Single-Phase Induction Motors

Introduction:

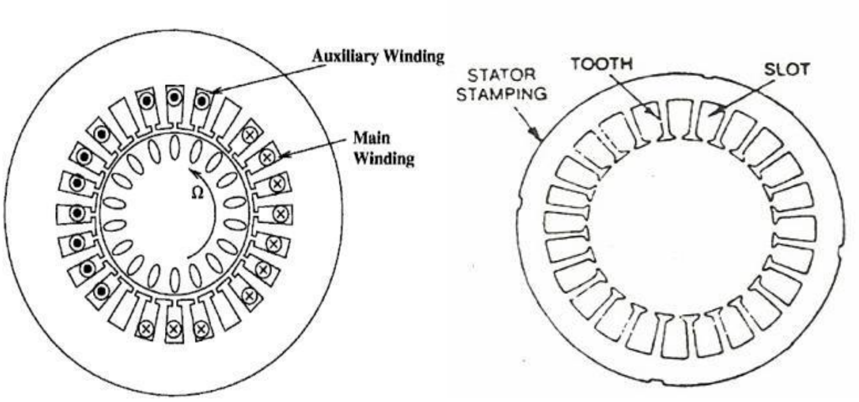
The single-phase induction motor is the most frequently used motor for refrigerators, washing machines, clocks, drills, compressors, pumps, and so forth. In addition to this, single phase motors are reliable, cheap in cost, simple in construction and easy to repair.

Construction:

The construction parts on of single phase induction motor consist of two main parts: **Stationary stator** and **revolving rotor**. The stator separate from rotor by small air gap have ranges from 0.4 mm to 4 mm depends upon the size of motor.

 Stator:

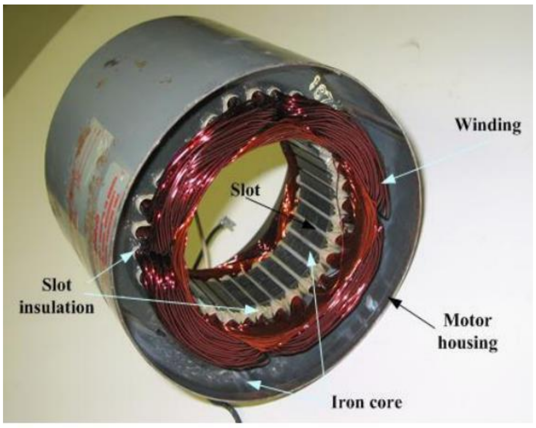
The single-phase motor stator has a laminated iron core with slots as shown in following figure.

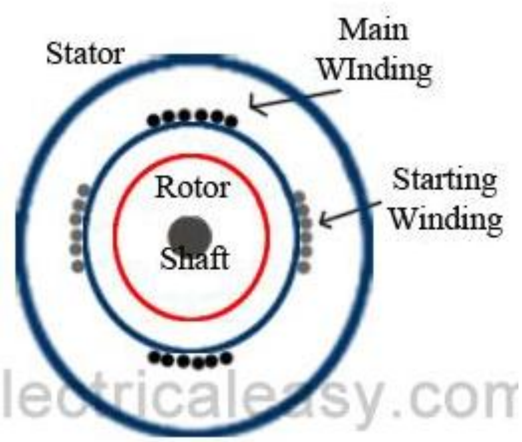


Two windings arranged vertically inside the slots of stator:

1- One is the main (or running winding).

2- Auxiliary winding (or starting winding) as showing in the figure below.

