Unit-5

SPECIAL MACHINES

Single phase Induction Motors:

Single-phase a.c supply is commonly used for lighting purpose in shops, offices, houses, schools etc..Hence instead of d.c motors, the motors which work on single-phase a.c. supply are popularly used. These a.c motors are called **single-phase induction motors**. A large no. of domestic applications use *single-phase induction motors*. Here we will learn **how does single phase induction motor work**.

The power rating of these motors is very small. Some of them are even fractional horsepower motors, which are used in applications like small toys, small fans, hairdryers etc. This article explains the **construction, working principle of single-phase induction motors**.

Construction of Single Phase Induction Motors:

Similar to a d.c motor, **single-phase induction motor** also has two main parts, one rotating and other stationary. The stationary part in *single-phase induction motors* is **Stator** and the rotating part is **Rotor**.

The stator has laminated construction, made up of stampings. The stampings are lotted on its periphery to carry the winding called **stator winding** or main winding. This is excited by a single-phase a.c supply. The laminated construction keeps iron losses to the minimum. The stampings are made up of material from silicon steel which minimises the hysteresis loss.

The stator winding is wound for a certain definite number of poles means when excited by single-phase a.c supply, stator produces the magnetic field which creates the effect of the certain definite number of poles. The number of poles for which stator winding is wound decides the synchronous speed of the motor. The synchronous speed is denoted as Ns and it has a fixed relation with supply frequency f and number of poles P. The relation is given by,

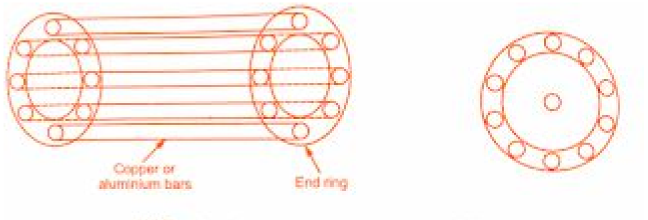
$$N_s = 120f/p \text{ RPM}$$

Must Read:

- Construction & Working principle of Synchronous Motor
- Armature Windings in Alternator and Types of Armature Windings

The induction motor never rotates with the synchronous speed but rotates at a speed that is slightly less than the synchronous speed. The rotor construction is of squirrel cage type.

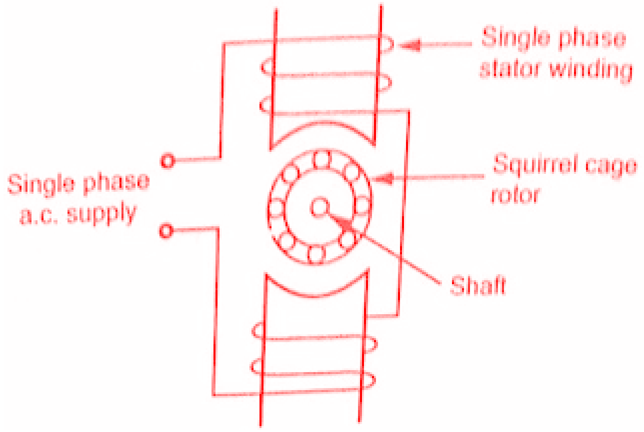
The bars are permanently shorted at both the ends with the help of conducting rings called end rings. The entire structure looks like cage hence it is called a squirrel cage rotor. The **construction of single-phase induction motors** is shown in below figure:



(a) Cage type structure

(b) Symbolic representation

As the bars are permanently shorted to each other, the resistance of the entire rotor is very very small. The air gap between stator and rotor is kept uniform and as small as possible. The main feature of this rotor is that it automatically adjusts itself for the same the number of poles as that of the stator winding. The schematic diagram of two-pole **single phase induction motor** is shown in the below figure:



Working Principle of Single Phase Induction Motors:

For the motoring action, there must exist two fluxes which interact with each other to produce the torque. In d.c motors, field winding produces the main flux while d.c supply given to armature is responsible to produce armature flux. The main flux and armature flux interact to produce the torque.

In the **single-phase induction motor**, single-phase a.c supply is given to the stator winding. The stator winding carries an alternating current which produces the flux which is also alternating in nature. This flux is called the main flux. This flux links with the rotor conductors and due to transformer action e.m.f gets induced in the rotor. The induced emf drives current through the rotor as the rotor circuit is the closed circuit.

