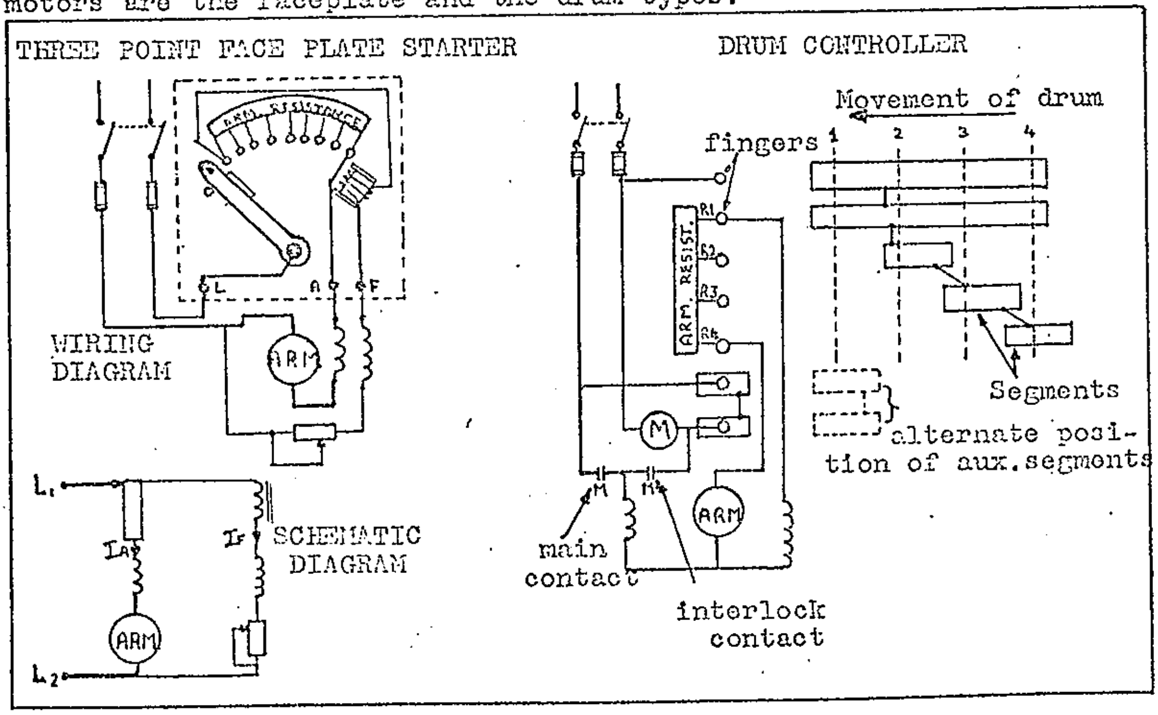
Example The armature of a 75 h.p. 230 volt 275 amp shunt motor has a resistance of 0.067 ohms. If the inrush current to armature is to be limited to 150 per cent of rated line value (a) calculate the resistance of the accelerating resistor (b) what approximate inrush current can be expected if the motor is started directly from 230 volt source without accelerating resistor?

Solution

(a) $R \text{ accel} = \dfrac{230}{1.5 \times 275} - .067 = 0.557 - 0.067 = \underline{0.49\text{ohm}}$

(b) $I \text{ inrush} = \dfrac{230}{0.067} = \underline{3,440 \text{ amps}}$

Two widely used manually operated starters for both A.C. and D.C. motors are the faceplate and the drum types.



Automatic Starters

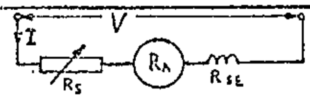
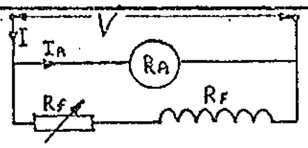
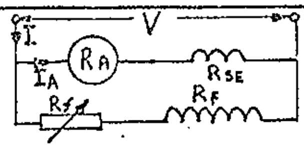
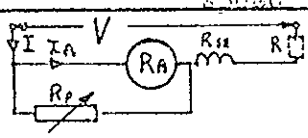
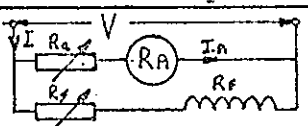
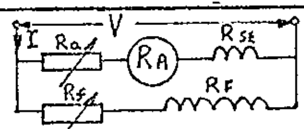
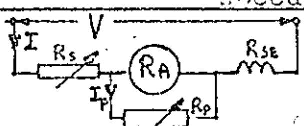
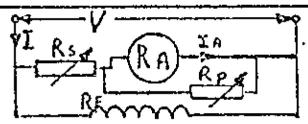
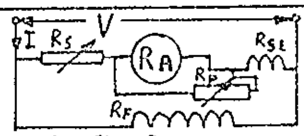
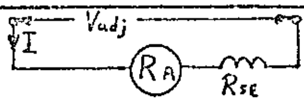
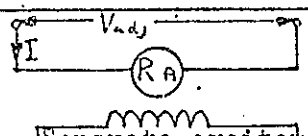
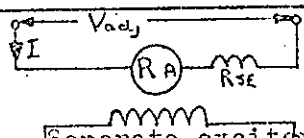
The reasons for using accelerating resistors are:-

(1) To limit inrush currents that are commutated because excessive current would tend to produce arcing and commutator burning.
(2) To minimize line disturbances caused by high inrush currents that produce excessive line resistance drops.
(3) To provide smooth acceleration so that driven machinery and equipment will not be subjected to undue mechanical stresses caused by sudden application of high torques.