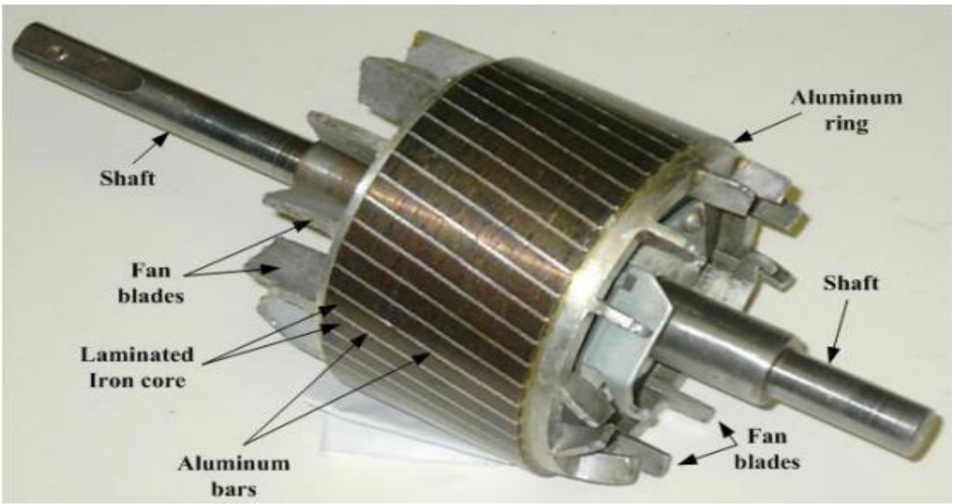




Stator of 1- phase induction motor

□ **Rotor**

The rotor, mounted on a shaft, It consists of a laminated cylindrical core with slots; aluminum bars are molded on the slots and short-circuited at both ends with a ring as shown in figure below. This type of rotor is called "Squirrel cage rotor ".



Squirrel cage rotor

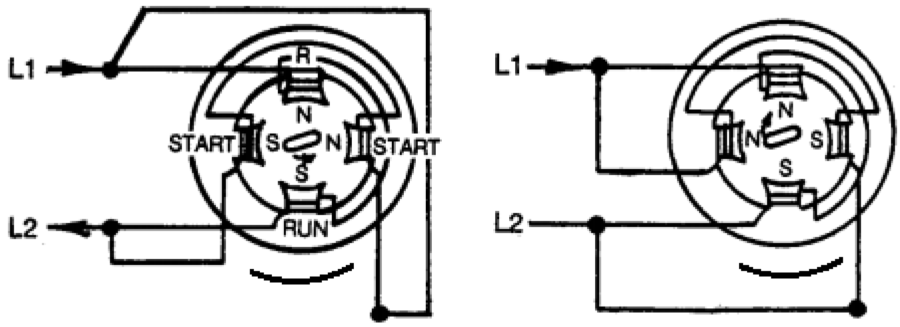
This forms a permanently short circuited winding which is strong. The entire construction (bars and end rings) resembles a squirrel cage and hence the name.
The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.

Most of single phase induction motors use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances. However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque. In this type of rotor the bars conductor are skew to reduce the noise.

Centrifugal Switch:

Many single-phase motors are not designed to operate continuously on both windings (main & auxiliary). At about 75 percent of the rated rotor speed, the centrifugal switch opens its contacts. It only takes a few moments for the motor to obtain this speed. An audible click can be heard when the centrifugal switch opens or closes.
Once the start winding is disconnected from the circuit, the momentum of the rotor and the oscillating stator field will continue rotor rotation. If, however, the motor is again stopped, the start winding is reconnected through the normally closed and spring-loaded centrifugal switch.

Reversal of Direction of Rotation:
The rotor will always turn from the start winding to the adjacent run winding of the same polarity. Therefore, the relationship between the start and run windings must be changed. To change the relationship and the direction of rotation, the polarity of only one of the fields must be reversed. In this manner, only one field polarity will change, and the rotor will still move toward the run winding of the same polarity as the start winding. The current entering the run winding or the current entering the start winding must be reversed, but not both.



Reversing the Direction of
Current Through the Start Winding.

Synchronous speed (N_s):

When the stator winding is given a 1-phase AC supply, the magnetic field is produced and the motor rotates at a speed (rotor speed (N_r)) slightly less than the synchronous speed (Ns) which is given by

$$N_s = \frac{120f}{p}$$

Where:
Ns: Synchronous speed (Is the speed of magnetic field) in rpm
f: Supply voltage frequency
p: No. of pole

Ex: Calculate the synchronous speed of 4 poles single phase induction motor. The line frequency is 60Hz.
Sol: Ns = 120f/p = (120 x 60Hz)/4 = 1800 rpm

Slip (S):
Is the difference between synchronous speed (Ns) and rotor speed (Nr). Expressed as % or per-unit of Synchronous speed. The slip is a ratio and doesn't have units.

$$S = \frac{N_S - N_r}{N_s}$$

Slip speed = sync. Speed − rotor speed = $N_S - N_r$

- if the rotor runs at synchronous speed (no load), then

$$S = 0$$

- if the rotor is stationary (locked), then

$$S = 1$$

Ex: A 0.5 hp, 6-pole induction motor is excited by a 1-phase, 60 Hz source. If the full-load speed is 1140 rpm, calculate: the Synchronous speed, slip speed, and the Slip.

