Single Phase Induction Motor: Working Principle & Construction

Single-phase power systems are more commonly used than three phase system_in homes, businesses, and to some extent in industry. This is because single-phase systems are more economical and sufficient for the low power needs of most houses, shops, and offices.

Single-phase motors are simple to build, cost-effective, reliable, and easy to maintain. Thanks to these benefits, they are used in appliances like vacuum cleaners, fans, and washing machines, as well as in devices like centrifugal pumps and blowers.

The single phase AC motors are further classified as:

1. Single phase induction motors or asynchronous motors.
2. Single phase synchronous motors.
3. Commutator motors.

This article will provide fundamentals, description and **working principle of single phase induction motor**.

Construction of Single Phase Induction Motor

Like any other electrical motor asynchronous motor also have two main parts namely rotor and stator.

Stator:

As its name indicates stator is a stationary part of induction motor. A single phase AC supply is given to the stator of single phase induction motor.

Rotor:

The rotor is a rotating part of an induction motor. The rotor connects the mechanical load through the shaft. The rotor in the single-phase induction motor is of squirrel cage rotor type.

The **construction of a single-phase induction motor** closely resembles that of a squirrel cage three-phase induction motor. However, the single-phase motor's stator features two windings, unlike the single three-phase winding found in three phase induction motor.

Stator of Single Phase Induction Motor

The stator of the single-phase induction motor has laminated stamping to reduce eddy current losses on its periphery. The slots are provided on its stamping to carry stator or main winding. Stampings are made up of silicon steel to reduce the hysteresis losses. When we apply a single phase AC supply to the stator winding, the magnetic field gets produced, and the motor rotates at speed slightly less than the synchronous speed N_s. Synchronous speed N_s is given

by $N_s = \frac{120f}{P}$

Where,

f = supply voltage frequency,

P = No. of poles of the motor.

The construction of the stator of the single-phase induction motor is similar to that of three phase induction motor except there are two dissimilarities in the winding part of the single phase induction motor.

1. Firstly, the single-phase induction motors are mostly provided with concentric coils. We can easily adjust the number of turns per coil can with the help of concentric coils. The mmf distribution is almost sinusoidal.

2. In all types except for the shaded pole motor, an asynchronous motor includes two stator windings: the main and the auxiliary winding. These windings are positioned at right angles to each other in what is known as space quadrature.
3. **Rotor of Single Phase Induction Motor**
4. The construction of the rotor of the single-phase induction motor is similar to the squirrel cage three-phase induction motor. The rotor is cylindrical and has slots all over its periphery. The slots are not made parallel to each other but are a little bit skewed as the skewing prevents magnetic locking of stator and rotor teeth and makes the working of induction motor more smooth and quieter (i.e. less noisy).
5. The squirrel cage rotor consists of aluminum, brass or copper bars. These aluminum or copper bars are called rotor conductors and placed in the slots on the periphery of the rotor. The copper or aluminum rings permanently short the rotor conductors called the end rings.
6. To provide mechanical strength, these rotor conductors are braced to the end ring and hence form a complete closed circuit resembling a cage and hence got its name as squirrel cage induction motor. As end rings permanently short the bars, the rotor electrical resistance is very small and it is not possible to add external resistance as the bars get permanently shorted. The absence of slip ring and brushes make the **construction of single phase induction motor** very simple and robust.

Working Principle of Single Phase Induction Motor

NOTE: We know that for the working of any electrical motor whether its AC or DC motor, we require two fluxes as the interaction of these two fluxes produced the required torque. When we apply a single phase AC supply to the stator winding of single phase induction motor, the alternating current starts flowing through the stator or main winding. This alternating current produces an alternating flux called main flux. This main flux also links with the rotor conductors and hence cut the rotor conductors.

According to the Faraday's law of electromagnetic induction, emf gets induced in the rotor. As the rotor circuit is closed one so, the current starts flowing in the rotor. This current is called the rotor current. This rotor current produces its flux called rotor flux. Since this flux is produced due to the induction principle so, the motor working on this principle got its name as an induction motor. Now there are two fluxes one is main flux, and another is called rotor flux. These two fluxes produce the desired torque which is required by the motor to rotate.