There are many types of automatic starters for D.C. motors but all are classified under two general methods of acceleration, namely (1) current limit acceleration, and (2) definite time acceleration. With the first of these, a set of series or current relays is made to function i.e., pick up and drop out, for changing values of armature current as the motor accelerates; the relays in turn, operate to energize contactors which cut out (short circuit) the resistors in steps.
The definite time acceleration method employs a set of timed relays that function in sequence at a definite rate, regardless of load. These relays act on contactors which then progressively short circuit a group of resistors.
It should be noted that with the first method, the load will determine how rapidly the motor is brought up to full speed while with the second method, the motor will repeatedly cause the motor to operate on a given time cycle regardless of load.

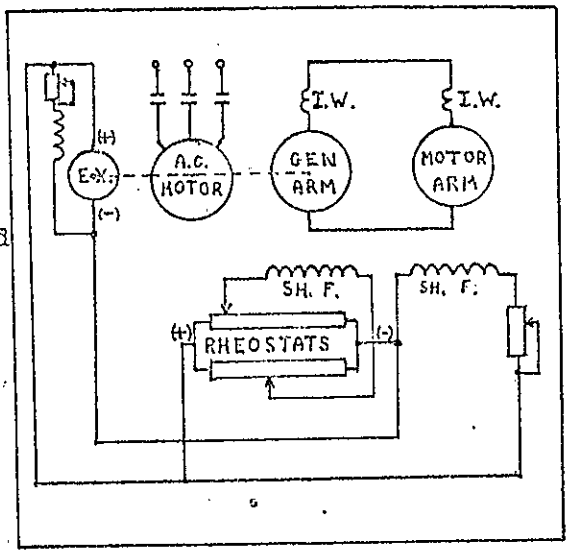
Speed control One of the D.C. motor's most valuable characteristics is its ability to provide a wide range of easily adjustable speeds. This is important because a high degree of speed control is often essential to certain motor-driven installations. It is significant that d.c. machines can be made to serve effectively for such applications because voltage and flux changes greatly influence the behaviour of these motors; this is in contrast to the A.C. induction type motor, whose speed does not change substantially under such conditions.

The following table gives the various means used to change speeds of D.C. motors:-

CONTROLLED ELEMENT	I-SERIES	II-SHUNT	III-COMPOUND
A FIELD RESISTOR	 raise Rs, lower speed	 raise Rf, raise speed	 raise Rf, raise speed
B FIELD AND ARMATURE RESISTORS	 lower Rf, lower speed	 raise Ra, lower speed raise Rf, raise speed	 raise Ra, lower speed raise R, raise speed
C SERIES AND SHUNT ARMATURE RESISTORS	 raise Rs, lower speed lower Rp, lower speed	 Raise Rs, lower speed lower Rp, lower speed	 raise Rs, lower speed lower Rp, lower speed
D TERMINAL VOLTAGE	 raise V, raise speed	 Separate exciter raise V, raise speed	 Separate exciter raise V, raise speed

<u>Ward Leonard Speed Control</u> This system uses the adjustable voltage method of speed control and offers many advantages over other methods. Although an expensive installation, it has wide application wherever low and high speeds must be accurately made, and where the service is severe and exacting. Rotation can be reversed by reversing polarity of the main generator. (used for main rolls in steelworks).
All control is centred in a rather small rheostat in the field circuit of the main generator.
The Ward Leonard system of speed control offers the following advantages:-

(1) Speed range much greater than that obtainable with shunt motor with armature and field control.
(2) Control component is generally a small field rheostat whose power requirement is about 1 to 2 per cent of total input so control is practically stepless.
(3) All heavy contactors eliminated because loop circuit is solidly connected. Motor is started, accelerated, speed adjusted, stopped and reversed by merely adjusting generator voltage.
(4) Generators with special characteristics can be matched to specific motor load requirements. This is particularly desirable in certain machine tools and for such heavy equipment as excavators.



With Compound motor - Shunt field should not be weakened too much or motor becomes a Series Motor (Effective)

<u>Braking</u>

<u>Plug Braking</u> - Reverse current applied to armature while still running in forward or vice versa thus C.E.M.F. <u>ADDS</u> to applied E.M.F. to bring motor to quick stop.

<u>Dynamic Braking</u> Applied current is removed from armature and C.E.M.F. is allowed to flow in armature CCT to bring motor to quick stop.

<u>Regenerative Braking</u> Used on hoists, cranes etc. to <u>limit</u> (Govern) speed when lowering. Motor overruns above critical speed and becomes generator therefore armature current reverses and holds armature to a maximum speed.

Note: Critical speed is speed at which C.E.M.F. Equals applied E.M.F.