Sol:

i) Synchronous speed (Ns) = 120f/ p = 120 * 60/60 = **1200 rpm**

ii) Slip speed = Ns – Nr = 1200 – 1140 = **60 rpm**

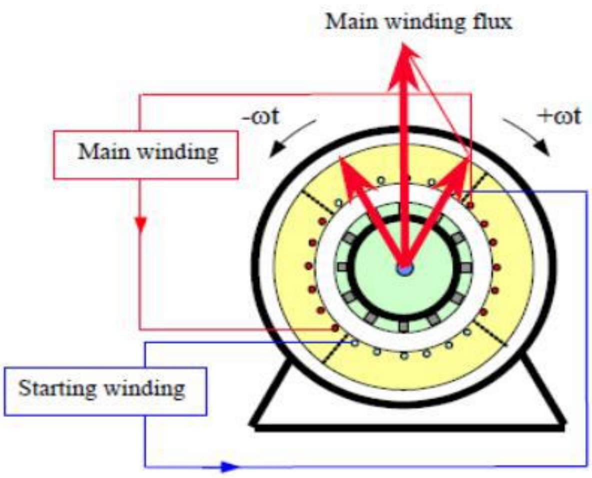
iii) Slip = (Ns – Nr)/ Ns = (60 / 1200) = **0.05**

Starting of Single-phase IM:

A single-phase induction motor is not self-starting (as 3-phase squirrel cage induction motor) but requires some starting means. The single-phase stator winding produces a magnetic field that pulsates in strength in a sinusoidal manner. The field polarity reverses after each half cycle but the field does not rotate. Consequently, the alternating flux cannot produce rotation in a stationary squirrel-cage rotor. However, if the rotor of a single-phase motor is rotated in one direction by some mechanical means, it will continue to run in the direction of rotation. As a matter of fact, the rotor quickly accelerates until it reaches a speed slightly below the synchronous speed. Once the motor is running at this speed, it will continue to rotate even though single phase current is flowing through the stator winding. This method of starting is generally not convenient for large motors.

Starting of Single-phase IM:

- A single-phase AC voltage supplies the main winding that produces a magnetic field change with time around one access so that this field call as pulsating. The currents which generated due to this field in rotor be in right side reverse to lift side, the total torque equal zero, as shown in figure below.



Single-phase motor main winding generates two rotating fields

- Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.

- The pulsating filed is divided a forward and reverse rotating field. Under these conditions, if only the main field energized, the motor will not start.

- The single phase induction motor can be satisfied after put auxiliary winding in slots of stator to shift the EMF.

- The auxiliary winding and main winding connect in parallel together and with supply.

- When the rotor move with speed until the synchronous speed the auxiliary wending will open from connection after few seconds.

- However, if an external torque moves the motor in any direction, the motor will begin to rotate.

Types of single phase induction motor:

The single phase induction motors are classified based on method of starting:

1. Split Phase Induction Motor:

- In addition to the main winding (running winding), the stator of single phase induction motor carries another winding called auxiliary winding (starting winding).

- The two winding (main & auxiliary) are connected in parallel to a single phase source.

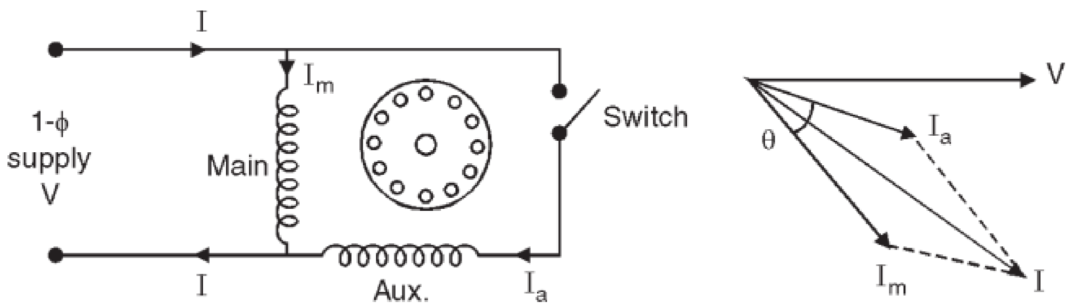
- A centrifugal switch is connected in series with auxiliary winding. The purpose of this switch is to disconnect the auxiliary winding from the main circuit when the motor attains a speed up to 75 to 80% of the synchronous speed.

