Single phase motors - split phase induction motor - induction-start, induction-run motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the types of AC single phase motors**
- **explain the necessity and methods of split-phasing the single phase to obtain a rotating magnetic field**
- **explain the principle, construction, operation characteristic and application of single phase resistance / induction-start / induction-run motors.**

Single phase motors perform a great variety of useful services at home, office, farm, factory, and in business establishments. These motors are generally referred to as fractional horsepower motors with a rating of less than 1 H.P. Most single phase motors fall into this category. Single phase motors are also manufactured in 1.5,2,3 and up to 10 H.P. as a special requirement.

Single phase motors may be broadly classified as split-phase induction motors and commutator motors according to their construction and method of starting.

Split-phase induction motors can be further classified as:

- resistance-start, induction-run motors
- induction-start, induction-run motors
- permanent capacitor motors
- capacitor-start, induction-run motors
- capacitor-start, capacitor-run motors
- shaded pole motors.
- stepper motor

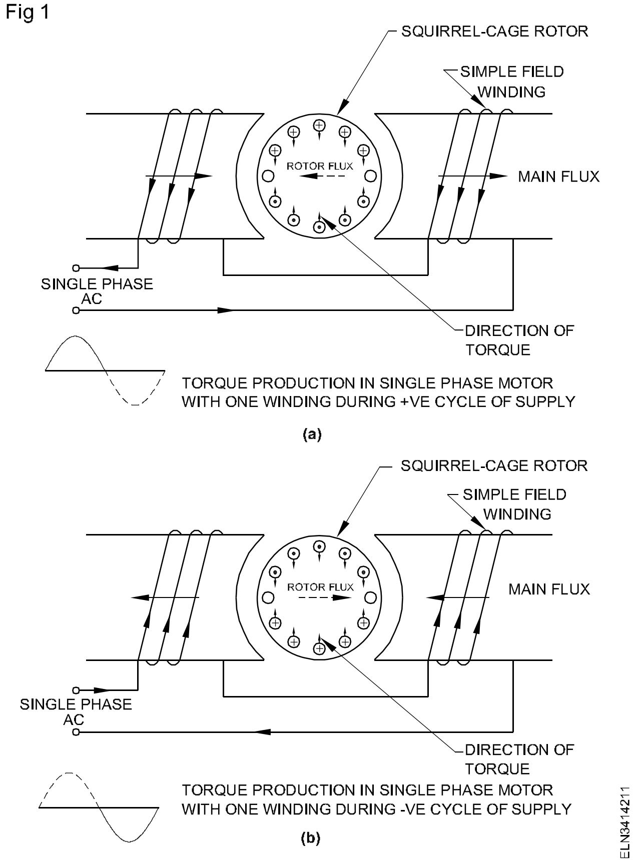
Commutator motors can be classified as:

- repulsion motors
- series motors.

The basic principle of operation of a split-phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating field. Hence to produce the rotating magnetic field, phase-spliting is to be done to make the motor to work as a two-phase motor for starting.

First, let us examine the behaviour of the magnetic field as set up by an AC current in a sinlge-phase field winding. With reference to Fig 1, at a particular instant, the current flowing in the field winding produces the magnetic field as shown in Fig 1a. Since the produced magnetic field is varying, it will induce currents in the rotor bars which in turn will create a rotor flux. This stator-induced flux, according to Lenz's law, opposes that of the main field. By applying this principle, the current direction in the rotor bars can be determined as shown in Fig 1a, as well as the torque created between the field and rotor currents. It is apparent that the downward torque produced by the upper rotor conductors is counteracted by the upward torque produced by the lower rotor conductors; hence no rotation results. In the next instant, as shown in Fig 1b, the voltage in the input supply changes its polarity, creating a main field with a change in direction. This main field produces a torque, downward in upper conductors, and upwards in bottom conductors resulting in the cancellation of torque with no movement of the rotor, in this case also. Since the field is pulsating, the torque is pulsating although no net torque is produced over a full cycle.

Fig 1



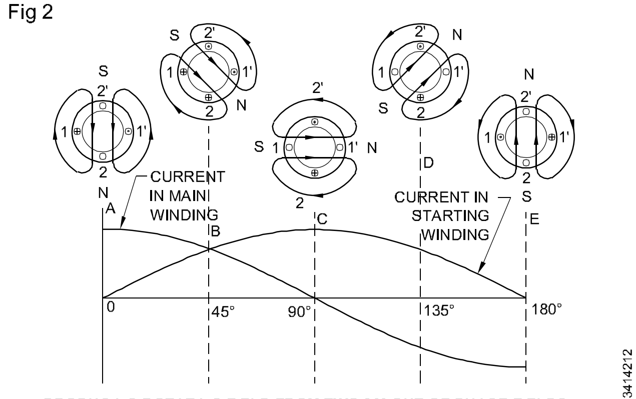
If the rotor is given a small jerk in any direction in the above mentioned cases, it will go on revolving, and will develop a torque in that particular direction due to interaction between the rotor and stator fluxes. Because of this effect, the split-phase motor, once started, needs only one winding to be connected to the supply for running. It is clear that a single phase induction motor, when having only one winding, is not self-starting. If the main field is made revolving instead of pulsating, a rotational torque could be produced in the rotor.

Producing a rotating field from two 90° out-of-phase fields: One of the methods of producing a rotating magnetic field is by split-phasing. This could be done by providing a second set of winding in the stator called the starting winding. This winding should be kept physically at 90 electrical degrees from the main winding, and should carry a current out of phase from the main winding. This, out of phase current, could be achieved by making the reactance of the starting winding being different from that of the main winding. In case both the windings have similar reactance and impedance, the resulting field, created by the main and starting windings, will alternate but will not revolve and the motor will not start.

By split-phasing, the two (main and starting) fields would combine to produce a rotating magnetic field as stated below.

Fig 2 shows that the main (1,1') and starting (2,2') windings are kept in the stator at 90° to each other. For consideration, only, one half cycle is shown with the effects at 45^0 increments.

Fig 2



PRODUCING ROTATING FIELD FROM TWO 90° OUT-OF-PHASE FIELDS

At position `A', only the main winding is producing flux, and the net flux will be in a vertical direction, as shown in the stator diagram. At instant `B', 45° later, both windings are producing flux, and the net flux direction will also have rotated 45°. At position `C', the maximum flux is now in a horizontal direction because only the starting winding is producing flux. At instant `D', the current from the main winding is building up again, but in a new direction, while that from starting winding is now decreasing. Therefore, the net flux at this instant will be as shown in position D. At position `E', the maximum flux is just the opposite of what it was at instant `A'. It should now be evident that the two out-of-phase fields are combining to produce a net rotating field effect.

Working of split-phase motor: At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field. The rotor is of a squirrel cage type, and the revolving magnetic field sweeps past the stationary rotor, inducing an emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field. This magnetic field opposes the revolving magnetic field and will combine with the main field to produce a revolving field. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor, which was explained earlier.

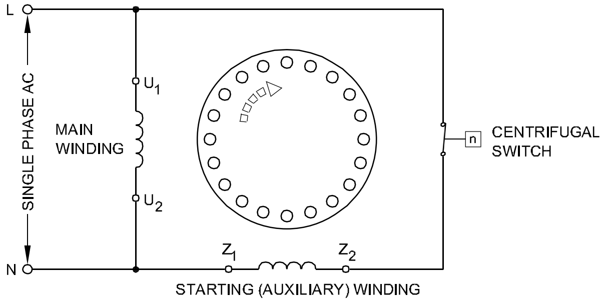
Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields form a revolving magnetic field.

Resistance-start, induction-run motor: As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily.

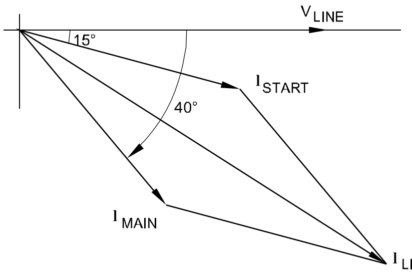
The essential parts are as shown in Fig 3a.

- Main winding or running winding
- Auxiliary winding or starting winding
- Squirrel cage type rotor
- Centrifugal switch

Fig 3



(a) RESISTANCE START INDUCTION RUN MOTOR

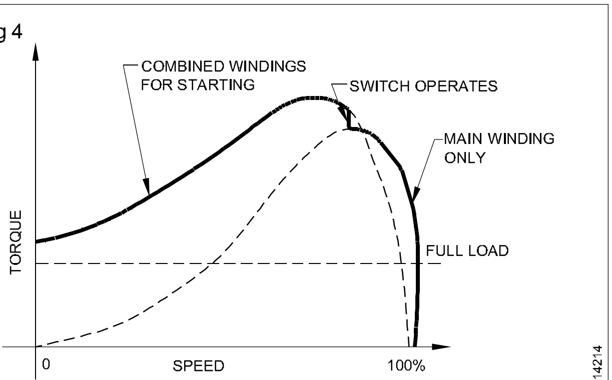


(b) PHASOR DIAGRAM AT THE INSTANT OF STARTING

The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using smaller conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots. It is obvious that the current would split as shown in Fig 3b. The starting current `I start' will lag the main supply voltage `V' line' by 15° and the main winding current. `I main' lags the main voltage by about 40°. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come up to about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch, and the motor will continue to operate as a single phase motor. At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be onserved from the typical torque-speed characteristics of this motor, as shown in Fig 4.

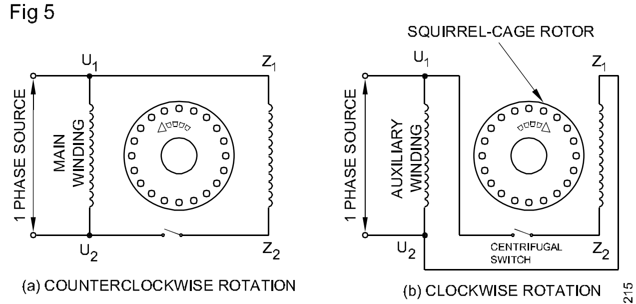
Fig 4



TORQUE SPEED CHARACTERISTIC OF SPLIT PHASE MOTOR

The direction of rotation of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotation could be obtained. Rotation will be, say counter-clockwise, if Z_1 is joined to U_1 and Z_2 is joined to U_2 as per Fig 5a. If Z_1 is joined to U_2 and Z_2 is joined to U_1, then the rotation will be clockwise, as shown in Fig 5b.

Fig 5



(a) COUNTERCLOCKWISE ROTATION

(b) CLOCKWISE ROTATION

METHOD OF CHANGING THE DIRECTION OF ROTATION OF RESISTANCE START INDUCTION RUN MOTOR

Application of resistance-start, induction-run motor: As the starting torque of this type of motors is relatively small and its starting current is high, these are manufactured for a rating up to 0.5 HP where the starting load is light. These motors are used for driving fans, grinders, washing machines and wood working tools.

Induction-start, induction-run motor: Instead of resistance start, inductance can be used to start the motor through a highly inductive starting winding. In such a case, the starting winding will have more number of turns, and will be imbedded in the inner areas of the stator slots so as to have high inductance due to more number of turns, and the area will be surrounded by more iron. As the starting and main windings in most of the cases are made from the same gauge winding wire, resistance measurement has to be done to identify the windings. This motor will have a low starting torque, higher starting current and lower power factor.

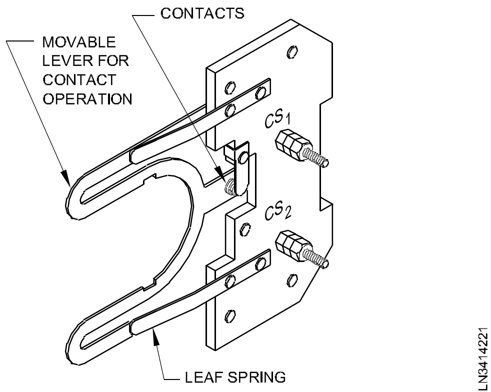
Centrifugal switch

Objectives: At the end of this lesson you shall be able to
- **explain the working, the method of maintenance and testing of a centrifugal switch**
- **explain the necessity of a manual D.O.L. starter and its working**
- **explain the operation of overload relays.**

The centrifugal switch: The centrifugal switch is located inside the motor and is connected in series with the starting winding in the case of capacitor-start, induction-run motors, and for disconnecting the starting capacitor in the case of a two value, capacitor-start, capacitor-run motor. Its function is to disconnect the starting winding after the rotor has reached 75 to 80% of the rated speed. The usual type consists of two main parts. Namely, a stationary part as shown in Fig 1, and a rotating part as shown in Fig 2. The stationary part is usually located on the front-end plate of the motor and has two contacts, so that it is similar in action to a single-pole, single-throw switch. When the rotating part is fitted in the rotor, it rotates along with it. When the rotor is stationary, the insulator ring of the rotating part is in an inward position due to spring tension. This inward movement of the insulator ring allows the stationary switch contacts to be closed which is due to the movable lever pressure against the leaf-spring tension in the switch.

When the rotor attains about 75% of the rated speed, due to centrifugal force, the governor weights fly out, and this makes the insulator ring to come outward. Due to this forward movement of the insulated ring, it presses the movable lever, and the contacts connected through terminals CS_1 and CS_2 open the starting winding.