Why Single Phase Induction Motor is not Self Starting?

According to double field revolving theory, we can resolve any alternating quantity into two components. Each component has a magnitude equal to the half of the maximum magnitude of the alternating quantity, and both these components rotate in the opposite direction to each other. For example – a flux, φ can be resolved into two components

$$\frac{\phi_m}{2} \; and \; -\frac{\phi_m}{2}$$

Each of these components rotates in the opposite direction i. e if one $\varphi_m/2$ is rotating in a clockwise direction then the other φ_m / 2 rotates in an anticlockwise direction.

When we apply a single phase AC supply to the stator winding of single phase induction motor, it produces its flux of magnitude, φ_m. According to the double field revolving theory, this alternating flux, φ_m is divided into two components of magnitude $\varphi_m/2$. Each of these components will rotate in the opposite direction, with the synchronous speed, N_s.

Let us call these two components of flux as forwarding component of flux, φ_f and the backward component of flux, φ_b. The resultant of these two components of flux at any instant of time gives the value of instantaneous stator flux at that particular instant.

$$i.e.\phi_r = \frac{\phi_m}{2} + \frac{\phi_m}{2} \; or \; \phi_r = \phi_f + \phi_b$$

Now at starting condition, both the forward and backward components of flux are exactly opposite to each other. Also, both of these components of flux are equal in magnitude. So, they cancel each other and hence the net torque experienced by the rotor at the starting condition is zero. So, the **single phase induction motors** are not self-starting motors.

Methods for Making Single Phase Induction as Self Starting Motor

From the above topic, we can easily conclude that the single-phase induction motors are not self-starting because the produced stator flux is alternating in nature and at the starting, the two components of this flux cancel each other and hence there is no net torque. The solution to this problem is that if we make the stator flux rotating type, rather than alternating type, which rotates in one particular direction only. Then the induction motor will become self-starting.

Now for producing this rotating magnetic field, we require two alternating flux, having some phase difference angle between them. When these two fluxes interact with each other, they will produce a resultant flux. This resultant flux is rotating in nature and rotates in space in one particular direction only.

Once the motor starts running, we can remove the additional flux. The motor will continue to run under the influence of the main flux only. Depending upon the methods for making asynchronous motor as Self Starting Motor, there are mainly four **types of single phase induction motor** namely,

1. Split phase induction motor,
2. Capacitor start inductor motor,
3. Capacitor start capacitor run induction motor,
4. Shaded pole induction motor.
5. Permanent split capacitor motor or single value capacitor motor.

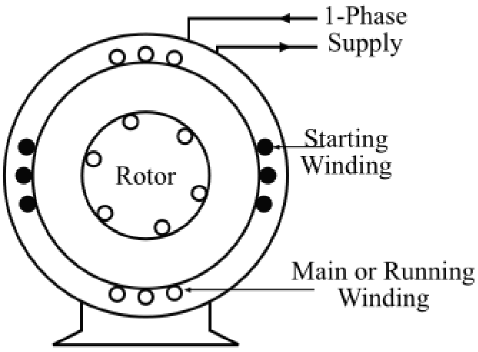
Comparison between Single Phase and Three Phase Induction Motors

1. Single phase induction motors are simple in construction, reliable and economical for small power rating as compared to three phase induction motors.
2. The electrical power factor of single phase induction motors is low as compared to three phase induction motors.
3. For the same size, the single-phase induction motors develop about 50% of the output as that of three phase induction motors.
4. The starting torque is also low for asynchronous motors/single phase induction motor.
5. The efficiency of single phase induction motors is less compared to that of three phase induction motors.

Single phase induction motors are simple, robust, reliable and cheaper for small ratings. They are available up to 1 KW rating.

Why doesn't a Single-Phase Induction Motor Self-Start?

A single-phase induction motor consists of a squirrel cage rotor and a stator carrying a single-phase winding. But, a single-phase induction motor is not self-starting like a 3-phase induction motor since it requires some starting means.