- The auxiliary windings are displaced in space by 90 electric degrees as shown in figure below.

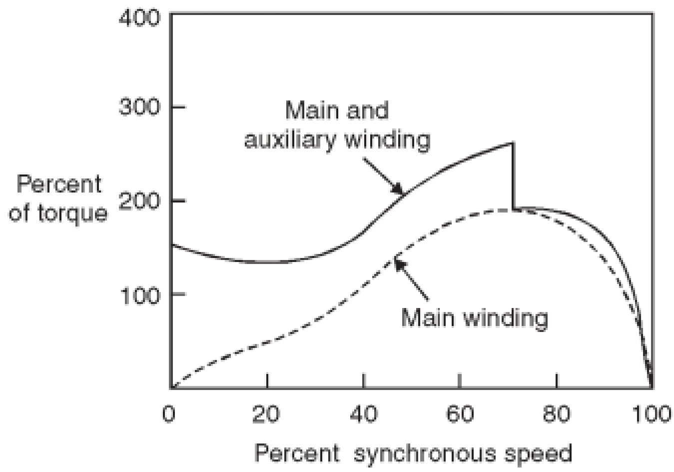
- When the two stator windings are energized from a single – phase supply, the current (Ia) in the auxiliary winding lags the voltage (V) by an angle, φa, which is small, whereas the current (Im) in the main winding lags the voltage (V) by an angle, φm, which is nearly 90°. Because the starting winding has a high resistance and relatively small reactance whiles the main winding has relatively low resistance and large reactance.

- Consequently, the currents flowing in the two windings have reasonable phase difference (25° to 30°) as shown in the phasor diagram this shifting in current is necessary for starting torque.

- The starting current is about 6 to 8 times the full load current.



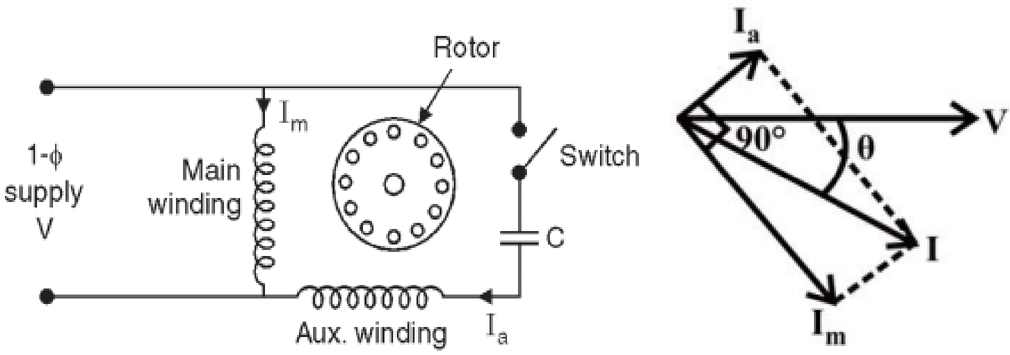
Split phase induction motor



Torque-speed characteristic of a split-phase motor

2. Capacitor Start Induction Motor:

- The capacitor-start motor is identical to a split-phase motor except that a capacitor C (3-20 μF) is connected in series with the starting winding as shown in figure below.

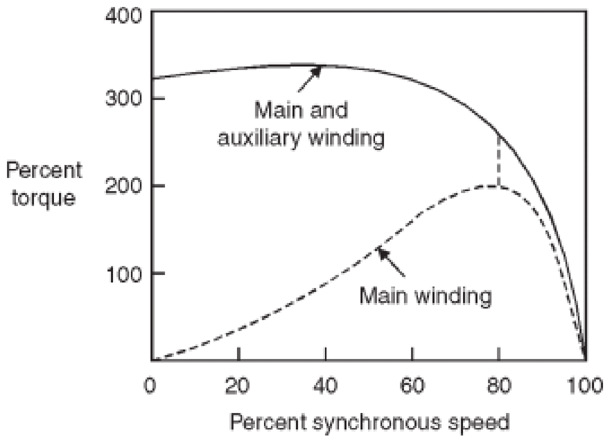


Capacitor start motor

- The auxiliary winding and the capacitor are disconnected at about 75% of the synchronous speed. Therefore, at the rated speed the capacitor start motor operates only on the main winding like a split-phase motor.