This rotor current produces another flux called rotor flux required for the motoring action. Thus second flux is produced according to the induction principle due to induced e.m.f hence the motor is called **induction motor**. As against this in d.c motor a separate supply is required to the armature to produce armature flux. This is an important difference between d.c motor and an induction motor.

Key Point: *Another important difference between the two is that the d.c. motors are self-starting while single-phase induction motors are not self-starting. Let us see* ***why single-phase induction motors are not self-starting*** *with the help of a theory called* ***double-revolving field theory***.

Must Read:

- Effect of Harmonic Components on EMF of Synchronous Generator
- Blondel two reaction theory

Double Revolving Field Theory in single-phase induction motors:

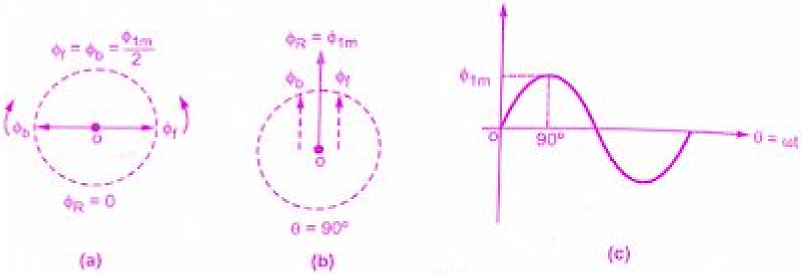
According to this theory, any alternating quantity can be resolved into two rotating components which rotate in opposite directions and each having magnitude as half of the maximum magnitude of the alternating quantity. In case of *single-phase induction motors*, the stator winding produces an alternating magnetic field having the maximum magnitude of Φ_{1m}.

"verdana" , sans-serif;"> According to **double-revolving field theor**y, consider the two components of the stator flux, each having magnitude half of maximum magnitude of stator flux i.e ($\Phi_{1m}/2$). Both these components are rotating in opposite directions at the synchronous speed Ns which is dependent on frequency and stator poles.

Let Φ_f is forward component rotating in anticlockwise direction while Φ_b is the backward component rotating in a clockwise direction. The resultant of these two components at any instant gives the instantaneous value of the stator flux at that instant. So resultant of these two is the original stator flux. The below figure shows the stator flux and its two components Φ_f and Φ_b .

At the start, both the components are shown the opposite to each other in figure(a). Thus the resultant $\Phi_R = 0$. This is nothing but the instantaneous value of stator flux at the start. After 90°, as shown in figure(b), the two components are rotated in such a way that both are pointing in the same direction.

Hence the resultant Φ_R is the algebraic sum of the magnitudes of the two components. So $\Phi_R = (\Phi_{1m}/2) + (\Phi_{1m}/2) = \Phi_{1m}$.This is nothing but the instantaneous value of the stator flux at $0 = 90°$ as shown in figure(c). Thus continuous rotation of two components gives the original alternating stator flux.

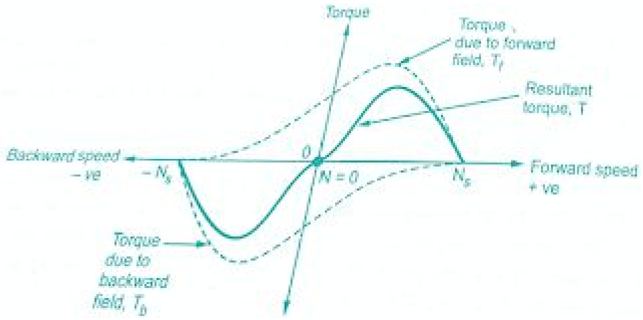


Both the components are rotating and hence get cut by the rotor conductors. Due to the cutting of flux, e.m.f gets induced in the rotor which circulates the rotor current. The rotor current produces rotor flux. This flux interacts with forwarding component Φ_f to produce a torque in one particular direction say anticlockwise direction. While the rotor flux interacts with the backward component Φ_b to produce a torque in the clockwise direction. So if anticlockwise torque is positive then clockwise torque is negative.

At the start, these two torques are equal in magnitude but opposite in direction. Each torque tries to rotate the rotor in its own direction. Thus net torque experienced by the rotor is zero at the start. And hence the **single-phase induction motors are not self-starting.**

Torque-Speed Characteristics in Single-phase Induction Motors:

The two oppositely directed torques and the resultant torque can be shown effectively with the help of **torque-speed characteristics**.