When a single-phase supply is fed to the stator winding of the single-phase induction motor, it produces a magnetic field that pulsates in strength in a sinusoidal manner. The polarity of the magnetic field reverses after each half cycle but the magnetic field does not rotate in the space.

As a result, the alternating flux cannot produce rotation in a stationary squirrel cage rotor because the magnetic flux can be resolved into two components, each one rotates in the opposite directions at the same speed. Consequently, the net flux is zero, the induced current in the rotor bars is zero, and hence, the resulting torque on the rotor conductors is zero. Therefore, **a 1-phase induction motor is not self-starting**.

How to Make a Single-Phase Induction Motor Self-Starting?

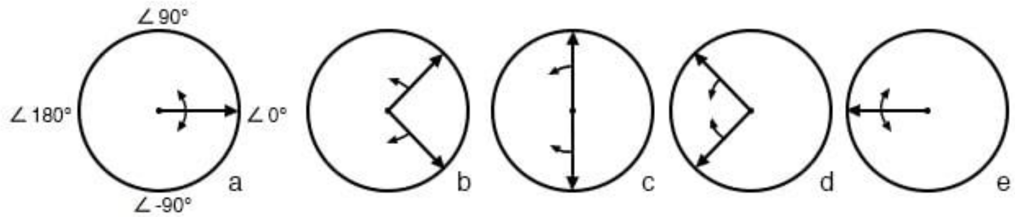
Somehow, by producing a rotating stator magnetic field, the 1-phase induction motor can be made self-starting. This may be accomplished by converting a single supply into two-phase supply through the use of an additional winding or auxiliary winding.

As soon as the motor attains a sufficient speed, the starting means may be removed depending on the type of the motor. Hence, the single-phase induction motors are classified and named according to the method used to make them self-starting which are given as follows −

- **Split-phase Induction Motor** – These motors are started by 2-phase motor action, which is achieved by the use of a starting or auxiliary winding.
- **Capacitor Motor** – To start a capacitor motor, the two-phase motor action is achieved by the use of an auxiliary winding and a capacitor.
- **Shaded Pole Motor** – This type of single-phase induction motor is started by the motion of magnetic field produced by the means of a shading coil around the portion of the pole structure.

Single Coil of a Single Phase Motor

The single coil of a single-phase induction motor does not produce a rotating magnetic field, but a pulsating field reaching maximum intensity at 0° and 180° electrical.



Single-phase stator produces a nonrotating, pulsating magnetic field

Another view is that the single-coil excited by a single-phase current produces two counter-rotating magnetic field phasors, coinciding twice per revolution at 0° (Figure above-a) and 180° (figure e). When the phasors rotate to 90° and -90° they cancel in figure c.

At 45° and -45° (figure b) they are partially additive along the +x axis and cancel along the y-axis. An analogous situation exists in figure d. The sum of these two phasors is a phasor stationary in space, but alternating polarity in time. Thus, no starting torque is developed.

However, if the rotor is rotated forward at a bit less than the synchronous speed, It will develop maximum torque at 10% slip with respect to the forward rotating phasor. Less torque will be developed above or below 10% slip.

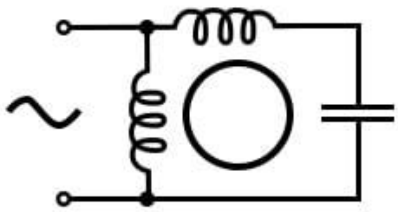
The rotor will see 200% - 10% slip with respect to the counter-rotating magnetic field phasor. Little torque (see torque vs slip curve) other than a double frequency ripple is developed from the counter-rotating phasor. Thus, the single-phase coil will develop torque, once the rotor is started.

If the rotor is started in the reverse direction, it will develop a similar large torque as it nears the speed of the backward rotating phasor.

Single-phase induction motors have a copper or aluminum squirrel cage embedded in a cylinder of steel laminations, typical of polyphase induction motors.