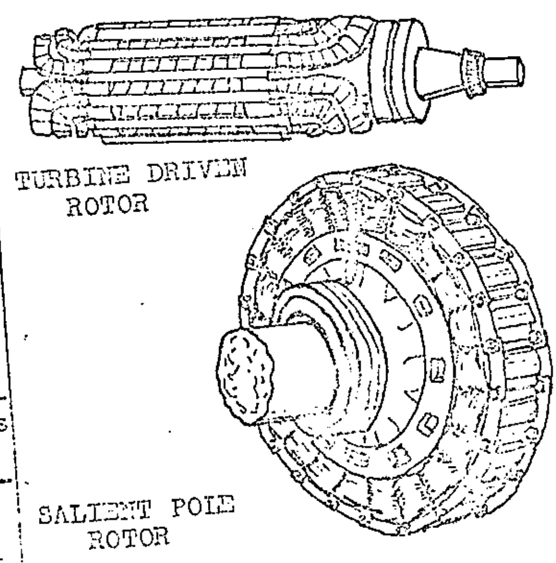
TITLE:- ALTERNATING CURRENT GENERATOR

LECTURER:-

DATE:-

EQUIPMENT:-

The A.C. generator, sometimes called the synchronous generator or alternator, consists essentially of the same two parts as the D.C. generator, i.e. the field magnet system and the armature. Unlike the arrangement in a D.C. generator however, the field magnets usually rotate (Rotor), and the armature is stationary (Stator) with the large types.



With the small types, the construction is similar, the main difference being that power is drawn off through slip rings instead of a commutator. These slip rings are essentially rings of copper, insulated from the shaft and each other and connected to the ends of the windings. Carbon brushes ride on these rings in the same manner as with a commutator but deliver A.C. to the load. (M.12.1)

The advantage of using a stationary armature with the large types is that it is easier to insulate armature coils for the high voltages usually generated (6,600 or 11,000 volts). By making the field magnet system rotate, only two slip rings are required (+ and -). There is no commutator. They are separately excited, each machine being provided with a small D.C. Generator, called an exciter, mounted on the same shaft: this supplies the magnetising current for the field magnets, usually at 110V or 250V.

Rotor Types

Rotors can be either salient pole or smooth cylindrical.

(1) Salient pole type is used with slow speed machines. Generators having this type of rotor are characterised by their large diameter and short axial length. A number of poles (from six up to about forty) are either bolted or fixed by using dovetails to a magnet wheel which is of large diameter. The poles are usually built up of steel stampings.

(2) Smooth cylindrical type suitable for turbo-generators. Number of poles, two or four. The rotor diameter is relatively small, but it is of large axial length. The useful range of two pole machines extends to about 50,000 KVA, but with four poles, units up to 200,000 KVA are possible.

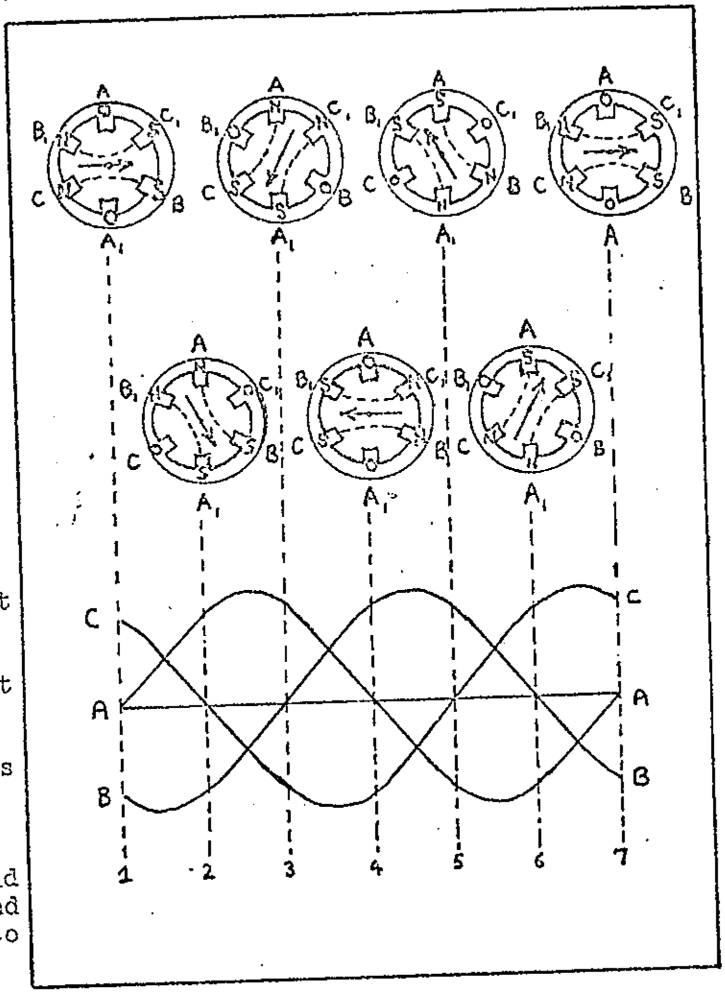
TITLE:- ALTERNATING CURRENT MOTORS

LECTURER:-

DATE:-

EQUIPMENT:-

Alternating current motors are of two kinds. Synchronous and Asynchronous.
They can be single phase or polyphase.
The principle of operation hinges around what is known as a rotating field. The diagram shows the waveform of a 3 phase supply applied to the stator. These wave forms are 120° out of phase with each other. The waveforms can represent either the three alternating magnetic fields generated by the 3 phases, or the currents in the phases. The waveforms are lettered to correspond to their associated phases. Using the waveforms, we can combine the magnetic fields generated every one sixth of a cycle (60 degrees) to determine the direction of the resultant magnetic field. At point 1, C is positive and B is negative. This means that current flows in opposite directions through phases B and C and so establishes the magnetic polarity of phases B & C. Observe that B1 is a north pole and B is a south pole, and that C is a north pole and C1 is a south pole. Since there is no current through A at this point, its magnetic field is zero.