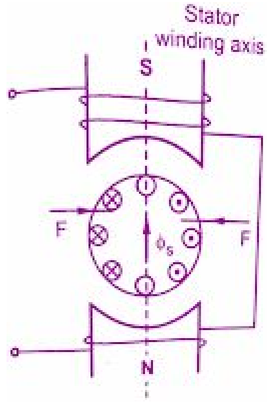
It can be seen that at start N = 0 and at that point resultant torque is zero.So **single phase induction motors** are not self starting.However if the rotor is given an initial rotation in any direction, the resultant average torque increases in the direction in which rotor is initially rotated and the motor starts rotating in that direction.

But in practice, it is not possible to give initial torque to rotor externally hence some modifications are done in the **construction of single phase induction motors** to make them self starting.Another theory which can also be used to explain **why single phase induction motor is not self starting** is cross-field theory.

Cross Field Theory in single phase induction motors:

Consider a **single phase induction motor** with standstill rotor as shown in the below figure.The stator winding is excited by the single phase a.c. supply.This supply produces an alternating flux Φ_s which acts along the axis of the stator winding.Due to this flux, emf gets induced in the rotor conductors due to transformer action.

As the rotor is closed one, this e.m.f circulates current through the rotor conductors.The direction of the rotor current is as shown in the below figure.The direction of rotor current is so as to oppose the cause producing it, which is stator flux Φ_s.

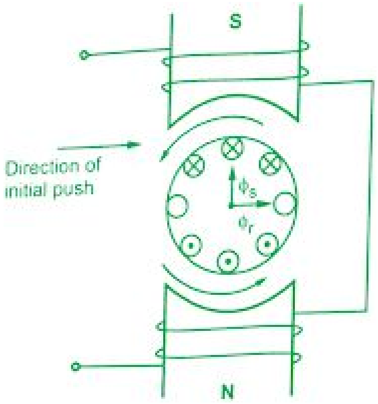


Now Fleming's left hand rule can be used to find the direction of the force experienced by the rotor conductors.It can be seen that when Φ_s acts in upward direction and increasing positively, the conductors on left experience force from left to right while conductors on right experience force from right to left.Thus overall, the force experienced by the rotor is zero.Hence no torque exists on the rotor and rotor can not start rotating.

We have seen that there must exist two fluxes separated by some angle so as to produce rotating magnetic field.According to **cross field theory**, the stator flux can be resolved into two components which are mutually perpendicular.One acts along the axis of the stator winding and other acts perpendicular to it.

Assume now that an initial push is given to the rotor in an anticlockwise direction. Due to the rotation, rotor physically cuts the stator flux and dynamically emf gets induced in the rotor. This is called speed e.m.f or rotational emf. The direction of such emf can be obtained by Fleming's right-hand rule and this emf is in phase with the stator flux Φ_s.

The direction of emf is shown in the figure below. This emf is denoted as E_{2N}. This emf circulates current through rotor which is I_{2N}. This current produces its own flux called rotor flux Φ_r. This axis of Φ_r is at 90° to the axis of stator flux hence this rotor flux it called cross-field.



Must Read:

- Rotating Magnetic field(R.M.F) in Synchronous Machines

Due to very high rotor reactance, the rotor current I_{2N} and Φ_r lag the rotational emf by almost 90°. Thus Φ_r is in quadrature with Φ_s in space and lags Φ_s by 90° in time phase. Such two fluxes produce the **rotating magnetic field.**

The direction of this rotating magnetic field will be the same as the direction of the initial push given. Thus rotor experiences a torque in the same direction as that of rotating magnetic field i.e. the direction of the initial push. So rotor accelerates in the anticlockwise direction under the case considered and attains a subsynchronous speed in the steady state.

Servo motor;

A servo motor is a linear or rotary actuator that provides fast precision position control for closed-loop position control applications. Unlike large industrial motors, a servo motor is not used for continuous energy conversion. Servo motors have a high speed response due to low inertia and are designed with small diameter and long rotor length.

Servo motors work on servo mechanism that uses position feedback to control the speed and final position of the motor. Internally, a servo motor combines a motor, feedback circuit, controller and other electronic circuit.

A servo motor is one of the widely used variable speed drives in industrial production and process automation and building technology worldwide.

Although servo motors are not a specific class of motor, they are intended and designed to use in motion control applications which require high accuracy positioning, quick reversing and exceptional performance.