Fig 1



In older types of centrifugal switches, the stationary part consists of two copper, semicircular segments. These are insulated from each other and mounted inside the front-end plate. The centrifugal switch connections are given to these segments. The rotating part is composed of three copper fingers that ride around the stationary segments, while the motor is at rest or running at lower than 75% of the rated speed. These parts are illustrated in Fig 3.

Fig 2

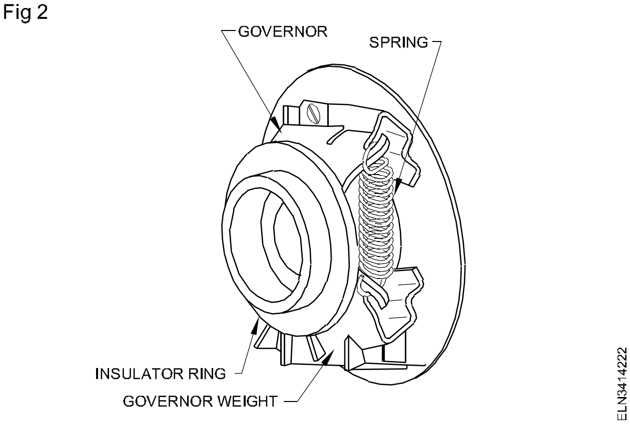
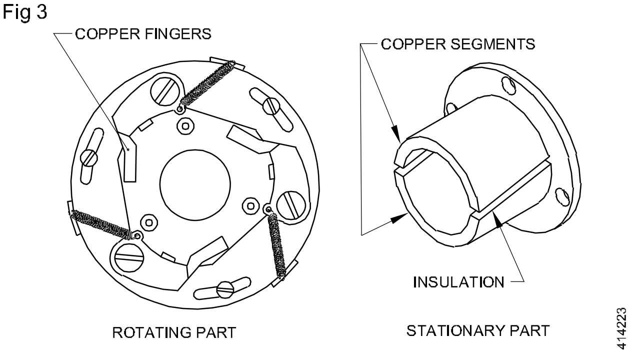


Fig 3



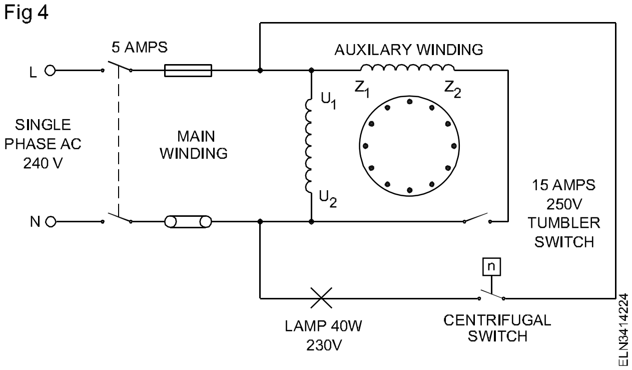
CENTRIFUGAL SWITCH

At the time of starting, the segments are shorted by the copper fingers, thus causing the starting winding to be included in the motor circuit. At approximately 75 percent of the full speed, the centrifugal force causes the fingers to be lifted from the segments, thereby disconnecting the starting winding from the circuit.

Maintenance of centrifugal switch: Access to the centrifugal switch could be had by removing the inspection plate, located in the end covers of the motor. In very many cases, the switch is accessible only when the end plate is removed. These switches need to be checked atleast once in six months to ensure their proper operation. Look for broken or weak springs, for improper movement, for dirt or corrosion or pittings in the contact points. Make sure all parts work freely without binding. Replace the switch, if found defective.

Testing the operation of a centrifugal switch: Though the centrifugal switch could be tested in a static condition, it will be very difficult to assess its operation at dynamic condition. As most of these switches cannot be checked without opening the end plate, the procedure becomes lengthy and cumbersome. To check the dynamic operation of the switch the following method is suggested. Disconnect the interconnecting terminals of the centrifugal switch from the supply and the starting winding. Connect the starting (auxiliary) winding through a 15 amps, single-pole, tumbler switch to the rated supply as shown in Fig 4, and keep the tumbler switch in the `ON' position.

Fig 4



Connect the terminals of the centrifugal switch, through a lamp as shown in Fig 4. Switch `ON' the motor. When the centrifugal switch is in the closed position, the lamp will light. As the motor picks up speed, say in about 20 seconds, open the tumbler switch to disconnect the starting winding. When the speed of the motor attains about 75% of the rated value, the centrifugal switch, if it operates correctly, will open its contacts which could be observed from the lamp going `off'. Soon after switching `on' the main supply, if the lamp is not lighted, or if it lights up but does not go out after 30-40 seconds (75 % of the rated speed) then the centrifugal switch is deemed to be not working, and should be repaired or replaced.

Manual D.O.L. starter: A starter is necessary for starting and stopping the motor, and for providing overload protection.

A manual starter, as it appears, is shown in Fig 5, an open view of the starter is shown in Fig 6, and the internal parts are shown in Fig 7, as a schematic diagram. A manual starter is a motor controller with a contact mechanism operated by hand. A push-button operates the mechanism through a mechanical linkage. As shown in Figs 6 & 7, the starter may have both a thermal overload relay and a magnetic overload relay for overload protection and short circuit protection respectively. Both the relays are made to operate independently, in case of overload or short circuit, to release the start-button for disconnecting the motor from supply. Most of the present day, manual starters have either of the two relays only. Basically, a manual starter is an ON-OFF switch with overload relay only.

Fig 5

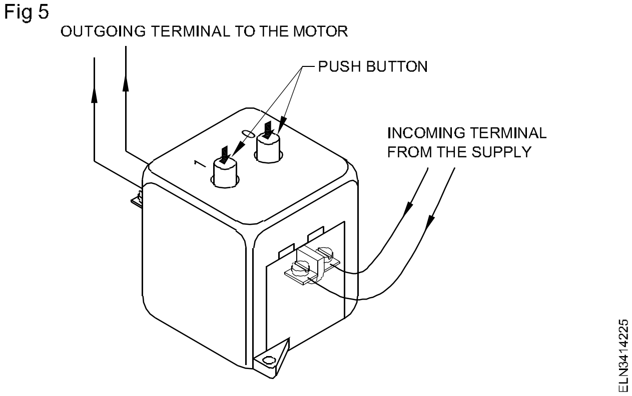
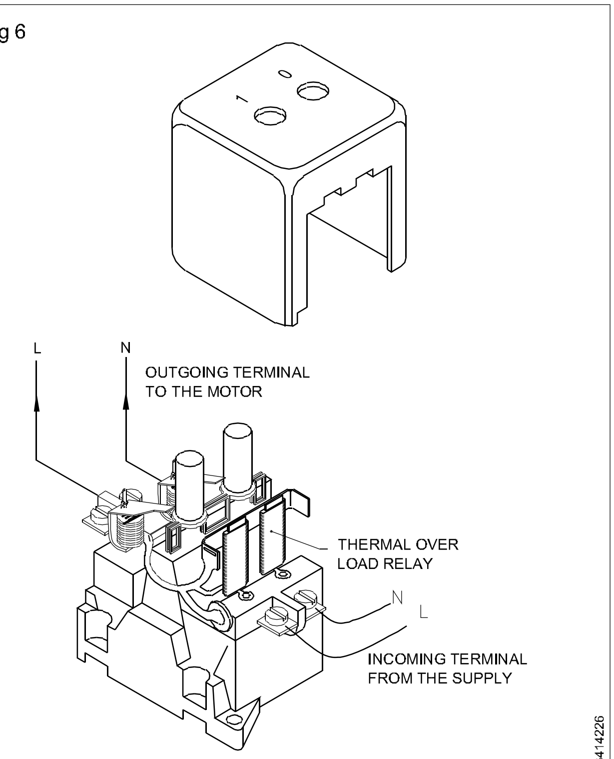
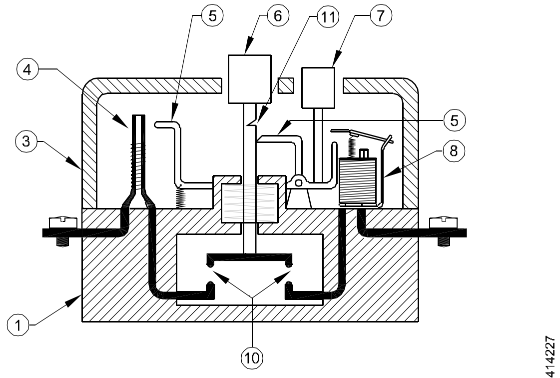


Fig 6



OPEN VIEW OF MANUAL D.O.L STARTER

Fig 7



SCHEMATIC DIAGRAM OF A MANUAL D.O.L STARTER

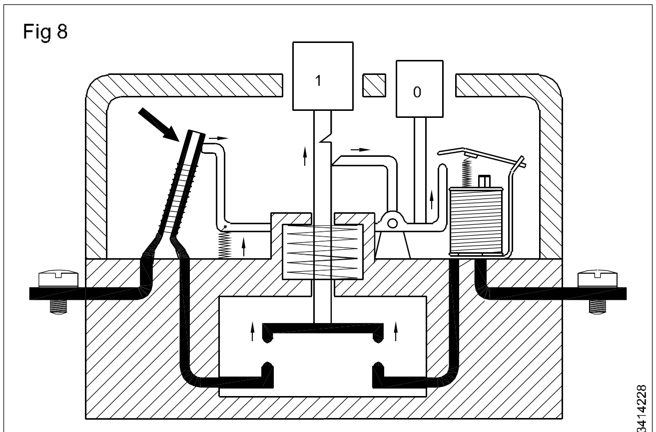
Manual starters are simple and they provide quiet operation.

Operation: Pushing the `ON' button closes the contacts. The contacts remain closed until the STOP button is pushed or the overload relay or the short circuit relay trips the starter.

As shown in Fig 7, when the `ON' push-button (6) is pressed, the switching contact (10) gets closed, and remains in a closed position, as the mechanical lever system (5) holds the stem of the `ON' button by the cavity (11) against the spring tension. By operating the stop button (7), the mechanical lever system (5) gets disengaged from the stem cavity, making the stem of the `ON' button to spring back, thereby opening the switching contacts (10).

Operation of overload relay: In the case of sustained overloads, the heavy currents passing through the heating element of the thermal overload relay heats up the bimetallic strip, making it to bend as shown by the arrow in Fig 8, thereby activating the mechanical lever system to open the switching contacts.

Fig 8



OPERATION OF O/L RELAY IN A MANUAL D.O.L. STARTER

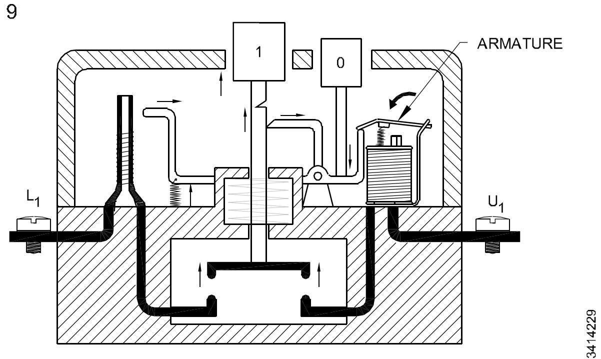
The current setting of the thermal overload relay can be changed by adjusting the setting screw, provided for this purpose (not shown in the figure.)

Operation of short-circuit relay:In the case of a short circuit in the motor circuit, the short circuit current will be very high in value. Though the thermal overload relay is also in series with such a short circuit current, it is sluggish in operation and takes considerable time to operate. On the other hand, the short circuit current within such time of delayed operation, will sufficiently damage the motor winding, power cables or the connected supply line.

The magnetic relay will operate faster than the thermal overload relay in such cases.

During normal load current the magnetic field produced by the coil will not have sufficient pull to attract the armature. But in case of short circuit, the current will be very high and the coil produces sufficient magnetism to attract the armature. Downward movement of the armature activates the mechacnical lever mechanism as shown by the arrow in Fig 9 and the switching contact opens. These contacts cannot be reclosed until the starter mechanism has been reset by pressing the Stop button.

Fig 9

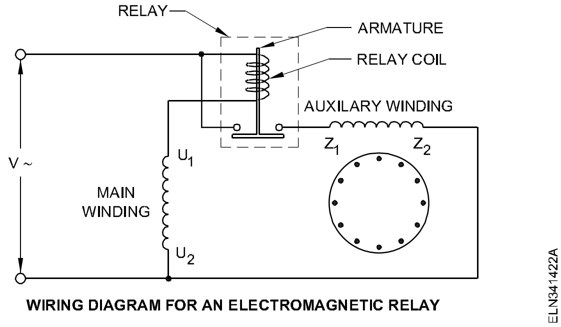


OPERATING OF MAGNETIC RELAY DURING SHORT CIRCUIT

Manual starters are used for fractional horsepower motors. They usually provide across-the-line starting. Manual starters cannot provide low-voltage protection or no-volt release. If power fails, the contacts remain closed, and the motor will restart when the power returns. This may be an advantage for pumps, fans, compressors, and oil burners. But in the case of machinery it can be dangerous to people operating the equipment, and hence, such manual starters are not recommended to be used in these places.

Electromagnetic relay: Single phase induction motors, like poly phase induction motors takes heavy current from the time during starting when started direct on line Advantage of this high starting current is taken to operate electromagnetic type relay which performs the same function as the centrifugal device. Connection diagram for such a relay is shown in Fig 10.