At point 2, 60 degrees later, the input current waveforms to phase A and B are equal and opposite and C is zero. The resultant magnetic field will then be in the direction shown (a shift of 60 degrees). At point 3, B is zero and the resultant magnetic field has rotated through another 60 degrees.
From points 1 to 7, (corresponding to one cycle of A.C.) it will be seen that the magnetic field rotates through 360° for every cycle of A.C.
The rotating field is said to turn at "synchronous" speed.
To determine the synchronous speed of a motor, the following formula may be used:

$$N = \frac{120f}{P}$$, where N = Synchronous speed
f = frequency
P = No. of poles of stator

Synchronous motor: Similar in construction to alternators; as the name implies, they run at the same average speed as the rotating field.

A simple form of small synchronous motor uses a permanent magnet as a rotor. When the field is energised, and a rotating field is set up, the magnet follows the rotating field and "locks in", so that the rotor turns at the same speed as the rotating field in the stator, i.e. synchronous speed.
Small single phase synchronous motors are used to operate electric clocks, timers etc. to a high degree of accuracy.
Large synchronous motors have their rotors energised by D.C. from a separate source, fed in via slip rings.
The speed of these machines depends upon the supply frequency and the number of poles.

Advantages of synchronous motors are:-

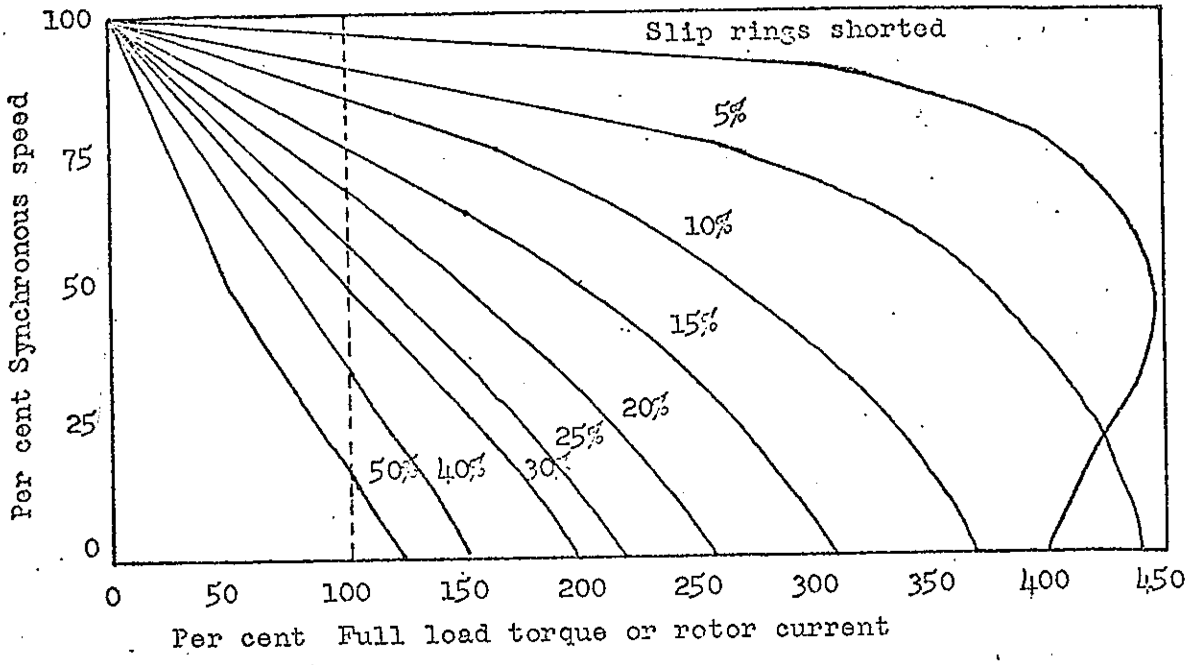
(1) Constant speed.
(2) Power factor can be varied over a wide range to suit the requirements of the load.
(3) Higher efficiency than other types of A.C. motors.

Disadvantages

(1) Speed is not adjustable.
(2) Single phase motors not self starting.
(3) Tendency to hunt.
(4) Separate D.C. source required.