Permanent-Split Capacitor Motor

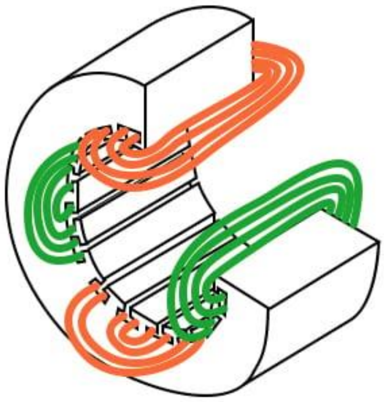
One way to solve the single phase problem is to build a 2-phase motor, deriving 2-phase power from single phase. This requires a motor with two windings spaced apart 90° electrical, fed with two phases of current displaced 90° in time. This is called a permanent-split capacitor motor.



Permanent-split capacitor induction motor

This type of motor suffers increased current magnitude and backward time shift as the motor comes up to speed, with torque pulsations at full speed. The solution is to keep the capacitor (impedance) small to minimize losses.

The losses are less than for a shaded pole motor. This motor configuration works well up to 1/4 horsepower (200 watts), though, usually applied to smaller motors. The direction of the motor is easily reversed by switching the capacitor in series with the other winding. This type of motor can be



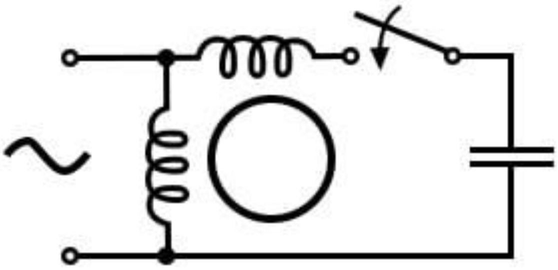
Single-phase induction motor with embedded stator coils

Single-phase induction motors may have coils embedded into the stator for larger size motors. Though, the smaller sizes use less complex to build concentrated windings with salient poles.

Capacitor-Start Induction Motor

In the figure below a larger capacitor may be used to start a single-phase induction motor via the auxiliary winding if it is switched out by a centrifugal switch once the motor is up to speed. Moreover, the auxiliary winding may be many more turns of heavier wire than used in a resistance split-phase motor to mitigate excessive temperature rise.

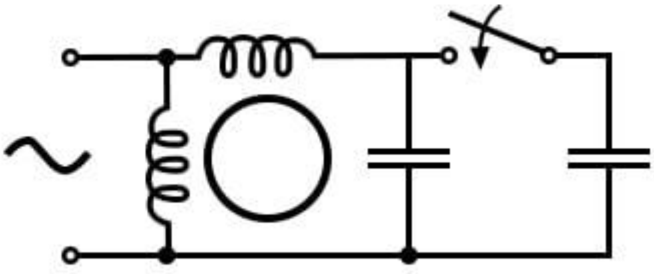
The result is that more starting torque is available for heavy loads like air conditioning compressors. This motor configuration works so well that it is available in multi-horsepower (multi-kilowatt) sizes.



Capacitor-start induction motor

Capacitor-Run Motor Induction Motor

A variation of the capacitor-start motor (figure below) is to start the motor with a relatively large capacitor for high starting torque, but leave a smaller value capacitor in place after starting to improve running characteristics while not drawing excessive current. The additional complexity of the capacitor-run motor is justified for larger size motors.



Capacitor-run motor induction motor

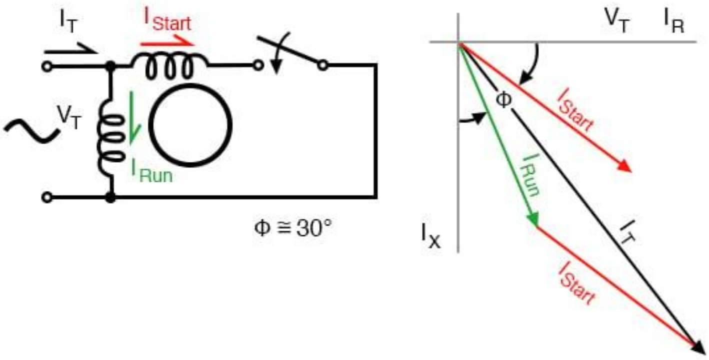
A motor starting capacitor may be a double-anode non-polar electrolytic capacitor which could be two + to + (or - to -) series-connected polarized electrolytic capacitors. Such AC rated electrolytic capacitors have such high losses that they can only be used for intermittent duty (1 second on, 60 seconds off) like motor starting.