Fig 10



WIRING DIAGRAM FOR AN ELECTROMAGNETIC RELAY

The relay has a coil which is connected in series with the main winding. The auxiliary winding is connected across the supply through a normally open contact of the relay. Since split-phase motors are usually started direct on line, the initial current inrush may be as high a five to six times the rated current. During the starting period, when the main winding current is high, the armature of the relay will be drawn upwards, thereby closing the relay contacts. The auxiliary winding will, therefore, get connected across the supply, thus helping the motor to start rotating. As the rotor starts rotating, the line current gradually goes on decreasing. After the motor reaches proper speed, the main winding current drops to a low value and causes the armature of the relay to fall downwards and open the contacts, thereby cutting out the auxiliary winding from the supply. Such relays are located outside the motor so that they can be easily serviced or replaced. As centrifugal switches are mounted internally, their servicing or replacement is not as simple as an externally mounted over-current relay.

Single phase, split phase type motor winding (concentric coil winding)

Objectives: At the end of this lesson you shall be able to

- **state the important points to be followed while winding split phase motors**
- **explain about coil distribution in concentric winding**
- **prepare the winding table, draw the connection and developed diagrams for concentric coil winding in single phase, split phase type motors.**

Split phase type : In general, single phase motors use a capacitor to split the phase. Some motors are, as found in fans, have the capacitor permanently connected to the supply. In some motors, the capacitor is used only for the starting period, then while running it is disconnected from the supply by the use of a centrifugal switch mechanism. In some other types of motors there are two capacitors, one for starting and the other for running. However, depending upon the power, function and the design of the motor, the capacitor value will be different in each case. Observe this point everytime you come across the split phase motor.

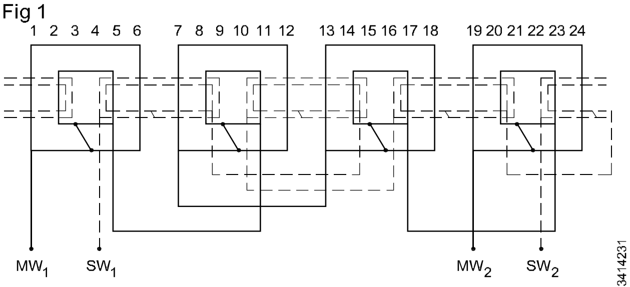
There are certain points to be followed while winding a split phase motor.

1 The single phase winding may have different shapes of coils as explained below.

a **Concentric coil winding (Fig 1):** This winding requires coils of different shapes in a phase/pole group, and different sizes between the phases in order to accommodate in the slots and for placing both main and starting windings. In addition to this, the coils in the same group may have different number of turns.

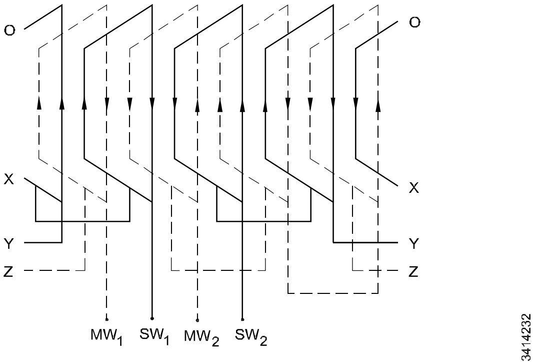
b **True mesh shaped coils (Fig 2):** These coils are of the same size and shape and the end windings form a very tight roll.

Fig 1



SINGLE PHASE CONCENTRIC WINDING 24SLOTS 4POLES

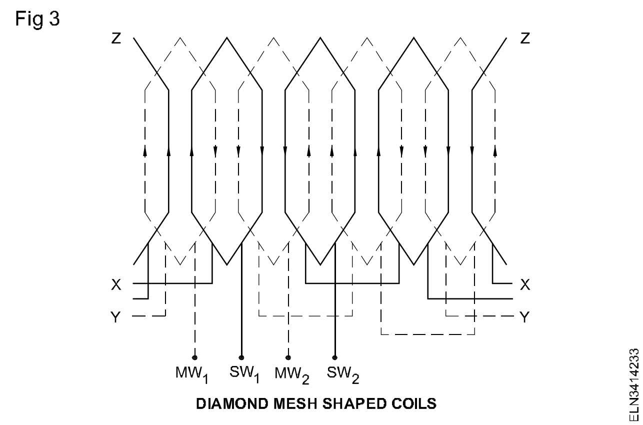
Fig 2



MESH SHAPED COILS

c **Diamond mesh shaped coils (Fig 3):** These coils are of the same size and shape and the end winding is longer and flatter than the true mesh type coils. The end of the coils has a loop, knuckle or nose.

Fig 3



DIAMOND MESH SHAPED COILS

2 The main and starting winding should be placed 90 electrical degrees apart from each other.

3 All the coil groups may or may not have the same number of coils.

4 The main winding is kept first in the stator slots and the starting winding is kept over the main windings.

5 Normally, the main winding consists of thick winding wire, and the starting winding of thin winding wire. In certain motors both the windings may have same size of winding wire.

6 The number of turns in the main and starting windings may or may not have the same number of turns.

7 In concentric coil winding, the coils in the same group may or may not have the same number of turns.

8 Each slot may contain one or two coil sides.

9 The overhang of the coils should be of exact in size. If it is less, the insertion of the coils will be difficult and if the size is more, the coils may not allow the end covers to be fitted.

10 While inserting concentric coils, start with the smaller pitched coil set.

11 There may be empty slots in the stator. Note their position.

Concentric winding: Concentric type of winding is probably the most common type of winding used in fractional horsepower single phase motors. The winding may be hand wound or may be form wound.

As the starting winding is designed to split the phase and is used to start the motor, it may have less slots (coils) allotted when compared to the main winding. For example there may be 8 coils for main winding and 4 coils only for the starting winding.

Further it is a standard practice to wind only about 70% of the slots of a single phase motor, as owing to the effect of the distribution or spread factor, no advantage is gained by making a single phase winding any wider. Even if the whole of the slots were to be wound, the extra winding would be useless for producing the useful torque.

Similarly it has been found that in single phase motors, no extra loss takes place if all the slots of each pole face are not wound. Thus the running winding looses nothing in efficiency, because some of the slots of each pole are taken for the starting winding.

Winding calculation and diagrams for concentric type winding : Let us discuss the following examples.

Example 1

Prepare the winding table, draw the connection and developed diagrams for a single phase, 4 pole, whole coil connected capacitor motor having 24 slots, 12 coils (8 coils for main and 4 coils for starting winding) with pitches 5, 3 for the main and 5 for the starting winding.

$$\text{Number of coils per pole in main winding} = \frac{\text{Total number of main winding coils}}{\text{Number of poles}} = \frac{8}{4} = 2 \text{ coils/pole}$$

In other words, there will be 8 coils in the main winding forming 4 pole groups. Each group will have two coils under each pole. Pitches assigned will be 5 and 3 for each coil group.

Number of coils per pole in starting winding = 4/4 =1 coil /pole.

There will be 4 groups in starting winding having one coil per group. Pitch assigned will be 5 for the coil.

Summarising the results we have the coil group as given below in Table 1.

Table 1

Winding	Groups	Coil per pole	Pitches	Coil throw	Connection
Main	4	2	5, 3	1-6, 2-5	Whole coil-end to end and start to start
Starting	4	1	5	1-6	Whole coil-end to end and start to start.

Calculation of electrical degrees required for phase splitting

Total electrical degrees = 180 x Total number of poles

= 180x4= 720 electrical degrees

Degrees/slot = 720/24 = 30 electrical degrees

No. of slots required for 90 electrical degrees dis-placement between main and starting winding = 90/30 = 3 slots.

Hence if the main winding starts in, say, slot number one, then the starting winding should be started in 1+3 = 4th slot.

Computing the above information in a winding table we have Table 2.

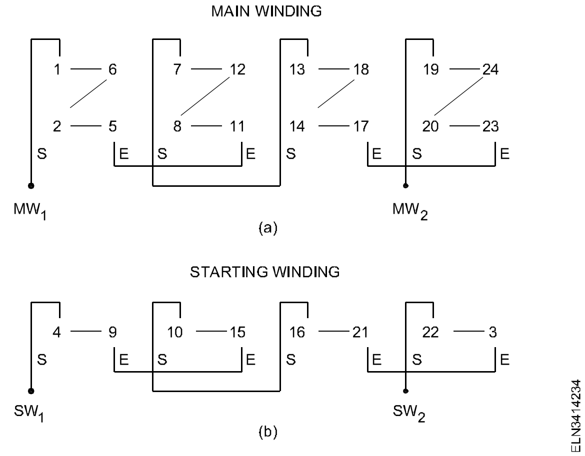
Table 2

Winding table

Winding	Slot position for poles			
	I pole	**II pole**	**III pole**	**IV pole**
Main	1 - 6	7 - 12	13 - 18	19 - 24
	2 - 5	8 - 11	14 - 17	20 - 23
Starting	4 - 9	10 - 15	16 - 21	22 - 3

Remembering whole coil connection the connection diagram is to be drawn as shown in Fig 4.

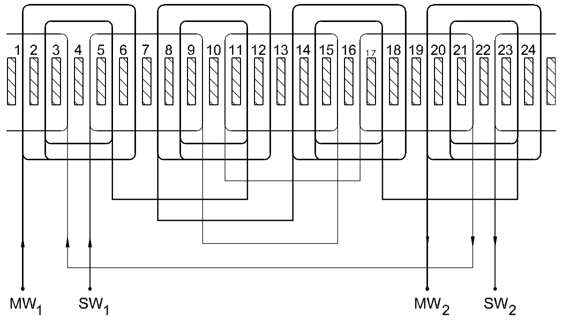
Fig 4



Remember ‘S’ is for starting and ‘E’ for end connection.

Based on the winding table the developed diagram is drawn as shown in Fig 5.

Fig 5



DEVELOPED DIAGRAM OF SINGLE PHASE INDUCTION MOTOR
(HAVING 24 SLOTS, 12 COILS, 4 POLES, BALANCED SINGLE LAYER WINDING)

Example 2

Prepare the winding table, draw the connection and developed diagrams for a single phase, 4-pole, whole coil connected capacitor motor having 36 slots 28 coils (16 coils for main and 12 coils for the starting winding).

Coil per group in main winding 16/4=4 coils/group/poles

Coil per group in starting winding 12/4 = 3 coils/group/ poles

$$\text{Pole pitch} = \frac{\text{Number of slots}}{\text{Number of poles}} - 1 = \frac{36}{4} - 1 = 9 - 1 = 8$$

The coil throw for main winding will be 1-9 and the winding table will be as shown in Table 3.

Table 3

Main winding - winding table

For the same group	**1st pole**	**2nd pole**	**3rd pole**	**4th pole**
1st coil	1 - 9	10 - 18	19 - 27	28 - 36
2nd coil	2 - 8	11 - 17	20 - 26	29 - 35
3rd coil	3 - 7	12 - 16	21 - 25	30 - 34
4th coil	4 - 6	13 - 15	22 - 24	31 - 33

Calculate the degrees/slot.

Total electrical degrees = 180 x 4 = 720 electrical degrees.

Degrees/slot = 720/36 = 20 electrical degrees

For phase displacement of 90 electrical degrees we require 90/20 = 4.5 slots. As it is impossible to start at 4.5 slots, let us start the starting winding in slot No.5.

Hence the coil throw for starting winding will also be 1 - 9, but it starts in the 5th slot. As such the winding table will be as shown in Table 4

Table 4

Starting winding - winding table

For the same group	**1st pole**	**2nd pole**	**3rd pole**	**4th pole**
1st coil	5 - 13	14 - 22	23 - 31	32 - 4
2nd coil	6 - 12	15 - 21	24 - 30	33 - 3
3rd coil	7 - 11	16 - 20	25 - 29	34 - 2

There will be several slots having 2 coil sides and some slots may have single coil side only.

Remembering the whole coil connection, the connection diagram will be as shown in Fig 6.

Based on the above, the developed diagram is shown in Fig 7.