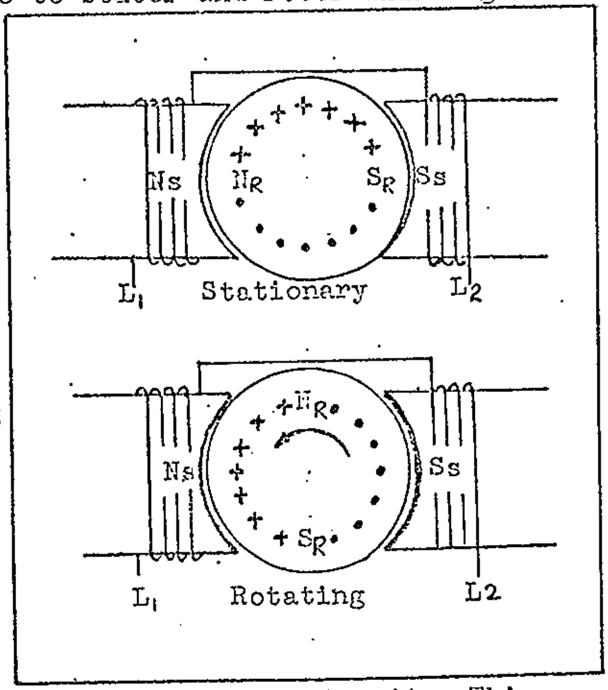
Induction motors: All A.C. machinery operating at non synchronous speeds are referred to as asynchronous machines. Induction motors are of this type.
An induction motor is similar electrically to a transformer whose magnetic circuit is separated into two parts, one of which is capable of being rotated. The stationary part, (stator) contains the primary winding which is energised by the supply mains. The rotating part, called the rotor, contains the secondary winding; this winding is not connected to any source of power, but has voltage and current induced in it by the alternating flux set up by the primary current. It may consist of a number of bars connected directly to heavy copper rings at each end of the rotor. This is called a squirrel cage rotor. It is from this induction between stator and rotor that the motor derives its name.
The effect of the current in the stator windings is to produce a magnetic flux in the stator core, which crosses the air gap between stator and rotor and completes its circuit in the rotor core.
This flux crosses the air gap and produces magnetic poles at the same mean distance apart as the pitch of the stator coils.
When supplied with an appropriate poly phase supply, the stator field will rotate and produce on the rotor the same effects as if it were surrounded by a system of rotating poles of constant strength.
The rotating flux cuts the conductors of the rotor and induces a current in it, and a torque is set up between rotor and stator.
For the motor to operate, the rotor must rotate slower than the field, because if the speed caught up there would be no relative motion, hence no currents induced in the rotor, and no torque.
The difference between rotor speed and the speed of the rotating field (synchronous speed) is called "slip".

Wound rotor motor: The rotor is made up of wound insulated coils which are carried out and terminated in three slip rings with this type of induction motor. Carbon brushes mounted on the slip rings are connected to a 3 phase external resistance bank, which is used to vary the resistance in the rotor circuit, and by this means, torque and speed can be regulated as the following table shows:-



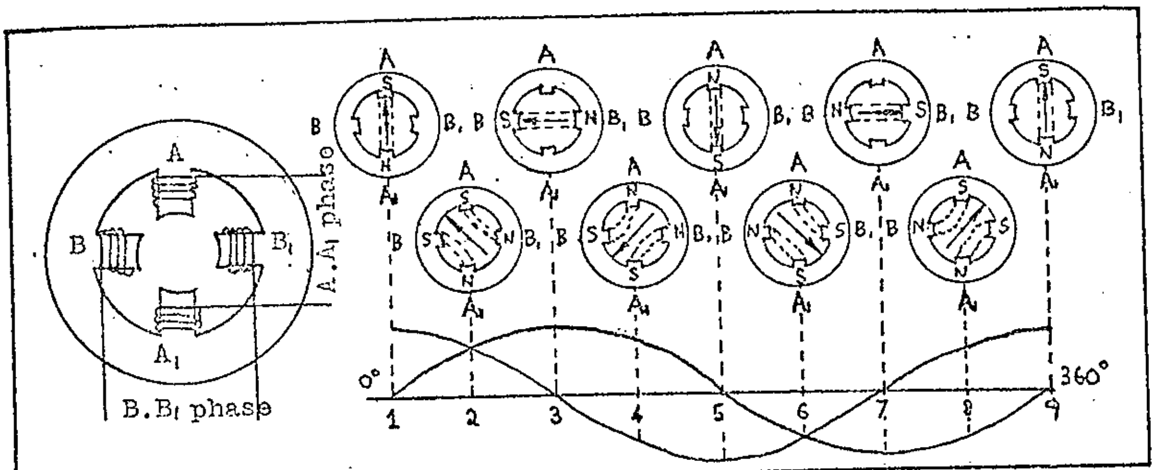
The advantage of the wound rotor and starter resistance is that starting current can be controlled and the starting torque is higher than with a squirrel cage rotor, also speed can be controlled. This type of motor is more expensive than the squirrel cage type, however.

Single Phase Motors: A single phase alternating current produces an alternating and not a rotating magnetic field. If however, the rotor of a single phase motor is made to rotate rapidly while the stator is supplied with an alternating current, the currents induced in the rotor conductors will themselves produce a magnetic field, and since this field will be out of phase with the primary field, the two magnetic field due to stator and rotor will together form a rotating field.

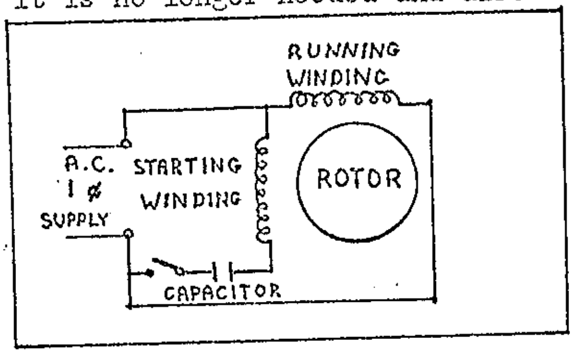


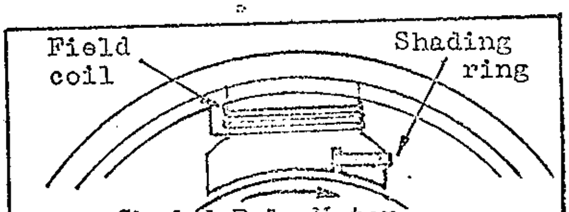
It should be clear that once a single phase motor is started turning by some means it will continue to turn by itself. It is impractical to start a motor by turning it over by hand so some electrical device must be incorporated into the stator circuit to make a rotating field be set up on starting.
Once the motor has started this device can be out of circuit since stator and rotor together will generate their own rotating field to keep the motor turning.