A capacitor for motor running must not be of electrolytic construction, but a lower loss polymer type.

Resistance Split-Phase Motor Induction Motor

If an auxiliary winding of much fewer turns, a smaller wire is placed at 90°electrical to the main winding, it can start a single-phase induction motor. With lower inductance and higher resistance, the current will experience less phase shift than the main winding.

About 30° of phase difference may be obtained. This coil produces a moderate starting torque, which is disconnected by a centrifugal switch at 3/4 of synchronous speed. This simple (no capacitor) arrangement serves well for motors up to 1/3 horsepower (250 watts) driving easily started loads.



Resistance split-phase motor induction motor

This motor has more starting torque than a shaded pole motor (next section), but not as much as a two-phase motor built from the same parts. The current density in the auxiliary winding is so high during starting that the consequent rapid temperature rise precludes frequent restarting or slow starting loads.

STARTING METHODS

Single phase induction motors are named according to the starting Methods (or) device employed. So based on starting methods, the various types of single phase induction motors are

1. Split phase Motor
2. Capacitor Motor
   - (i) Capacitor Start Motor
   - (ii) Capacitor run Motor
   - (iii) Capacitor start and capacitor run Motor
3. Shaded Pole Motor
4. Reluctance Motor

Split Phase Motors

The stator of the split phase induction motor consits of two windings. One is known as starting or auxiliary winding and the another is called as main or running winding. Both the windings are placed in the stator slots but starting winding is displaced in space b 90°, with the main winding on the stator slots, so as to create at start a condition similar to two-phase machine, which will enable the Single Phase motor to produce rotating magnetic field at starts. Connection diagram of both the windings has been shown in Fig.3.39.

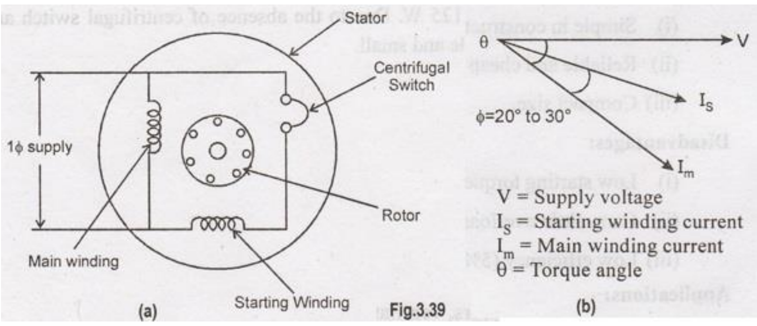


Fig.3.39

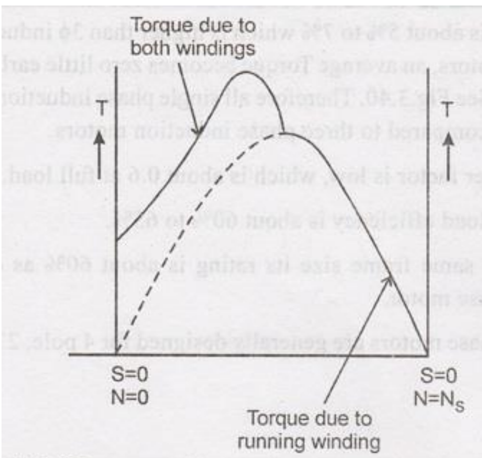


Fig.3.40 Torque speed characteristics of split-phase motor

Further the windings are designed in such a manner that main winding is highly inductive and the auxillary winding has a greater resistance.

When the motor is connected to single phase supply it trans current, I which is the vector sum of currents flowing through both the windings. Since starting winding has more resistance single of lags of starting winding correct, I_s is less as compared to the??? Winding current, In (See fig 3.39(b)). The angle between the two corrects, e is called torque angle, so starting torque produced is proportional to sing and motor will no have high starting torque if 0 is approaching to 90°. Generally in split phase motor ne auxiliary winding is disconnected, when the motor picks up speed. This is achieved by mi connecting a centrifugal switch or time lag relay in series with auxiliary windings. 90/This switch or device is normally closed type and when motor picks up speed, near to about 80% it opens automatically with centrifugal force in case of centrifugal switch and due to time adjustment in case of TDR (i.e. Time Delay Relay). Thus puts the starting winding out of the circuit.