Fig 6

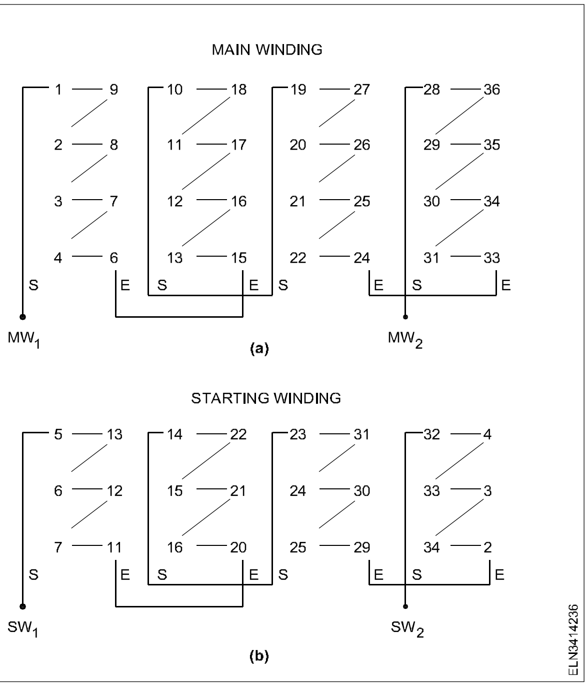
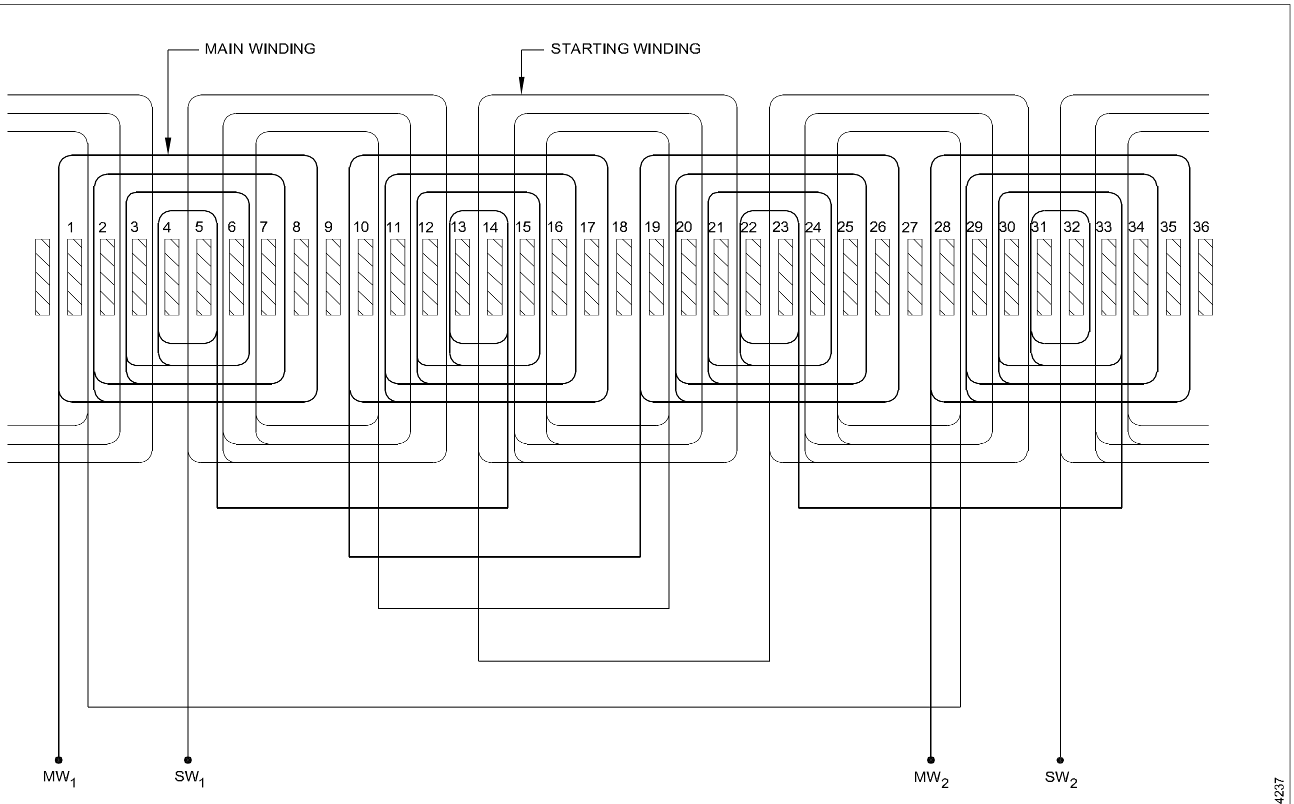


Fig 7



DEVELOPED DIAGRAM OF SINGLE PHASE 4POLE WHOLE COIL CONNECTED CAPACITOR MOTOR HAVING 36 SLOTS 16 COILS FOR MAIN WINDING 12 COILS FOR STARTING WINDING

Capacitor - start, induction - run motor

Objectives: At the end of this lesson you shall be able to

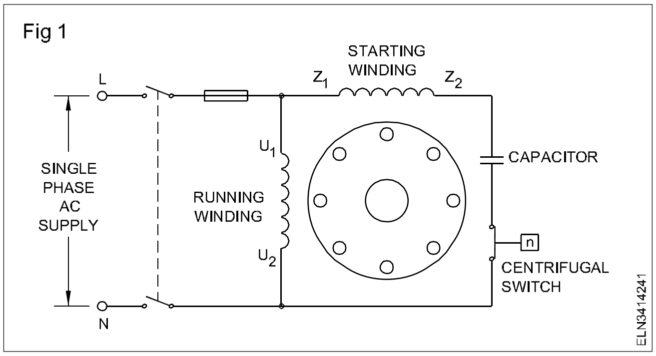
- **explain the construction and working of an AC single phase, capacitor-start, induction-run motor**
- **explain the characteristic and application of a capacitor- start, induction-run motor.**

A drive which requires a higher starting torque may be fitted with a capacitor-start, induction-run motor as it has excellent starting torque as compared to the resistance-start, induction-run motor.

Construction and working: Fig 1 shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is connected across the main supply, whereas the starting winding is connected across the main supply through a capacitor and a centrifugal switch. Both these windings are placed in a stator slot at

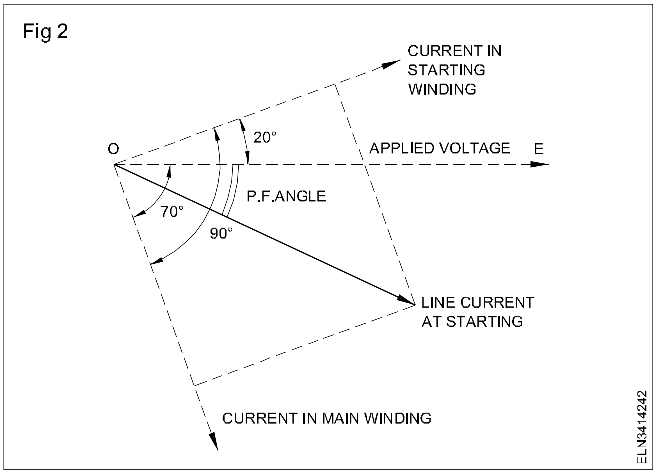
90° electrical degrees apart, and a squirrel cage type rotor is used.

Fig 1



As shown in Fig 2, at the time of starting, the current in the main winding lags the supply voltages by about 70° degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20° degrees.

Fig 2



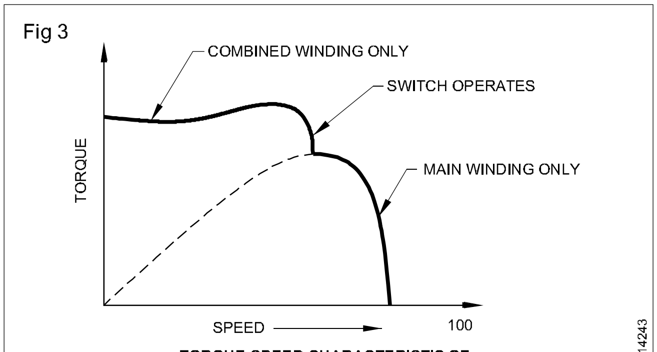
Hence, the phase difference between the main and starting winding becomes near to 90 degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding, and the motor then operates as an induction motor, with only the main winding connected to the supply.

Reversing the direction of rotation: In order to reverse the direction of rotation of the capacitor start, induction-run motor, either the starting or the main winding terminals should be changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of any one of the fields will reverse the torque.

Characteristic: As shown in Fig 2, the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a higher power factor and an excellent starting torque, several times higher than the normal running torque, as shown in Fig 3. The running torque adjusts itself with load by varying inversely with respect to speed as shown in the characteristic curve in Fig 3.

Fig 3



TORQUE-SPEED CHARACTERISTIC OF CAPACITOR START INDUCTION RUN MOTOR

Application: Due to the excellent starting torque and easy direction-reversal characteristic, these machines are used in belted fans, blowers, dryers, washing machines, pumps and compressors.

Capacitors used in single phase capacitor motors

Objectives: At the end of this lesson you shall be able to

- **state the precautions to be followed while using a capacitor in a single phase capacitor motor**
- **explain the methods of testing capacitors.**

A capacitor is a device which can store electrical energy in the form of electrostatic charge. However the main purpose of the capacitor in the single phase motors is to split the phase for producing the rotating magnetic field. In addition, they also draw the leading current, thereby improving the power factor.

Precautions to be followed while using a capacitor in a single phase capacitor motor: Paper or electrolytic capacitors of non-polarized types are used for starting AC capacitor type motors. These capacitors have special marking for use in AC circuits, and will not have polarity marking. Paper or electrolytic capacitors for use in DC circuits have polarity markings. They must not be used in AC circuits as the reversal of AC voltage will heat up the capacitor, producing enormous gas inside the can, thereby blowing it into pieces.

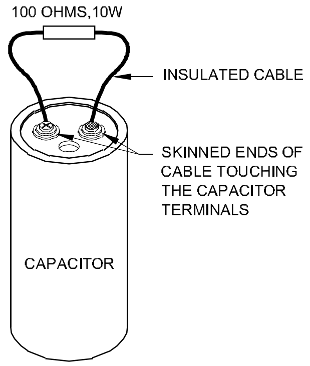
The AC voltage rating inscribed on the capacitor will have two ratings. One for working voltage and another for the maximum value of voltage. Working voltage refers to the normal R.M.S. rating of the supply mains while the maximum rating will be AC peak voltage which will be $\sqrt{2}$ times the rated R.M.S. voltage. Hence, while replacing a capacitor, a careful scrutiny of voltage rating is essential, as otherwise the capacitor may fail and may also explode.

The duty cycle is another important point to be checked. In most of the capacitors, the marking will indicate whether it is for intermittant (short duty) or continuous (long duty) rating. Though continuous rated capacitors can be used for intermittant rating, never an intermittant (short duty) rating capacitor should be used for continuous rating. This has some relation with the centrifugal switch operation, frequency of starting and stopping and load. When the load is heavy or the centrifugal switch is not proper, there will be a chance for the starting winding, along with the capacitor, to be in the main circuit for a long time. In such cases the capacitor, which is intermittant rated, will fail due to overheating. This should be checked when the capacitor fails often in a specified capacitor-start motor.

The capacity of the capacitor, which is given in microfarads, should be the same as is specifed by the manufacturer of the motor. A lower value will result in poorer starting torque and high starting currents, whereas a higher rating may not allow the speed to reach the rated value resulting in the starting winding to be in main line for a long time there by ending in poor operation and efficiency. In capacitor-start, capacitor-run motors, there will be two capacitors. As the starting capacitor will be 5 to 15 times of the rating of the running capacitor, and will also be of intermittant-rated electrolytic type, when compared to the running capacitor, which will be of continuous-rated, oil-filled type. Due care should be taken while connecting these capacitors in the motor, avoiding wrong selection and connection.

While handling a capacitor, due care should be taken to avoid shocks. A good capacitor can hold its charge for several days, and when touched, may give a severe shock. Hence, before touching any terminal of the capacitor, which is in use, the electrical charge should be discharged through a test lamp or through a 100 ohms 10 watts resistor as shown in Fig 1. Direct shorting of the capacitor terminals for discharging should be avoided as far as possible as this results in creating an enormous strain to the inner parts of the capacitor and it may fail.

Fig 1

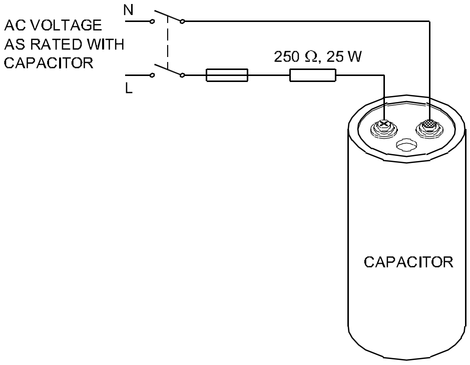


METHOD OD DISCHARGING A CAPACITOR

Method of testing capacitors: Before removing a capacitor from the motor connection for testing, it should be discharged to avoid fatal shocks. The following methods are recommended for testing the large value paper, electrolytic or oil-filled capacitors.

Charge-discharge test: Check the working voltage indicated on the capacitor. If the value is equal or more than that of the usual, single phase voltge, say 240V AC 50 Hz, we can connect it to the supply through a 100 ohms, 25 watts resistor as shown in Fig 2. Preferably, keep the capacitor, while testing on line voltage, inside a covered cardboard box or in a wooden box. Sometimes, if the capacitor is defective, it may explode and cause injury to you. Switch on the circuit for about 3-4 seconds. Then switch `OFF' the supply, and remove the supply terminals carefully with the help of an insulated pliers, without touching the capacitor terminals. Then, short the capacitor terminals with the help of a screwdriver. A bright spark is an indication that the capacitor is working. A dull spark or no spark indicates the capacitor is weak or open. On the other hand, no sparks while touching with the supply terminals indicate that the capacitor is opened. In the case of low capacity capacitors, the spark will be very feeble even if the capacitor is in good condition. Further, this check or the ohmmeter test described in the next para, does not indicate the de-rated value of the capacitor. Hence a capacity check is necessary as will be explained later.