- The main problem in split-phase induction motor is low starting torque, as this torque is a function of, or related to the phase difference (angle) between the currents in the two windings. To get high starting torque, the phase difference required 90°. when the starting torque will be proportional to the product of the magnitudes of two currents ($Ts = k * Im * Ia * sin\varphi$). As the current in the main winding is lagging by φm, the current in the auxiliary winding has to lead the input voltage by φa, with (φa + φm = 90°).
(where k is a constant whose magnitude depends upon the design of the motor)
- This can be can be achieved by having a capacitor in series with the auxiliary winding, which results in additional cost, with the increase in starting torque

- However, a capacitor start motor is used when the starting torque requirements are 4 to 5 times the rated torque as shown in figure below (not as in split phase motor).



Torque-speed characteristic of a capacitor start motor

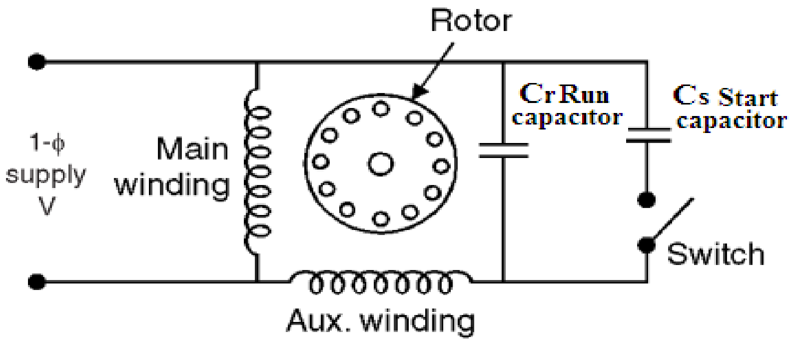
3. Capacitor Start Capacitor-Run Induction Motor:

- This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting.

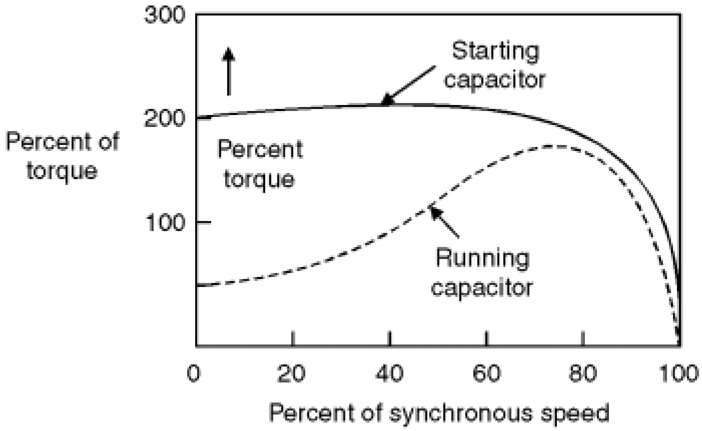
- Two capacitors Cr and Cs are used in the starting winding as shown in figure below:

- The smaller capacitor Cr required for optimum running conditions is permanently connected in series with the starting winding.

- The much larger capacitor Cs is connected in parallel with Cr for optimum starting and remains in the circuit during starting. The starting capacitor Cs is disconnected when the motor approaches about 80% of synchronous speed. The motor then runs as a single-phase induction motor.



Capacitor-start capacitor-run motor



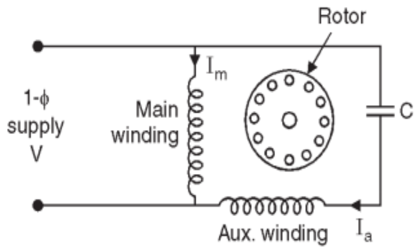
Torque-speed characteristic of a capacitor-start capacitor-run motor

4. Permanent Split Capacitor Motor:

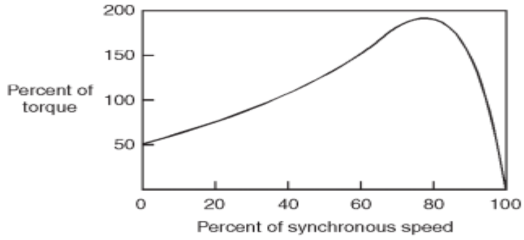
- The schematic diagram of this type of motor is shown in figure below.

- This type of motor does not have a centrifugal switch, thus reducing maintenance problems.

- This type of motor is essentially the same as a two-value capacitor motor operating on the running connection and will have approximately the same torque characteristics. Since only the running capacitor (which is of relative low value) is connected in series with the auxiliary winding on starting, the starting torque is greatly reduced.