Split phase motor generally heve starting torque about twice the full load torque of the motor. Its typical torque speed curve has been shown in Fig.5.14. The curve clearly shows, the starting torque, the speed at which centrifugal switch or such device operates and its normal running region. Other important information related to its performance are:

1. Its starting current is about 6 to 8 times of the full load current.
2. Its slip is about 5% to 7% which is higher than 30 induction motor. Because in 1f motors, an average Torque becomes zero little earlier than synchronous speed. See Fig.3.40. Therefore all single phase induction motors have greater slip as compared to three phase induction motors.
3. Its power factor is low, which is about 0.6 at full load.
4. Its full load efficiency is about 60% to 65%.
5. For the same frame size its rating is about 60% as compared to that of polyphase motor.
6. Split phase motors are generally designed for 4 pole, 230V, 50Hz, 1f supply system.

Applications:

i. Drills
ii. Press burners
iii. Fans
iv. Blowers
v. Washing Machines
vi. Centifugal Pumps
vii. Grinders
viii. Wood working tools

Capacitor Motors

The stator of the capacitor motors also has two windings like split phase induction motor i.e. starting winding and running winding. But in this motor phase angle between the currents of man and starting winding is obtained by connecting a capacitor in series with the starting winding. Circuit and not by keeping the difference of resistance and reactance with ???. In fact capacitor motor is also a split phase motor but, it is in the improved forms and may be called as split phase capacitor motor. The use of capacitor has may advantages such as

1. The starting torque is much higher as compared to usual split phase motor as the torque angle is about 90°.
2. Starting live current is less.
3. Power factor of the motors gets improved.

The capacitors may be connected in series with the starting winding in three different ways. There fore, there are three types of capacitor motors.

i. Capacitor start motor

As shown in Fig.3.41 this motor has one dry type electrolytic capacitor which is specially designed for ac and is connected with centrifugal switch in series with the starting winding. As discussed in the case of resistance split-phase induction motor the centrifugal switch of this motor will also disconnect the starting winding, once the motor has picked up speed-say upto 80% of its synchromy speed. The starting capacitors used are designed for definite duty cycle and not for continuous use. So a faulty centrifugal switch ????.

The number of times of the starting winding is more in this motor as compared to starting winding turns used in resistance split-phase motor. This leads to large number of ampere times, providing large rotating flux and high starting torque. The typical torque - speed characteristic of this type of motor has been shown in Fig.3.42

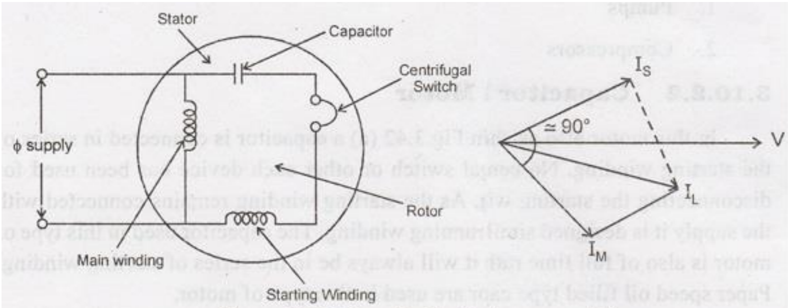


Fig.3.41 Capacitor Start Motor

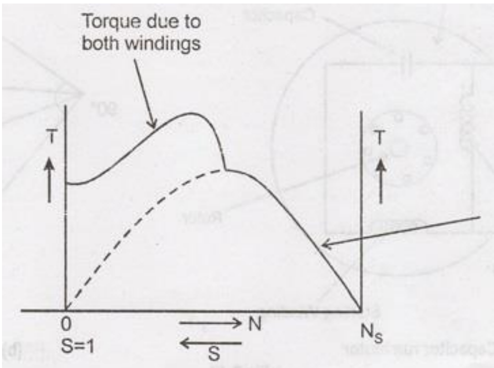


Fig.3.42

Other important informations related to its performance are:

1. Its starting current is about 4 to 5 times of its full load current.
2. Its slip is about 5%
3. Its power factor is high at starting but low when running. Its full-load factor is about 0.65.
4. Its full-load efficiency is about 65%
5. In this motor angle q between the furo current is nearly 90° at start (see box fig.3.41(b)) so motor has more starting torque as compared to split-phase motors.