Fig 2

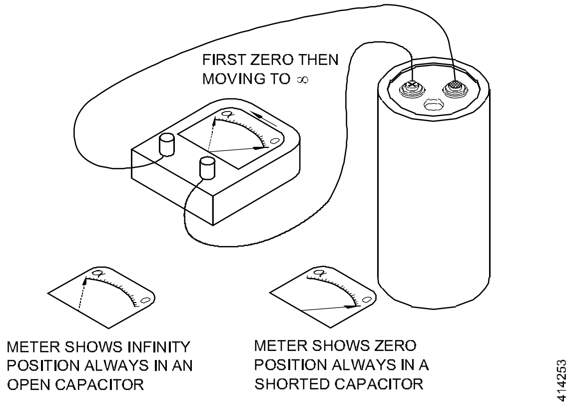


CHARGE TEST ON CAPACITOR

Ohmmeter test: Before using the ohmmeter, the capacitor should be thoroughly discharged to avoid damage to the ohmmeter. Set the range of the ohmmeter to resistance and adjust to zero ohms. Touch the terminals of the capacitor and watch the deflection of the meter. If the needle deflects towards zero and then moves towards infinity, the capacitor is working. Reverse the test leads and test it again, the needle will do the same thing again in a good capacitor. If the capacitor is open, the needle will not go to zero position but will remain in infinity side. On the other hand, in a shorted capacitor, the needle will be in zero position but will not go to infinity side at all. These results are illustrated in Fig 3.

Capacity test: Connection should be as shown in Fig 4. Keep the resistance value maximum at the time of switching `on' to protect the ammeter. Keep the capacitor inside a cardboard or wooden box to avoid injury in case of explosion. The ammeter (I) and voltmeter (V) readings are to be taken when the resistor is completely cut out from the circuit. From the meter readings, the capacity rating of the capacitor in microfarads can be calculated.

Fig 3



TESTING A CAPACITOR WITH A MULTIMETER

$$\text{Capacity of capacitor in } C_F \text{ Farad} = \frac{I}{2\pi FV}$$

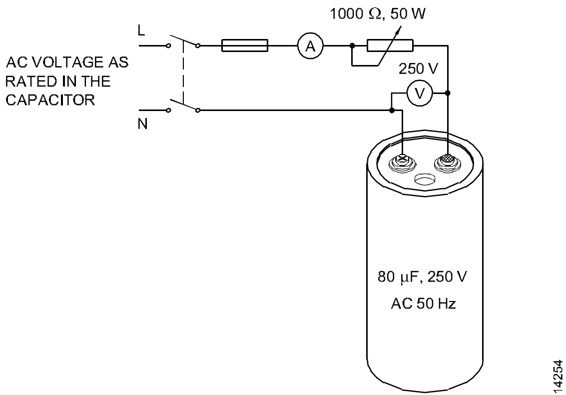
$$\text{Capacity in microfarad } C_{mf} = \frac{I \times 10^6}{2\pi FV}$$

$$= \frac{3182 \times I}{V} \text{ microfarads.}$$

If the capacity is 20 percent more or less than the notified value, replace it.

Insulation test on capacitors: According to BIS 1709-1984 recommendations, the insulation test conducted between the shorted capacitor terminals and the metal can, when measured by a 500V megger/insulation tester, should not be less than 100 megohms. If the can is of insulating material, the measurement could be made between the capacitor terminals and the metal strap holding the can.

Fig 4



CAPACITY TEST ON CAPACITOR

Permanent capacitor motor - capacitor-start, capacitor-run motor and shaded pole motor

Objectives: At the end of this lesson you shall be able to

- **distinguish between the single and two-value, capacitor-start, capacitor-run motors**
- **explain the working of a permanent capacitor motor, state its characteristic and use**
- **explain the working of a capacitor-start, capacitor-run motor, state its characteristic and use.**

Capacitor-start, capacitor-run motors are of two types as stated below.

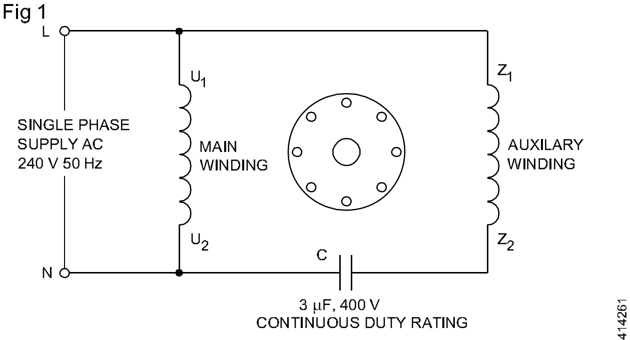
- Permanent capacitor motor (Single value capacitor motor)
- Capacitor-start, capacitor-run motor (Two-value capacitor motor)

Permanent capacitor motor: This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high, while at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the auxiliary winding, and remains so throughout the operation. These capacitors should be of oil-type construction and have continuous duty rating.

To avoid low efficiency, the capacity of the condensers is kept low, which, in turn, brings down the starting torque to about 50 to 80% of the full-load torque.

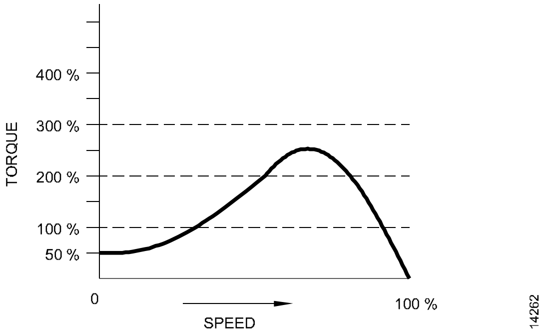
The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction-run motor with low starting torque but with higher power factor, during starting as well as in running.

Fig 1



CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

Fig 2



TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

This motor is most suitable for drives, which require a lower torque during start, easy changes in the direction of rotation, stable load operation and higher power factor during operation. *Examples* - fans, variable rheostats, induction regulators, furnace control and arc welding controls. This motor is cheaper than the capacitor-start, induction-run motor of the same rating.

Capacitor-start, capacitor-run motors: As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque, and their power factor during starting is high. However, their running torque is not good, and their power factor, while running, is low. They also have lesser efficiency and cannot take overloads.

These problems are eliminated by the use of a two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting, whereas a smaller capacitor of oil-filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start induction-run motor, with the exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

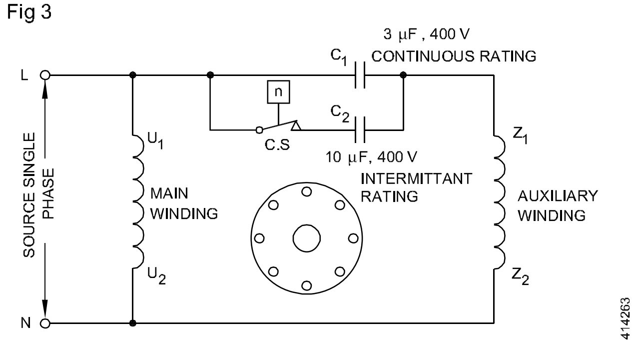
The starting capacitor which is of short-duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

Characteristic

The torque-speed characteristic of this motor is shown in Fig 5. This motor has the following advantages.

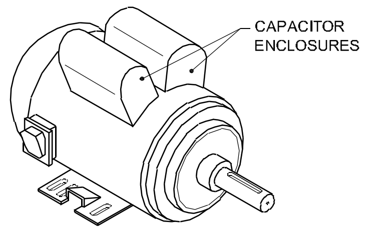
- The starting torque is 300% of the full load torque.
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running P.F. are good.
- Highly efficient running.
- Extremely noiseless operation.
- Can be loaded up to 125% of the full-load capacity.

Fig 3



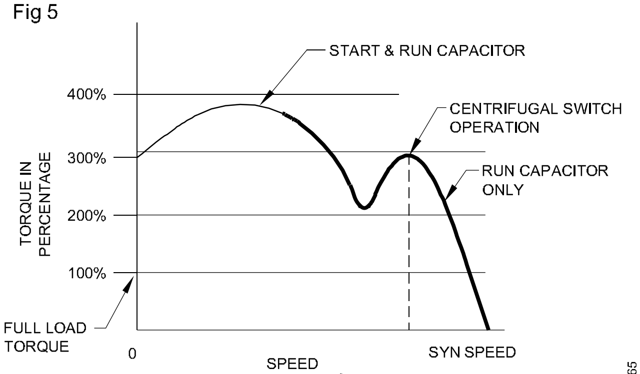
SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 4



CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 5



TORQUE-SPEED CHARACTERSTIC OF CAPACITOR-START CAPACITOR-RUN MOTOR

Application

These motors are used for compressors, refrigerators, air-conditioners etc. where the duty demands a higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction- run motors of the same capacity.

The shaded pole motor

Objectives: At the end of this lesson you shall be able to
- **explain the construction of a shaded pole motor and their functions**
- **explain the principle of working of the shaded pole motor**
- **explain the characteristic of the shaded pole motor and its application.**

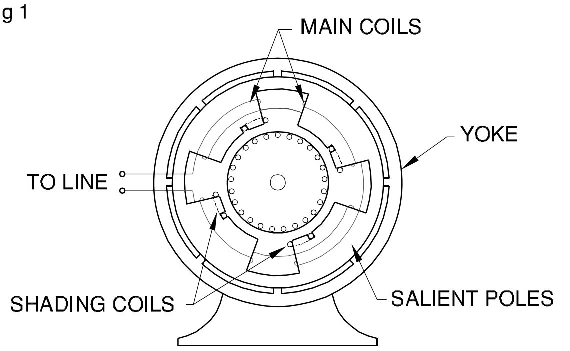
Shaded pole motor (construction)

The motor consists of a yoke with salient poles as shown in Fig 1 and it has a squirrel cage type rotor.

Construction of a shaded pole

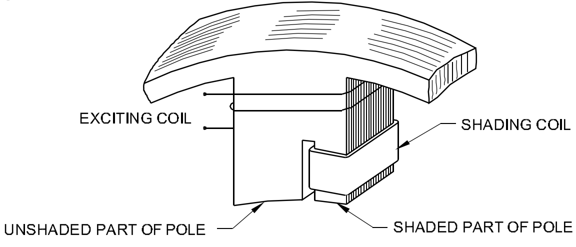
A shaded pole made up of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole. Around the smaller portion of the pole, a short circuited copper ring is placed which is called the shading coil and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig 2.

Fig 1



A SINGLE-PHASE MOTOR WITH SHADING COILS FOR STARTING

Fig 2



A TYPICAL SHADED-POLE CONSTRUCTION

Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is given to the exciting coil the magnetic axis shifts from the unshaded part of the pole to the shaded part as explained in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole. This magnetic axis which is moving, cuts the rotor conductors, and hence, a rotational torque is developed in the rotor. Due to this torque, the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

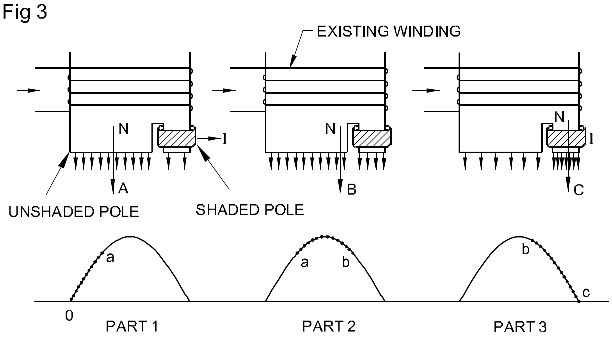
Shifting of the magnetic flux from the unshaded part to the shaded part could be explained as stated below.

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron core it will have high inductance.

When the exciting winding is connected to an AC supply a sine wave current passes through it. Let us consider the positive half cycle of the AC current as shown in Fig 3. When the current raises from 'zero' to point 'a', the change in current is very rapid (fast), hence induces an emf in the shading coil by the principle of Faraday's laws of electromagnetic induction. The induced emf in the shading coil produces a current which in turn produces a flux which is in opposite direction to the main flux in accordance with Lenz's law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig 3 in the same form of flux arrows. This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow (longer one) in part 1 of Fig 3. On the other hand as shown in Part 2 of Fig 3 when current rises from point 'a' to 'b' the change in current is slow, the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shaded portion. This makes the magnetic axis to be shifted to the centre of the whole pole as shown by the arrow in part 2 of Fig 3.

In the next instant, as shown in part 3 of Fig 3, when the current falls from 'b' to 'c', the change in current is fast and its value of change is from maximum to minimum. Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the centre of the shaded part as shown by the arrow in part 3 of Fig 3.

Fig 3

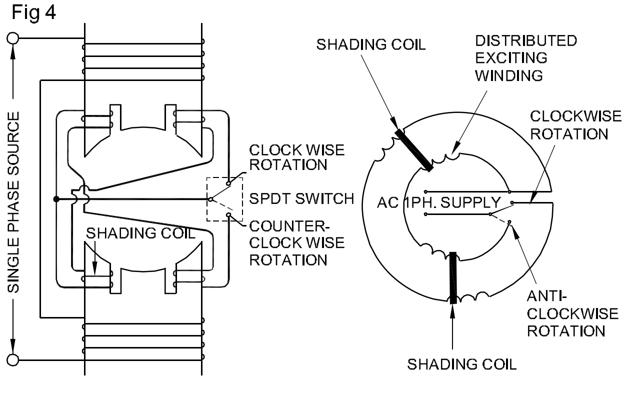


CHANGE OF MAGNETIC AXIS SHOWN FROM POSITION A TO C

From the above explanation it is clear that the magnetic axis shifts from the unshaded part to the shaded part which is more or less physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing the direction. Two such types are shown in Fig 4. In a) the double set of shading coils method is shown and in b) the double set of exciting winding method is shown.