Permanent split capacitor motor



Torque-speed characteristic

The power factor of this motor, when it is operating (running), is high. The operation is also quiet and smooth.

- The application of this type of single-phase motor is normally limited to the direct drive of such loads as those of ceiling fans and blowers in heaters and air conditioners, which do not require normal or high starting torques. These motors are not suitable for belt-driven applications and are generally limited to the lower horsepower ratings.

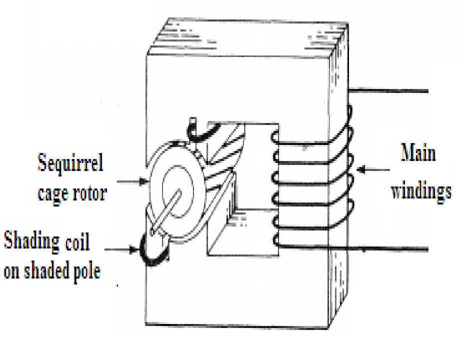
5. Shaded-Pole Induction Motor:

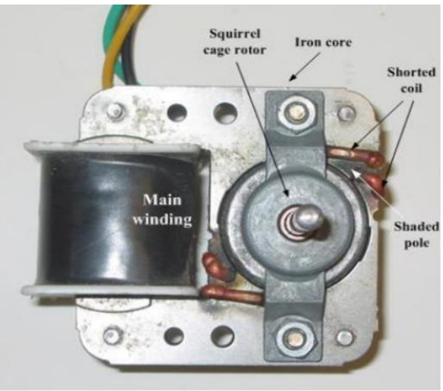
- The shaded-pole motor does not use two windings to develop the torque necessary to turn the rotor.

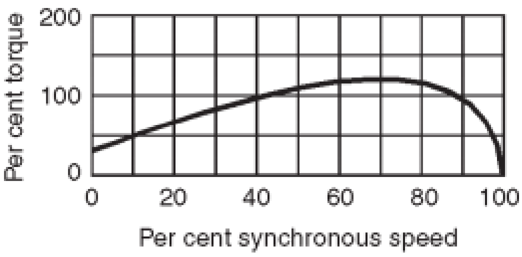
- It has salient poles on the stator excited by single-phase supply.

- Each pole is surrounded by a short-circuited turn of copper strip called shading coil; this part of the pole is called the shaded pole.

- The shaded pole motor is available only in very small sizes, usually not larger than 1/20 hp.







Torque-speed characteristic of a shaded-pole motor

The operation:

•The main winding produces a pulsating flux that links with the squirrel cage rotor.
• This flux induces a voltage in the shorted winding.
•The induced voltage produces a current in the shorted winding.
•This current generates a flux that opposes the main flux in the shaded pole (the part of the pole that carries the shorted winding).
•The result is that the flux in the un-shaded and shaded parts of the pole will be unequal.

•These two fluxes generate an unbalanced rotating field. The field amplitude changes as it rotates.

• This rotating field produces a torque, which starts the motor in the direction of the shaded pole.

The **advantages** of shaded pole induction motor are

- Very economical and reliable.
- Construction is simple and robust because there is no centrifugal switch.

The **disadvantages** of shaded pole induction motor are

- Low power factor.
- The starting torque is very poor.
- The efficiency is very low , the copper losses are high due to presence of copper band.
- The speed reversal is also difficult and expensive as it requires another set of copper rings.

Applications of Shaded pole motors induction motor are- Due to their low starting torques and reasonable cost these motors are mostly employed in small instruments, hair dryers, toys, record players, small fans, electric clocks etc. in addition ,it most frequent application is in ventilation fans.

Application of Single Phase Induction Motor:

The split phase induction motors are used for fans, blowers, centrifugal pumps and office equipments. Typical ratings are $\frac{1}{20}$ to $\frac{1}{2}$ hp; in this range they are the lowest cost motors available. The capacitor start motors are used for compressors, pumps, refrigeration and air-conditioning equipments and other hard to start-loads.

The capacitor start capacitor run motors are manufactured in a number of sizes from $\frac{1}{8}$ to $\frac{3}{4}$ hp and are used in compressors, conveyors, pumps and other high torque loads. The permanent split capacitor motors are manufactured in the range of $\frac{1}{20}$ hp to $\frac{3}{4}$ hp and are used for direct connected fans, blowers, centrifugal pumps and loads requiring low starting torque.

The shaded pole motors are used in toys, hair driers, deskfans etc.