One of the most common methods used is to "split" the phase by having the running winding made up of a low resistance, high impedance winding i.e. comparatively few turns of quite large diameter wire, wound to embrace the maximum amount of iron in the core. A start winding is introduced into the circuit. This winding has large no. of turns of fine wire for maximum resistance and embraces minimum amount of iron in the core for low impedance. This design gives a phase displacement between the two windings, and if they are placed in the stator with a 90° physical displacement, a rotating field effect can be obtained which is sufficient to start the motor.
The effect obtained is similar to a two phase rotating field as shown:-



The starting winding is switched out by a centrifugal switch at about 75 per cent full speed since it is no longer needed and also since it would soon overheat due to the fine size of the wire. Placing a capacitor in series with the start winding gives a larger phase displacement between the two windings. This has a two fold effect:- Firstly, the starting torque is greatly improved and secondly, the inrush current when starting is reduced. The direction of rotation is reversed with these types of motor by either reversing the start connections <u>or</u> the run connections but not both.





Shaded Pole Motor

<u>Shaded Pole Motor</u>: This type of motor, one of the simplest and cheapest to manufacture, is an induction machine provided with an auxiliary short circuited winding displaced in magnetic position from the main winding. In its most usual form it has salient poles surrounded by a main coil and a short circuited turn of copper strap around a portion of the pole piece.
Being an induction motor with a squirrel cage rotor, the latter receives power in much the same way as does the rotor of a polyphase induction motor. One important difference concerns the motion of the magnetic field however. The field of the shaded pole motor merely shifts from one side of the salient pole to the other since the field set up by the shading ring lags the main field and is offset from it.
The torque of such motors, generally made in very small sizes, is therefore not uniform but varies from instant to instant.
These motors are generally used on fans and other small apparatus.
To reverse the direction of a shaded pole motor, the stator has to be physically reversed.

The advantages of single phase induction motors are:-

(1) Can be operated from a single phase supply.
(2) Require no extra starter for most sizes.
(3) Rotation in most cases easily reversed.
(4) Robust in construction and do not require a commutator and brushgear.
(5) Since they have no brushgear they are suitable for use in inflammable locations.

(6) Fairly silent running.
(7) Operate at nearly constant speed.
(8) Do not cause radio interference.

Limitations are:-
(1) Speed can only be changed in fixed steps by using expensive pole changing windings.
(2) Speed fixed by number of poles and mains frequency.
(3) Maximum possible speed is 2900 R.P.M. on 50 cycles supply with a 3 pole motor.
(4) Split phase type has low starting torque, high starting currents and low overload capacity.
(5) Relatively low power factor and efficiency.

TITLE:- A.C. MOTOR STARTERS & SPEED CONTROL

LECTURER:-

DATE:-

EQUIPMENT REQUIRED:

Direct On Line Starting Since the A.C. impedance of a stator winding of an A.C. motor is considerably higher than is the resistance of the armature winding of a D.C. motor, inrush currents to the former, with the application of full voltage is very much less than the latter. This means, therefore, that the smaller type of A.C. motors, need not, for the most part, be restricted to the usual current-limiting starting procedures of D.C. motors, although reduced voltage methods are used with larger types, not so much to protect the motors against high inrush currents and sever electromagnetic stresses as to minimise line voltage disturbances. In particular, it can be said that initial surge currents to A.C. motors with full voltage starting rarely exceeds six to seven times rated value, and these high currents are of a short duration only and also, they pass directly into the windings through wired connections and not sliding contacts.