Fig 4



a) DOUBLE SET OF SHADING COILS METHOD

b) DOUBLE SET OF EXISTING WINDING METHOD

METHODS FOR REVERSING SHADED-POLE MOTORS-TWO-POLE CONSTRUCTION

Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motors as stated below:

- low starting torque
- very little overload capacity

- low efficiency.

The efficiency varies from 5% to 35% only in these motors.

Because of its low starting torque, the shaded pole motor is generally used for small table fans, toys, instruments, hair dryers, advertising display systems and electric clocks etc.

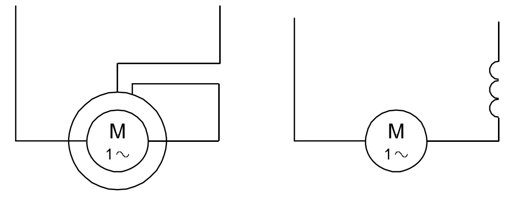
Universal motor

Objectives: At the end of this lesson you shall be able to
- **compare a universal motor with the DC series motor with respect to its construction**
- **explain the operation, characteristic and application of a universal motor**
- **explain the method of changing the direction of rotation**
- **describe the methods of controlling the speed of a universal motor.**

Comparison between a universal motor and a DC series motor: A universal motor is one which operates both on AC and DC supplies. It develops more horsepower per Kg. weight than any other AC motor, mainly due to its high speed. The principle of operation is the same as that of a DC motor. Though a universal motor resembles a DC series motor, it requires suitable modification in the construction, winding and brush grade to achieve sparkless commutation and reduced heating when operated on AC supply, due to increased inductance and armature reaction.

A universal motor could, therefore, be defined as a series or a compensated series motor designed to operate at approximately the same speed and output on either direct current or single phase alternating current of a frequency not greater than 50 Hz, and of approximately the same RMS voltage. Universal motor is also named as AC single phase series motor, and Fig 1 shows the multi-line representation according to B.I.S. 2032, Part IV.

Fig 1



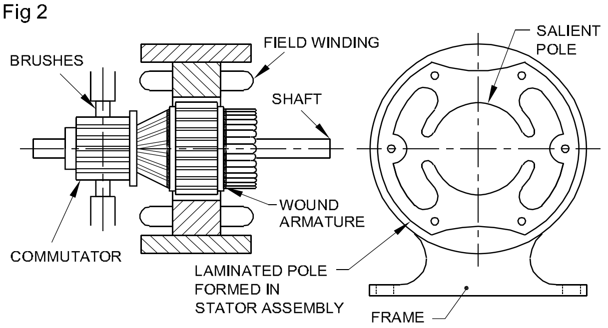
SIMPLIFIED MULTI-LINE REPRESENTATION

COMPLETE MULTI-LINE REPRESENTATION

MULTILINE REPRESENTATION OF AC SINGLE PHASE SERIES MOTOR (BIS 2032-PART IV.)

The main parts of a universal motor are an armature, field winding, stator stampings, frame, end plates and brushes as shown in Fig 2.

Fig 2



PARTS OF A UNIVERSAL MOTOR

The increased sparking at the brush position in AC operation is reduced by the following means.

- Providing compensating winding to neutralize the armature M.M.F. These compensating windings are either short-circuited windings or windings connected in series with the armature.
- Providing commutating inter-poles in the stator and connecting the inter-pole winding in series with the armature winding.
- Providing high contact resistance brushes to reduce sparking at brush positions.

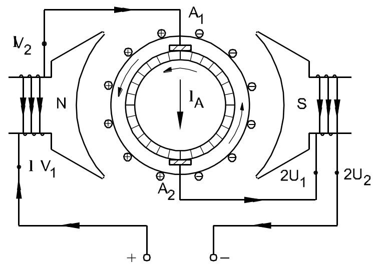
The table given below indicates the differences between a universal motor and a DC series motor.

Universal motor	**DC series motor**
Can run on AC and DC supplies.	Can run smoothlly on DC supply. However when connected to AC supply, it produces heavy sparks at brush positions and beomes hot due to armature reaction and rough commutation.
Compensating winding is a must for large machines.	Does not require compensating winding.
Inter-poles provided in larger machines.	Does not require inter-poles normally.
High resistance grade brushes are necessary.	Normal grade brushes will suffice.
Air gap is kept to the minimum.	Normal air gap is maintained.

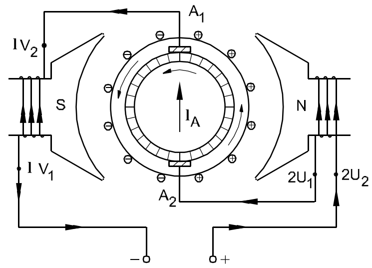
Operation: A universal motor works on the same principle as a DC motor, i.e. force is created on the armature conductors due to the interaction between the main field flux and the flux created by the current-carrying armature conductors. A universal motor develops unidirectional torque regardless of whether it operates on AC or DC supply. Fig 3 shows the operation of a universal motor on AC supply. In AC operation, both field and armature currents change their, polarities, at the same time resulting in unidirectional torque.

Characteristic and application: The speed of a universal motor is inversely proportional to the load, i.e. speed is low at full load and high on no load. The speed reaches a dangerously high value due to low field flux at no loads. In fact the no-load speed is limited only by its own friction and windage losses. As such these motors are connected with permanent loads or gear trains to avoid running at no-load, thereby avoiding high speeds.

Fig 3



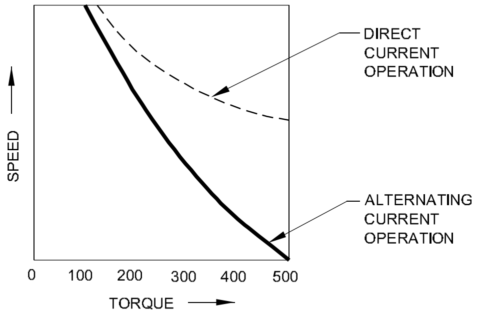
a) INSTANTANEOUS AC POLARITY IN +VE HALF OF THE CYCLE



b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

Fig 4 shows the typical torque speed relation of a universal motor, both for AC and DC operations. This motor develops about 450 percent of full load torque at starting, as such, higher than any other type of single phase motor. Universal motors are used in vacuum cleaners, food mixers, portable drills and domestic sewing machines.

Fig 4



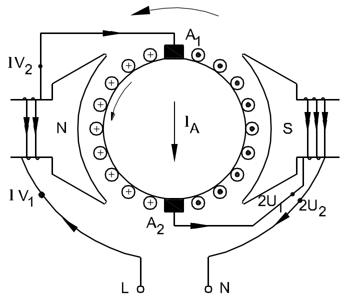
TORQUE-SPEED CHARACTERISTIC OF A UNIVERSAL MOTOR

Change of rotation: Direction of rotation of a universal motor can be reversed by reversing the flow of current through either the armature or the field windings. It is easy to interchange the leads at the brush holders as shown in Fig 5.

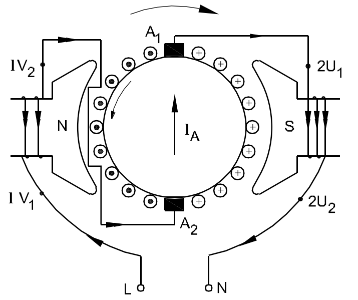
However, when the armature terminals are interchanged in a universal motor having compensating winding, care should be taken to interchange the compensating winding also to avoid heavy sparking while running.

Speed control of universal motor: The following methods are adopted to control the speed of a universal motor.

Fig 5



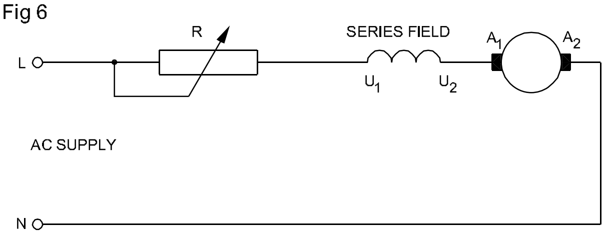
(a) DIRECTION OF ROTATION: ANTICLOCKWISE



b) DIRECTION OF ROTATION:CLOCKWISE BY CHANGING ARMATURE TERMINALS

Series resistance or applied voltage control method: The motor speed is controlled by connecting a variable resistance in series with the motor. Foot-pedal operated sewing machines incorporate such a control. Fig 6 shows the connections.

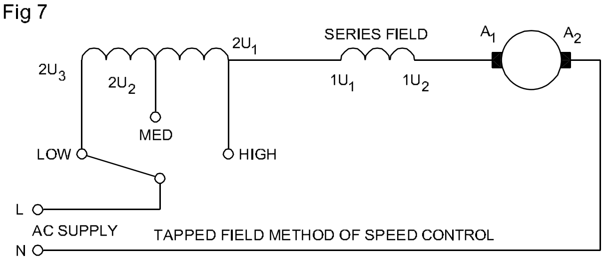
Fig 6



SPEED CONTROLS BY APPLIED VOLTAGE CONTROL

Tapped field method: In this method, the field winding is tapped at 2 or 3 points and the speed is controlled by the varying field MMF. Fig 7 shows such a connection. Most of the domestic food mixers employ this method of speed control.

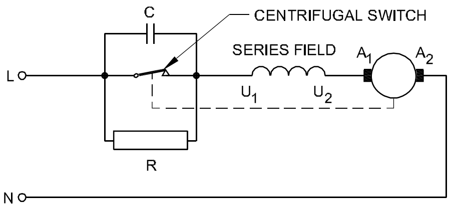
Fig 7



TAPPED FIELD METHOD OF SPEED CONTROL

Centrifugal switch method: A centrifugal mechanism adjusted by an external lever is connected in series with the motor as shown by Fig 8. If the speed reaches beyond a certain limit, according to the lever setting, the centrifugal device opens the contacts and inserts the resistance R in the circuit, which causes the motor speed to decrease. When the motor speed falls and reaches a predetermined value, the centrifugal switch contact closes, the motor gets reconnected to the supply and the speed rises. Some advanced type of food mixers employ this sort of speed control. A capacitor is used across the centrifugal switch to reduce the switching spark and to suppress the radio interference. Apart from the above methods of speed control, a thyristor is used in certain food mixers to control the speed electronically.

Fig 8



CENTRIFUGAL SWITCH MECHANISM FOR SPEED CONTROL

Troubleshooting of universal motor

Objectives: At the end of this lesson you shall be able to

- **state the advantages and disadvantages of universal motor**
- **explain the method of troubleshooting in universal motor.**

As the name suggest universal motors can operate on either AC or DC supply. By a compromise of design fractional horse power motors may be built to operate satisfactorily on either 240 V 50 Hz AC or direct current at 240 volts. Such motors are known as universal motors.

Advantages of universal motors

- These motors develop high starting torque and have the ability to adjust the torque and speed proportionally when loaded.
- Universal motors can operate on direct current or AC supply.
- Tapped fields provide an easy method of controlling speed.

Disadvantages of universal motors

- Since these motors operate at very high speed upto 40,000 rpm considerable air noise is present.
- Because of the large increase in the power input under stalled onditions and the loss of motor cooling, they can burn out within a short time when overloaded too much.
- Useful for intermittent duty application only.
- They produce radio and television interference.

Troubleshooting chart for universal motor: Table 1 gives possible faults, which occur in universal motor, their causes, mode of testing and suggested rectification. As a universal motor is similar in design to the DC machine, trainees are advised to refer trouble shooting chart pertaining to DC machines also.

Table 1

Troubleshooting chart for universal motor

Trouble	Causes	Mode of testing	Rectification
Motor fails to start	a) No voltage due to blown fuse	a) Test by test lamp or voltmeter	a) Replace the blown fuse.
	b) Open overload relay of starter.	b) Test by test lamp or voltmeter	b) Reset or rectify the overload relay contact
	c) Low voltage due to improper supply voltage.	c) Test by voltmeter.	c) Rectify the loose connections at the switch & fuse.
	d) Open circuited field or armature.	d) Test by ohmmeter or Megger.	d) If possible join properly or replace the winding.
	e) Improper contact of carbon brushes with commutator.	e) Visual inspection and test by test lamp	e) Adjust for proper contact of carbon brush with commutator.
	f) Dirty commutator.	f) Visual inspection and test by test lamp.	f) Clean by buffing the commutator using smooth sandpaper.
Shock to the operator	a) Grounded field or armature circuit due to weak insulation.	a) Test by Megger or test lamp.	a) Rectify the defect and apply shellac varnish to armature and field winding

Trouble	Causes	Mode of testing	Rectification
	b) Insufficent earth.	b) Test by Megger or test lamp.	b) Provide proper earth to the motor.
Over heating of motor	a) Shorted coil of field or armature.	a) Visual inspection and resistance measurement	a) Rewind field or armature coil which is shorted
	b) Tight bearing due to worn out or locked bearing.	b) Test the shaft for free rotation. Check the shield for over heating.	b) Clean the bearings and check for damage. Replace bearing if necessary.
	c) Heavy sparking at commutator due to pitted commutator.	c) By visual inspection.	c) Clean the commutator and true the surface of the commutator.
	d) Shorted commutator.	d) Test the armature by growler.	d) Replace or repair the commutator
	e) Grounded field or armature.	e) Test by Megger.	e) Repair or rewind the field or armature.
Humming sound. Lack of torque due to overheat	a) Short circuited field.	a) Test by ohmmeter.	a) Rewind the field winding.
	b) Shorted armature coil.	b) Test by Growler.	b) Rewind shorted armature winding.