Applications

1. Pumps
2. Compressors

ii. Capacitor Run Motor

In this motor also as shown in Fig.3.42 (a) a capacitor is connected in series of the starting winding. No centrifugal switch or other such device has been used for disconnecting the starting winding. As the starting winding remains connected with the supply it is designed similar to running winding. The capacitor used in this type of motor is also of full time rating as it will always be in the series of starting winding. Paper speed oil filled type capacitor are used in this type of motor.

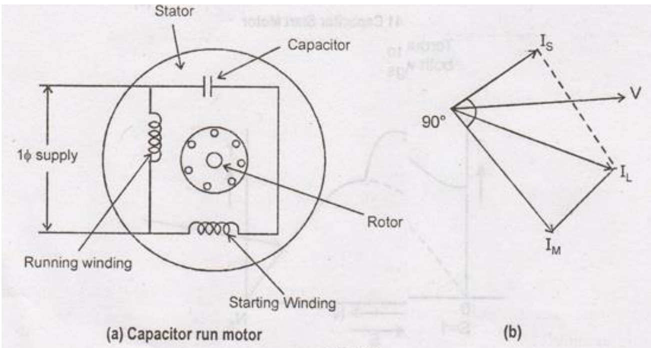


Fig.3.42

In this motor also as shown in Fig.3.42 (b) the time-phase difference between two currents is nearly 90°, so the starting torque of this motor is also higher and the rotating field produced will be a uniform one, thus providing noise less operation.
The capacitor remains in the circuit so resultant line current is less, power factor is high, which is nearly unity.
Its full load efficiency will be higher, about 75%. Fig 3.43 shows its typical forque speed characteristics.

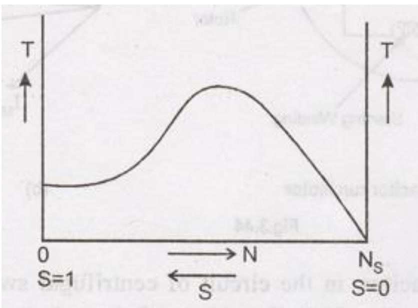


Fig.3.43

Applications
1. Fans
2. Room Coolers
3. Portable tools

iii. Capacitor Start and Capacitor Run Motor

When high starting torque is required as lampared to capacitor run motor and the advantages of keeping the capacitor in the circuit is also to be achieved then instead of using one capacitor two capacitors of different ratings are employed.
As shown in Fig.3.44(a), one capacitor m series which centrigual switch or other such device and another capacitor is permanently connected in the starting winding circuit.
When motor is connected to single phase supply, similar to Capacitor start motor, centrifugal switch will disconnect the capacitor in its circuit and now the motor will be operating like capacitor run motor. Hence the motor drives the name, capacitor start and capacitor run motor.
For Phasor diagram, see Fig.3.44(b)

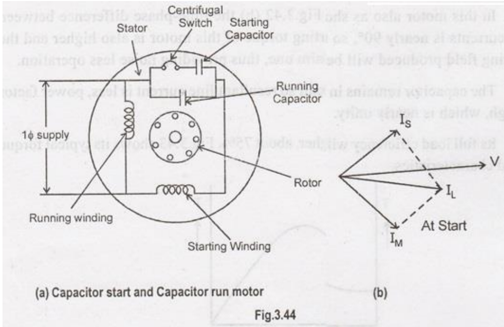


Fig.3.44

The value of the capacitor, in the circuit of centrifugal switch i.e., starting capacitor, is large, about 80 μF to 300 μF and it is of electrolytic type. The running capacitor is of low value, about 3 μF to 16 μF and it is an oil impregeated paper type capacitor.