It uses encoder or speed sensor to provide speed feedback and position. This feedback signal is compared with input command position (desired position of the motor corresponding to a load), and produces the error signal (if there exist a difference between them).

The error signal available at the output of error detector is not enough to drive the motor. So the error detector followed by a servo amplifier raises the voltage and power level of the error signal and then turns the shaft of the motor to desired position.

Types of Servo Motors

Basically, servo motors are classified into AC and DC servo motors depending upon the nature of supply used for its operation. Brushed permanent magnet DC servo motors are used for simple applications owing to their cost, efficiency and simplicity.

These are best suited for smaller applications. With the advancement of microprocessor and power transistor, AC servo motors are used more often due to their high accuracy control.

DC Servo Motors

A DC servo motor consists of a small DC motor, feedback potentiometer, gearbox, motor drive electronic circuit and electronic feedback control loop. It is more or less similar to the normal DC motor.

The stator of the motor consists of a cylindrical frame and the magnet is attached to the inside of the frame.

The rotor consists of brush and shaft. A commutator and a rotor metal supporting frame are attached to the outside of the shaft and the armature winding is coiled in the rotor metal supporting frame.

A brush is built with an armature coil that supplies the current to the commutator. At the back of the shaft, a detector is built into the rotor in order to detect the rotation speed.

With this construction, it is simple to design a controller using simple circuitry because the torque is proportional to the amount of current flow through the armature.

And also the instantaneous polarity of the control voltage decides the direction of torque developed by the motor. Types of DC servo motors include series motors, shunt control motor, split series motor, and permanent magnet shunt motor.

Working Principle of DC Servo Motor

A DC servo motor is an assembly of four major components, namely a DC motor, a position sensing device, a gear assembly, and a control circuit. The below figure shows the parts that consisting in RC servo motors in which small DC motor is employed for driving the loads at precise speed and position.

A DC reference voltage is set to the value corresponding to the desired output. This voltage can be applied by using another potentiometer, control pulse width to voltage converter, or through timers depending on the control circuitry.

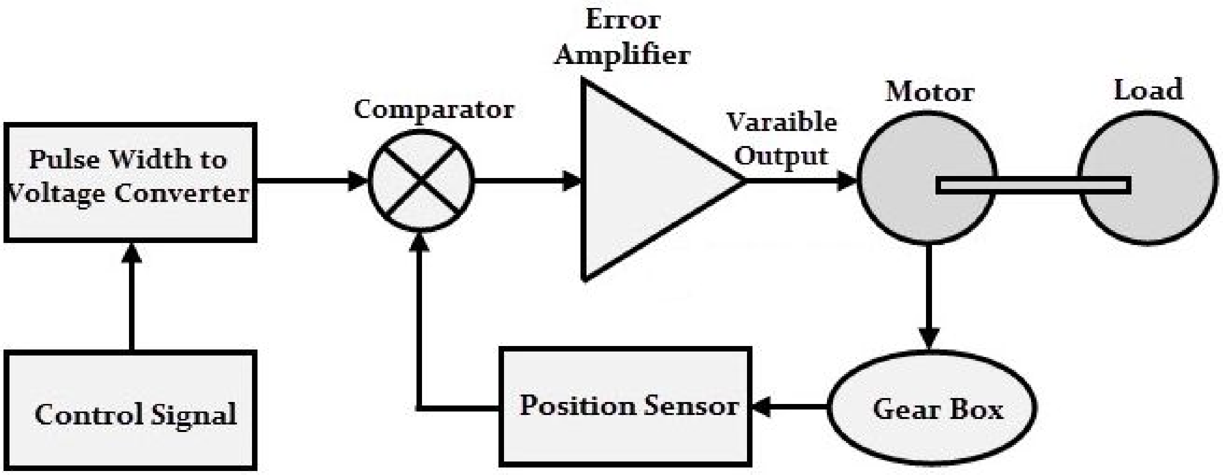
The dial on the potentiometer produces a corresponding voltage which is then applied as one of the inputs to error amplifier.

In some circuits, a control pulse is used to produce DC reference voltage corresponding to desired position or speed of the motor and it is applied to a pulse width to voltage converter.

In this converter, the capacitor starts charging at a constant rate when the pulse high. Then the charge on the capacitor is fed to the buffer amplifier when the pulse is low and this charge is further applied to the error amplifier.

So the length of the pulse decides the voltage applied at the error amplifier as a desired voltage to produce the desired speed or position.