Repulsion motor

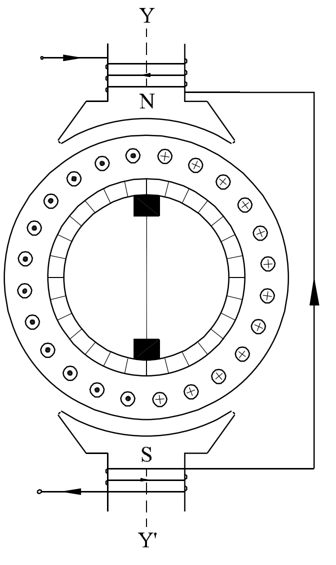
Objectives: At the end of this lesson you shall be able to
- **explain the principle, working, types and construction of the repulsion motor**
- **explain the characteristic and application of the repulsion motor.**

Repulsion motors, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, abilitiy to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

The repulsion principle: The principle of torque production in a repulsion motor could be explained as follows. Fig 1 shows a two-pole motor with its magnetic axis vertical. An armature, having a commutator which is short-circuited through the brushes, is placed in the magnetic field. When the stator winding is connected to an AC supply, it produces an alternating magnetic field. Assume that at an instant, a north pole at the top and a south pole at the bottom are produced by this alternating magnetic field. Because of this a voltage will be induced in all the rotor conductors by the transformer action. The direction of current in the conductors will be in accordance with Lenz's law such that they create a north pole at the top just below the stator north pole, and a south pole at the bottom just at the top of the stator south pole to oppose the induction action. Hence the stator poles and the rotor poles will oppose each other in the same line. There will, therefore, be no torque developed due to the abscence of the tangential component of the torque.

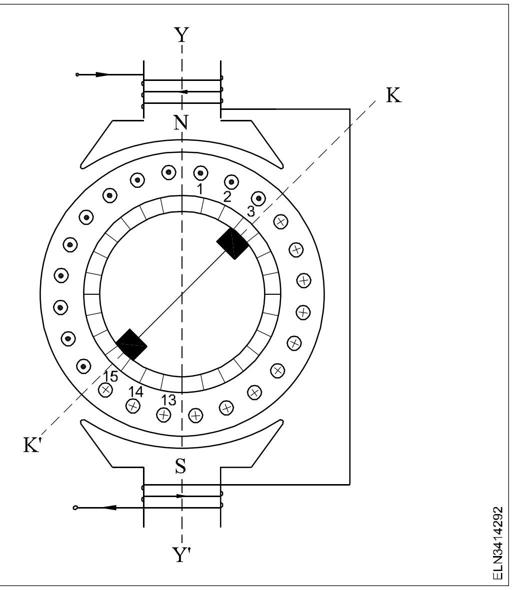
Let us assume that the short-circuited brush-axis is moved to a position as in Fig 2. Due to the present brush position, the magnetic axis of the armature is no longer co-linear with respect to the vertical axis of the main poles.

Fig 1



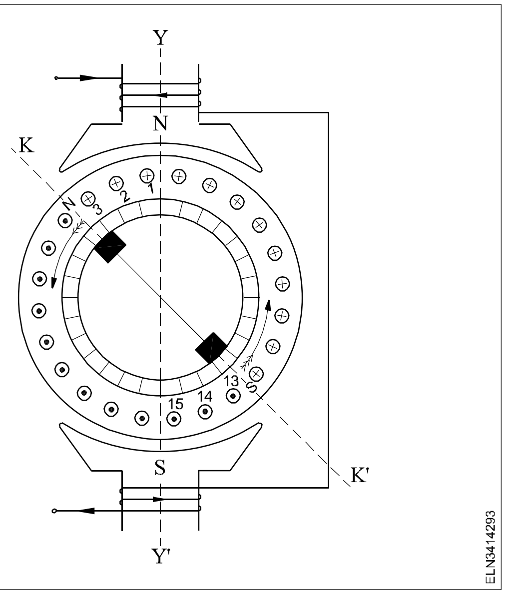
It will now be along the axis `KK' with north and south poles shifted around by an angle `A°' depending upon the shifting of the brushes. In this position, the direction of current in the conductors 1,2,3 and 13,14,15 is reversed, and hence, the armature becomes an electromagnet having the north (N) and south (S) poles in the `KK' axis just at an angle of `A°' from the main magnetic axis. Now there is a condition that the rotor north pole will be repelled by the main north pole, and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this motor is named as repulsion motor.

Fig 2



Direction of rotation : To change the D.O.R. of this motor, the brush-axis needs, to be shifted from the right side as shown in Fig 2 to the left side of the main axis in a counter-clockwise direction as shown in Fig 3.

Fig 3



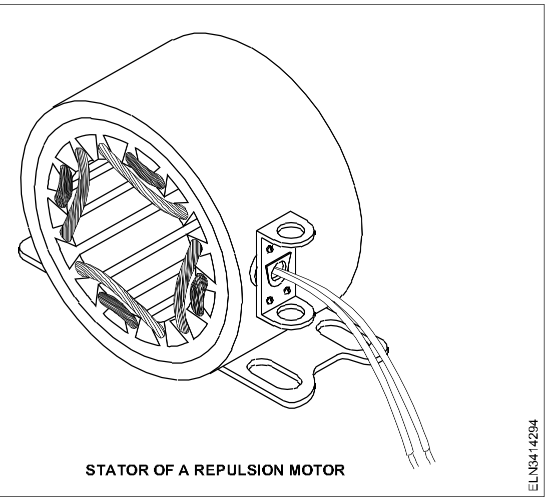
This working principle applies equally well for all types of repulsion motors having distributed windings in the stator.

Types of repulsion motors : There are four types of induction motors as stated below.

- Repulsion motor
- Compensated-repulsion motor
- Repulsion-start, induction-run motor
- Repulsion-induction motor

Construction: The construction of stators is the same in all the types, except for certain variation in the compensated-repulsion motor. In general, for all types of repulsion motors the stator winding is of the distributed, non-salient pole type, housed in the slots of the stator, and only two terminals as shown in Fig 4 are brought out. It is wound for four, six or eight poles. The rotor for each type of motor is different, and will be explained under each type.

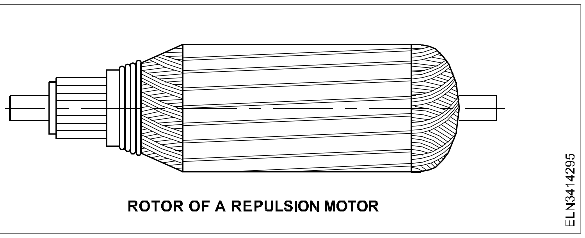
Fig 4



STATOR OF A REPULSION MOTOR

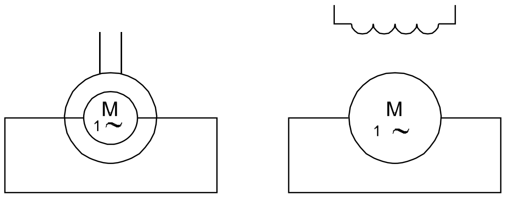
Repulsion motor: The general construction of the repulsion motor is similar to the one explained under the `Repulsive principle'. However the rotor of the repulsion motor is like a DC armature that is as shown in Fig 5, having a distributed lap or wave-winding. The commutator may be similar to the DC armature, that is axial type, having commutator bars in parallel to the shaft or radial or vertical bars on which brushes ride horizontally. The shorted brush position can be changed by a lever attached to the rocker-arm. The B.I.S. symbol for the repulsion motor is shown in Fig 6.

Fig 5



ROTOR OF A REPULSION MOTOR

Fig 6



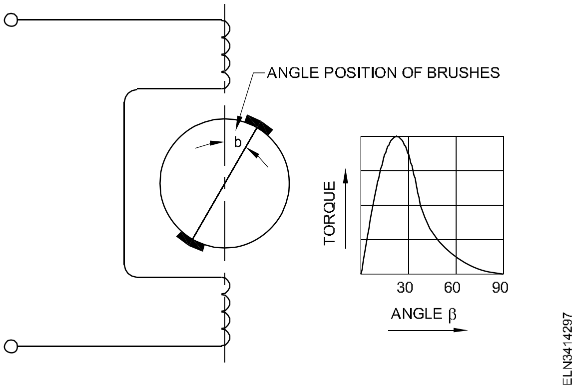
SIMPLIFIED MULTI LINE REPRESENTATION

COMPLETE MULTI LINE REPRESENTATION

REPULSION MOTOR

As explained earlier, the torque developed in a repulsion motor will depend upon the amount of brush-shaft as shown in Fig 7, whereas the direction of shift decides the direction of rotation. Further, the speed also depends upon the amount of brush-shift and the magnitude of the load. The torque speed characteristic of the motor is shown in Fig 9.

Fig 7

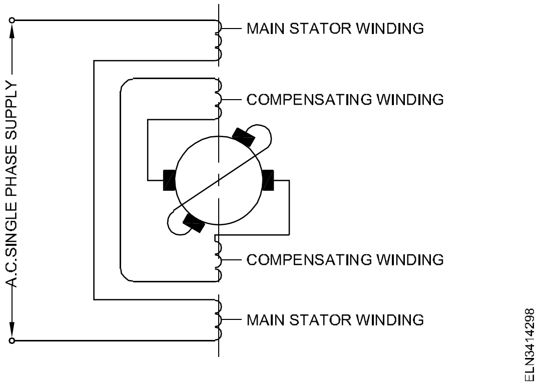


Relationship between the torque and brush-position angle in a repulsion motor

Though the starting torque varies from 250 to 400 percent of the full load torque, the speed will be dangerously high during light loads. This is due to the fact that the speed of the repulsion motor does not depend on frequency or number of poles but depends upon the repulsion principle. Further, there is a tendency of sparking in the brushes at heavy loads, and the P.F. will be poor at low speeds. Hence, the conventional repulsion motor is not much used and the other three improved types are popular.

Compensated repulsion motor : The rotor of the compensated repulsion motor is similar to that of the repulsion motor, except that there is another set of brushes placed in the middle position between the usual short circuited brushes. On the other hand, the stator has an additional winding, called the compensatory winding as shown in Fig 8.

Fig 8

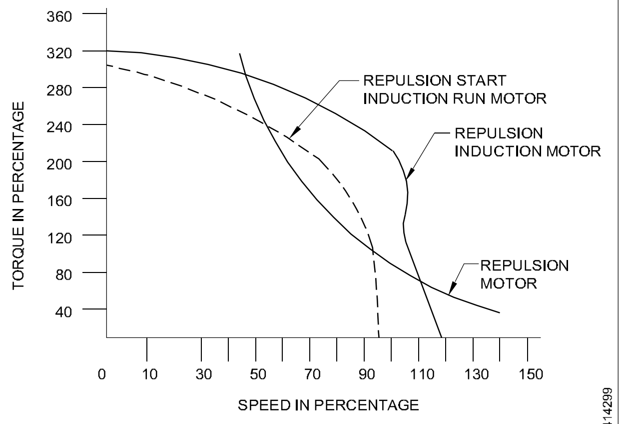


The purpose of the compensating winding is to improve the power factor and to have better speed regulation. This compensating winding is housed in the inner slots of the stator and connected in series with the armature.

Repulsion-start, induction-run motor : The rotor of this motor is similar to that of a repulsion motor but the commutator and the brush mechanism are entirely different. This motor starts like a repulsion motor, and after attaining about 75% of the rated speed, there is a necklace-type shorting mechanism, activated by a centrifugal force which short circuits the entire commutator. From then on, this motor works as an induction motor with a short-circuited rotor (armature). After the commutator is short-circuited, in some machines, there is a special mechanism to lift the brushes to avoid wear and tear of the brushes and the commutator.

The torque speed characteristic of this motor is shown in Fig 9.

Fig 9



SPEED LOAD CHARACTERISTIC OF REPULSION MOTOR

Repulsion-induction motor : The rotor of this motor has a squirrel cage winding deep inside the rotor, in addition to the usual winding. The brushes are short-circuited, and they continuously ride over the commutator. Generally the starting torque is developed in the wound part of the rotor, while the running torque is developed in the squirrel cage winding. The speed torque characteristic is shown in Fig 9. This develops a little less torque, say about 300% of the full load torque, and can start with a load and run smoothly on no load. This motor has its starting characteristic similar to DC compound motor, and running characteristic similar to an induction motor.

APPLICATION: In these motors the average starting torque varies from 300-400 percent of the full load torque, and these motors are preferred in places where the starting period is of comparatively long duration, due to heavy load. These motors are used in refrigerators, air-compressors, coil winders, pertrol pumps, machine tools, mixing machines, lifts and hoists, due to their excellent starting torque, ability to withstand sustained overloads, good speed regulation and easy method of reversal of direction of rotation.

Stepper motor

Objectives: At the end of this exercise you shall be able to
- **state the basic theory and open loop operation of stepper motor**
- **list and explain the each type of stepper motor**
- **state the advantages, disadvantages and application of stepper motor.**

Basic theory

A stepper motor is basically a synchronous motor. There are no brushes. It is an electromechanical device converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of pulses applied.