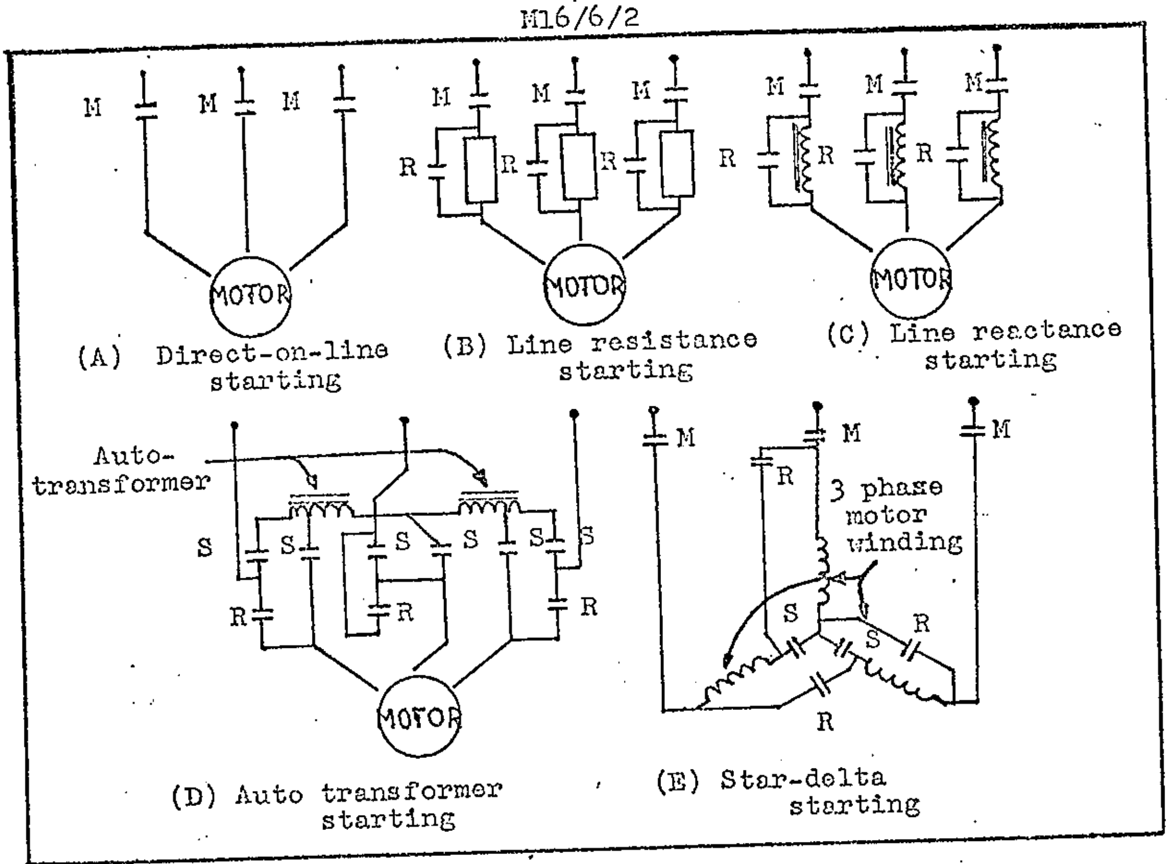
Reduced Voltage Starters If it is desired to limit the starting currents to lower values than those indicated above, one of four schemes may be employed. In each case, less than rated voltage is applied to the motor terminals during a major part of the accelerating period, under which condition the inrush current is reduced in proportion to the voltage reduction. However, due to less torque being available, the motor is likely to accelerate slowly at the reduced voltage, causing excessive motor heating, especially if frequently repeated. Great care should be taken in choosing a starter to avoid this condition.
The main types of starters are:-

(1) The insertion of line resistors to introduce artificial voltage drops, Fig. B.

(2) The insertion of line reactors for the same reason. Fig. C.
From the sketches of the power circuits it can be seen the resistors and reactors incur voltage drops during the accelerating period, when the (M) main contacts only are closed, and thus permit the motor to start under reduced-voltage conditions. After the motor reaches full, or nearly full speed, the (R) run contacts close to short circuit the resistors or reactors when a contactor is energised, under which condition normal operation continues.

(3) Fig. D represents a typical autotransformer (compensator) starting arrangement in which the customary open-delta connection is employed.
In the actual compensator, the two windings shown are placed on the two outside legs of a three legged core and reduced voltage taps are brought out at the 50, 65 and 85 per cent points. As indicated, when the (S) start contacts close, the motor starts on reduced voltage, determined by the tap selected, and after the motor accelerates to full or nearly full speed, the S contacts open and the R contacts close. When this happens, the compensator is completely disconnected from the circuit and the motor runs properly from the full voltage source.

Advantage The biggest advantage of this method is its "double barrelled" effect, i.e. using line resistance or line reactance, the line current and motor current are the same. With the compensator method, the motor is supplied with reduced voltage by transformer action, thus this reduced voltage draws a certain current but the line current is the same fraction of motor current as is the secondary to primary voltage ∴ with a starting voltage of 50 per cent, the line current will be 25 per cent.