Hence in order to have both, high starting torque and better operating power factor, capacitor start and capacitor run motor can be used.

Fig.3.45 shows the torque-speed (or slip) characteristic. Starting torque of this motor is about 300% of full load torque. Resultant line current is low and power factor is high, but its cost is also high.

Applications

1. Loaded Conveyors
2. Compressors
3. Reciprocating pumps
4. Stokers

This motor is used when high starting torque is required.

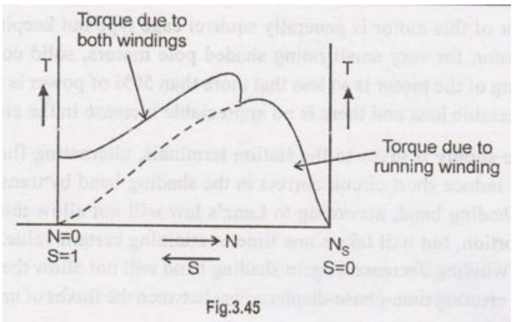


Fig.3.45

The direction of rotation of all the split phase motors, whether resistance split phase motor or split phase capacitor motors, can be reversed by interchanging the connections of the supply to either of the starting winding or of the running winding.

Shaded pole motor

The stator of the motor has salient poles with saw cut at about 1/3rd position of the pole and is surrounded by a coppering usually called as shading band, see Fig.3.46(a). Poles of shaded pole motor carry single phase ac winding known as field winding.

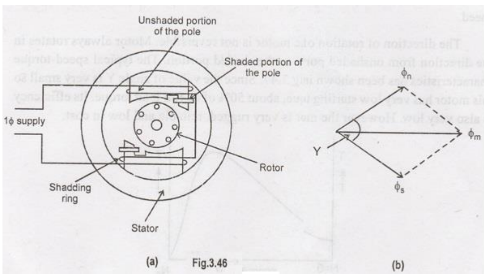


Fig.3.46

The rotor of this motor is generally squirrel cage type but keeping in mind the cost of the motor, for very small rating shaded pole motors, solid core can also be used. The rating of the motor is so less that more than 50% of power is lost. It will not produce appreciable heat and there is no appreciable increase in the electricity bill.

When ac supply is gives to the station terminals, alternating flux is produced. This flux will induce short circuit correct in the shading band by transformer action. This flux of shading band, according to Lenz's law will not allow the flux to rise at area in this portion, but will take some time to attaining certain value. When current through main winding decreases, again shading band will not allow the field to dk out quickly. Thus, creating time-phase-displacement between the fluxes of unshaded portion and shaded portion.

Let f_s is the flux in shaded portion, f_n represents the flux in unshaded portion of the pole and f_m is the main pole flux. The relation between these fluxes has been shown in Fig.3.46 (a).

In this motor flux does not rotate through 360° but appears to sweep over pole- faces from unshaded portion to shaded portion. Under the influence of this flux small starting torque, as the angle between f_s and f_n is very small, is produced. As soon as rotor starts rotating due to single phase induction motor action, additional torque is produced and rotor rotates continuously with the speed little less than the synchronous speed.

The direction of rotation of the motor is not reversible. Motor always rotates in the direction from unshaded portion to the shaded portion. The typical speed-torque characteristics has been shown in Fig.3.47. Since the value of angle Y is very small so this motor has very low starting torque, about 50% of its full load torque. Its efficiency is also very low. However the motor is very rugged, reliable and low in cost.

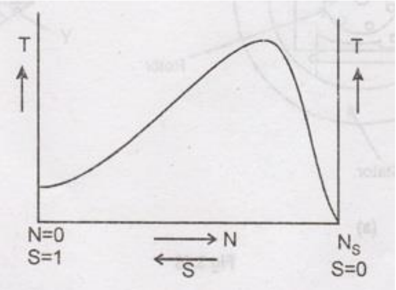


Fig.3.47

Applications

i. Small fans
ii. Electric clocks
iii. Hair dryers
iv. Grama phones