This device does not rotate continuously, but it rotates in the form of pulses. There are different types of motors available based on the stepper rotation, manufactured with steps per revolution of 12,24,72,144,180 and 200 in stepping angles of 300, 150, 50, 2.50, 20 and 1.80 per steps.

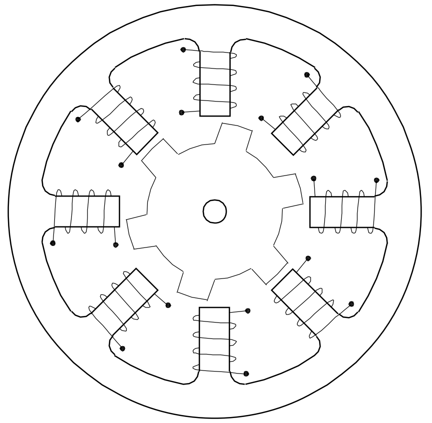
Open loop opearation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. The position is known simply by keeping track of the input step pulses.

Stepper motor types: There are three basic stepper motor types. They are

1 Variable-reluctance (Fig 1)

Fig 1



2 Permanent-magnet (Fig 2)

3 Hybrid (Fig 3)

1 Variable-reluctance (VR): This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view (Fig 1) shows a typical VR stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

Fig 2

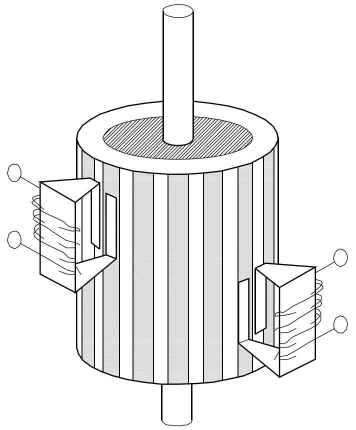
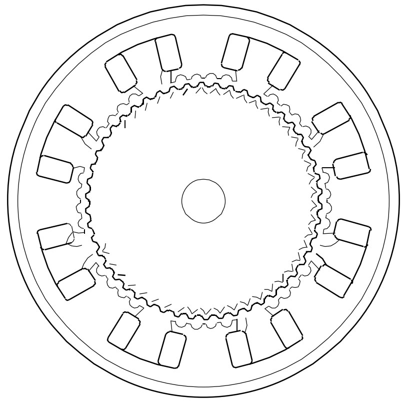


Fig 3



2 Permanent magnet (PM): Often referred to as a "tin can" or "can stock" motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.50 to 150 (48 - 24 steps/ revolution) PM motors as the name implies have permanent magnets added to the motor structure (Fig 2). The rotor no longer has teeth as with VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

3 Hybrid (HB): The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.60 to 0.90 (100 - 400 steps per revolution) The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft (Fig 3). The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the airgap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types.

Advantages and disadvantages

Advantages

1 The rotation angle of the motor is proportional to the input pulse.

2 The motor has full torque at stand still (if the windings are energized)

3 Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3-5% of a step and this error is non cumulative from one step to the next.

4 Excellent response to starting/stopping/reversing.

5 Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing

6 The motor's response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7 It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8 A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1 Resonances can occur if not properly controlled

2 Not easy to operate at extremely high speeds.

Application

There are different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

Hysteresis motor

Objectives: At the end of this lesson you shall be able to
- **state the construction details of hysteresis motor**
- **explain the working principle of hysteresis motor**
- **state the torque-speed characteristics**
- **list the advantages, disadvantages and application of hysteresis motor.**

A hysteresis motor is a synchronous motor without salient (or projected) poles and without dc excitation which starts by the hysteresis losses induced in its hardened steel secondary member by the revolving filed of the primary and operates normally at synchronous speed and runs on hysteresis torque because of the retentivity of the secondary core.

It is a single-phase motor whose operation depends upon the hysteresis effect i.e., magnetization produced in a ferromagnetic material lags behind the magnetizing force.

Construction:

It consists of: (i) Stator

(ii) Rotor

i) Stator: A stator designed to produce a synchronously-revolving field from a single-phase supply. The stator carries main and auxiliary windings (which is called split phase hysteresis motor) so as top produce rotating magnetic field as shown in Fig 1. The stator can also be shaded pole type (which is called shaded pole hysteresis motor) as shown in Fig 2.

ii) Rotor: The rotor of hysteresis motors are made with magnetic material of high hysteresis losses. i.e. whose hysteresis loop area is very large as shown in Fig 3. The rotor does not carry any winding or teeth. It consists of two or more outer rings and crossbars, all made of specially selected heat-treated hard steel. The type of Steel that has a very large hysteresis loop is chosen. When a rotating filed moves past the rotor, this hysteresis effect causes a torque to be developed and the motor starts to run. As synchronous speed is approached, the crossbars presents a low reluctance path to the flux thereby setting up permanent pole in the rotor and causing the motor to continue to rotate at synchronous speed.

Fig 1

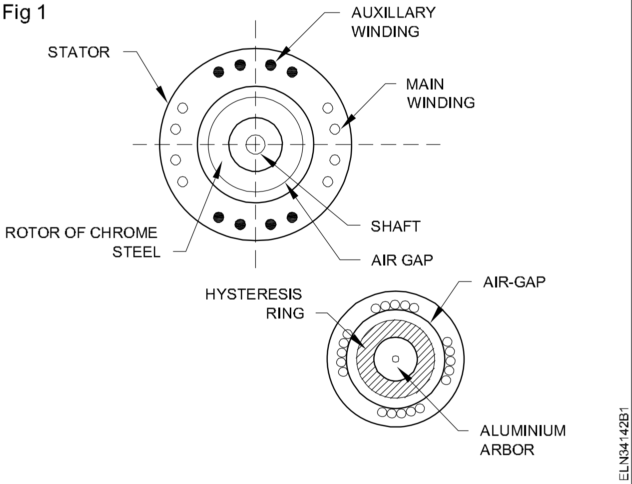


Fig 2

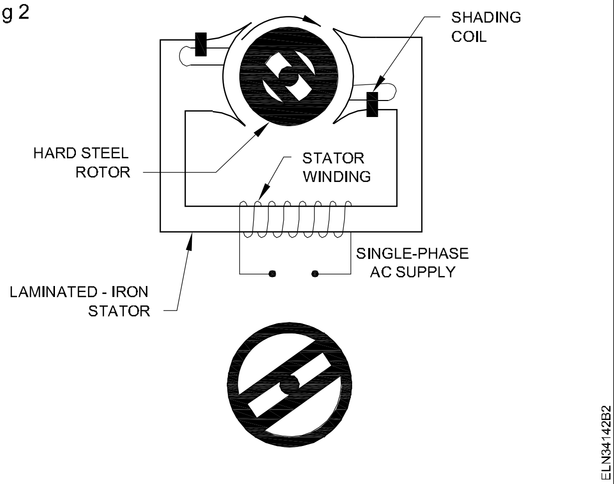
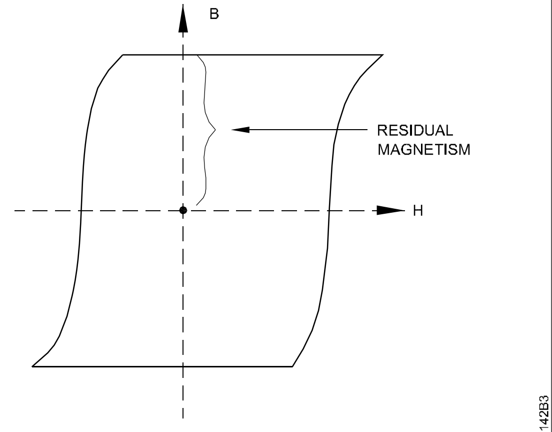


Fig 3



HYSTERESIS LOOP FOR ROTOR MATERIAL

Working principle

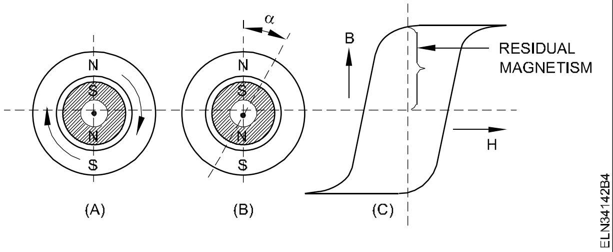
When stator is energized, it produces rotating magnetic field. The main and auxiliary, both the windings must be supplied continuously at start as well as in running conditions so as to maintain the rotating magnetic field. The rotor, initially, starts to rotate due to eddy-current torque and hysteresis torque developed on the rotor. Once the speed is near about the synchronous, the stator pulls rotor into synchronism.

In such case, as relative motion between stator field and rotor field vanishes, so the torque due to eddycurrents vanisehes. When the rotor is rotating in the synchronous speed, the stator revolving field flux produces poles on the rotor as shown in Fig 4.

Due to the hysteresis effect, rotor pole axis lags behind the axis of rotating magnetic field. Due to this, rotor poles get attracted towards the moving stator poles. Thus rotor gets subjected to torque called hysteresis torque. This torque is constant at all speeds.

When the stator field moved forward, due to high residual magnetism (i.e. retentivity) the rotor pole strength remains maintained. The hyteresis torque is independent of the rotor speed. The high retentivity ensures the continuous magnetic locking between stator and rotor. Only hysteresis torque is present which keeps rotor running at synchronous speed.

Fig 4

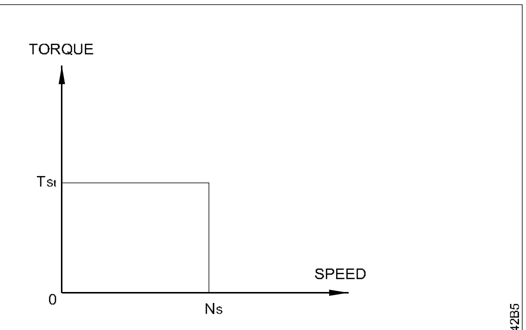


Hysteresis losses are produced in the rotor of a hysteresis motor is proportional to the area of hysteresis loop. These losses are dissipated as heat in the rotor.

Torque-Speed Characteristics

The starting and running torque is almost equal in this type of motor. As stator carries mainly the two-windings its direction can be reversed interchanging the terminals of either main winding or auxiliary winding. The torque-speed characteristics is as shown in Fig 5.

Fig 5



TORQUE - SPEED CHARACTERISTICS OF HYSTERESIS MOTOR

Advantages

The advantages of hysteresis motor are:

1 As rotor has no teeth, no winding, there are no mechanical vibrations.

2 Due to absence of vibrations, the operation is quiet and noiseless.

3 Suitability to accelerate inertia loads. 4. Possibility of multispeed operation by employing gear train.

Disadvantages

The disadvantages of hysteresis motor are:

1 The output is about one-quarter that of an induction motor of the same dimension.

2 Low efficiency

3 Low power factor

4 Low torque

5 Available in very small sizes

Applications

Due to noiseless operation it is used in sound recording instruments, sound producing equipments, high quality record players, electric clocks, teleprinters, timing devices etc.

Reluctance motor

Objectives: At the end of this lesson you shall be able to
- **list out the types of reluctances motor**
- **explain the operation of reluctance motor**
- **list out the application of reluctance motor.**

A reluctance motor is a type of electric motor that induces non-permanent magnetic poles on the ferromagnetic rotor. Torque is generated through the phenomenon of magnetic reluctance.

There are various types of reluctance motor:

- Synchronous reluctance motor
- Variable reluctance motor
- Switched reluctance motor
- Variable reluctance stepping motor.

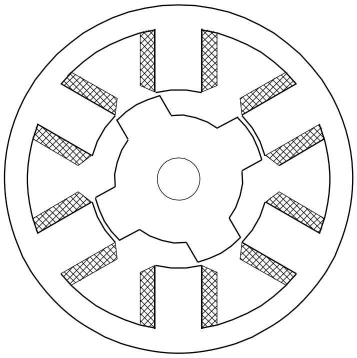
Reluctance motors can deliver very high power density at low cost, making them ideal for many applications. Disadvantages are high torque ripple (the difference between maximum and minimum torque during one revolution) when operated at low speed, and noise[caused by torque ripple

Operation of reluctance motor

The stator consists of multiple projecting (salient) electromagnet poles, similar to a wound field brushed DC motor (Fig 1). The rotor consists of soft magnetic material, such as laminated silicon/steel, which has multiple projections acting as salient magnetic poles through magnetic reluctance. For switched reluctance motors, the number of rotor poles is typically less than the number of stator poles, which minimizes torque ripple and prevents the poles from all aligning simultaneously-a position which cannot generate torque.

When a rotor pole is equidistant from the two adjacent stator poles, the rotor pole is said to be in the "fully unaligned position". This is the position of maximum magnetic reluctance for the rotor pole. In the "aligned position", two (or more) rotor poles are fully aligned with two (or more) stator poles, (which means the rotor poles completely face the stator poles) and is a position of minimum reluctance.

Fig 1



RELUCTANCE MOTOR 6 STATOR & 4 ROTOR

When a stator pole is energized, the rotor torque is in the direction that will reduce reluctance. Thus the nearest rotor pole is pulled from the unaligned position into alignment with the stator field (a position of less reluctance). (This is the same effect used by a solenoid, or when picking up ferromagnetic metal with a magnet.) In order to sustain rotation, the stator field must rotate in advance of the rotor poles, thus constantly "pulling" the rotor along.