(A) Direct-on-line starting

(B) Line resistance starting

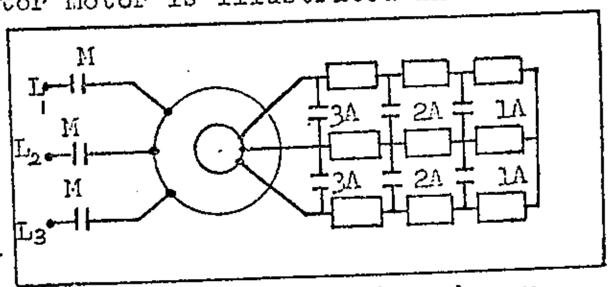
(C) Line reactance starting

(D) Auto transformer starting

(E) Star-delta starting

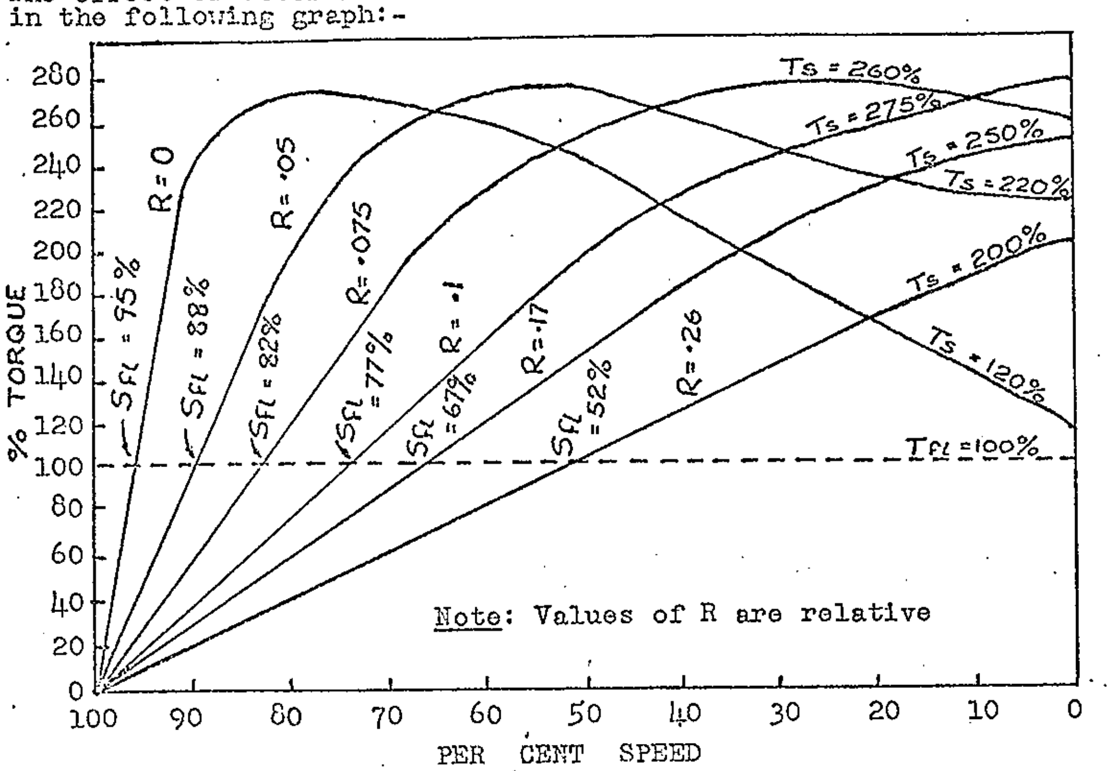
(4)
Star Delta Starter Fig. E represents the star/delta method. This method is interesting and economical in that no external equipment such as resistors, reactors, or transformers are needed to provide each phase with reduced voltage during the accelerating period. However, with this scheme, the motor must be designed to run in delta. Thus, when the M & S contacts close, the motor starts star connected with about 58 per cent voltage across each phase; then after reaching full speed, the S contacts are opened first, after which the R contacts close to connect the three winding phases in delta for full voltage operation. This system supplies about 1/3 starting torque of D.O.L. Motor must have six terminals.

(5) Wound Rotor Motor The ohmic value of the rotor resistance of a polyphase induction motor greatly affects three important operating characteristics. These are (1) starting torque (2) Starting current and (3) the speed under varying load conditions. The rotor resistance cannot be varied with a squirrel cage motor. For most applications this is not serious, but with some circuits, one or more of these characteristics must lend themselves to adjustment.
Induction motors with wound rotors fulfill these requirements. A simplified diagram showing how external resistors are connected in a rotor circuit of a wound rotor motor is illustrated in the following sketch.



In practice, the total external resistance is selected on the basis of the desired starting torque, and maximum permissable starting current. The number of steps is selected on the basis of the number of speed points and an acceptable smoothness of acceleration. The higher the external resistance, the lower will be the inrush current. This is because the rotor circuit is, in reality, the secondary of a transformer whose total impedence affects the magnitude of, not only the current in that circuit, but, by transformer action the current taken by the stator.

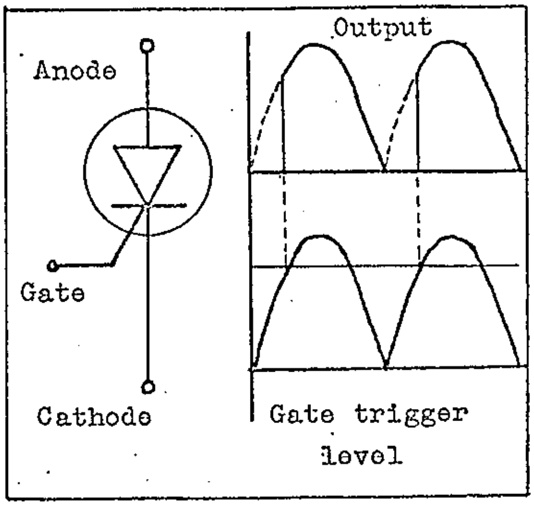
The effect of rotor resistance on a wound rotor motor is illustrated in the following graph:-



Unlike a D.C. motor which has rotor and stator fed from D.C. source, the A.C. induction motor is singly fed, i.e. currents are induced in the rotor by a synchronously rotating field. The speed of an induction motor is tied to the line frequency, the number of poles, and, for motors with phase wound rotors, to the resistance that is inserted in the secondary circuit. It follows, therefore, that speed control is possible by employing (1) a variable frequency source (2) one of several pole changing schemes, and (3) variable resistors in the rotor circuit of a phase wound rotor motor. However, the induction motor is essentially a constant speed energy converter, and under normal operating conditions the speed changes only slightly between no load and full load.

S.C.R. Speed Control

An electronic device which can be used to control the speeds of some A.C. motors incorporates a silicon controlled rectifier. An S.C.R. is basically a diode which can be switched on by a voltage applied to a gate.



An S.C.R. has high resistance in both directions until correct voltage is applied to the gate, it will then conduct in one direction only. Once conducting, the gate has no effect and can only be switched off by removal of anode voltage. On a speed control for motors, the S.C.R. is fired when and where desired on the sine wave. This effectively cuts the average voltage applied to the motor, so that it runs at a reduced rate. The back e.m.f. is also reduced as the motor has a high torque at low speeds. If the motor is replaced with a lamp, i.e. a purely resistive load, the lamp will dim as the average voltage is reduced.