In digital control, microprocessor or microcontroller are used for generating the PWM pluses in terms of duty cycles to produce more accurate control signals.



The feedback signal corresponding to the present position of the load is obtained by using a position sensor. This sensor is normally a potentiometer that produces the voltage corresponding to the absolute angle of the motor shaft through gear mechanism. Then the feedback voltage value is applied at the input of error amplifier (comparator).

The error amplifier is a negative feedback amplifier and it reduces the difference between its inputs. It compares the voltage related to current position of the motor (obtained by potentiometer) with desired voltage related to desired position of the motor (obtained by pulse width to voltage converter), and produces the error either a positive or negative voltage.

This error voltage is applied to the armature of the motor. If the error is more, the more output is applied to the motor armature.

As long as error exists, the amplifier amplifies the error voltage and correspondingly powers the armature. The motor rotates till the error becomes zero. If the error is negative, the armature voltage reverses and hence the armature rotates in the opposite direction.

AC Servo Motors

AC servo motors are basically two-phase squirrel cage induction motors and are used for low power applications. Nowadays, three phase squirrel cage induction motors have been modified such that they can be used in high power servo systems.

The main difference between a standard split-phase induction motor and AC motor is that the squirrel cage rotor of a servo motor has made with thinner conducting bars, so that the motor resistance is higher.

Based on the construction there are two distinct types of AC servo motors, they are synchronous type AC servo motor and induction type AC servo motor.

Synchronous-type AC servo motor consist of stator and rotor. The stator consists of a cylindrical frame and stator core. The armature coil wound around the stator core and the coil end is connected to with a lead wire through which current is provided to the motor.

The rotor consists of a permanent magnet and hence they do not rely on AC induction type rotor that has current induced into it. And hence these are also called as brushless servo motors because of structural characteristics.

When the stator field is excited, the rotor follows the rotating magnetic field of the stator at the synchronous speed. If the stator field stops, the rotor also stops. With this permanent magnet rotor, no rotor current is needed and hence less heat is produced.

Also, these motors have high efficiency due to the absence of rotor current. In order to know the position of rotor with respect to stator, an encoder is placed on the rotor and it acts as a feedback to the motor controller.

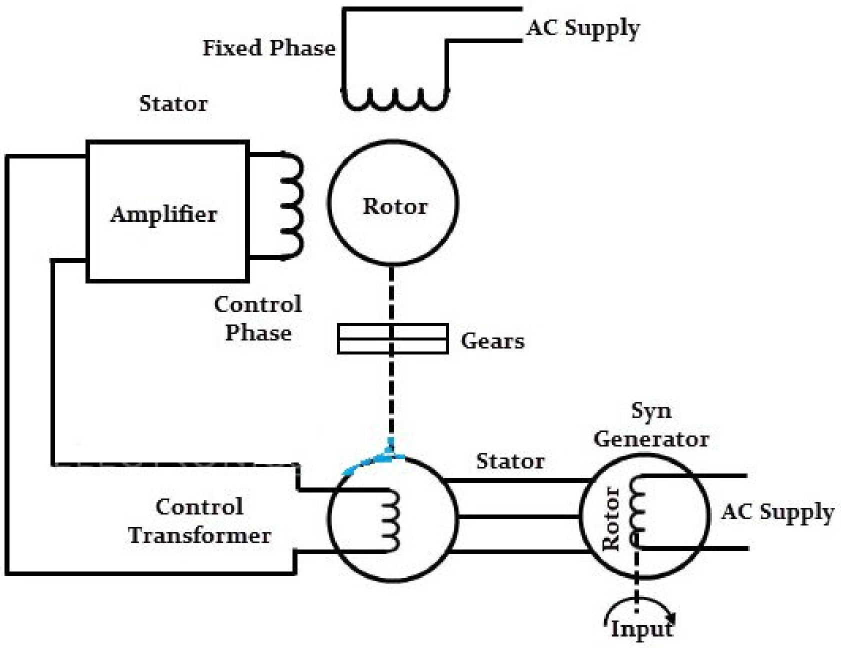
The **induction-type AC servo moto**r structure is identical with that of general motor. In this motor, stator consists of stator core, armature winding and lead wire, while rotor consists of shaft and the rotor core that built with a conductor as similar to squirrel cage rotor.

The working principle of this servo motor is similar to the normal induction motor. Again the controller must know the exact position of the rotor using encoder for precise speed and position control.

Working Principle of AC Servo Motor

The schematic diagram of servo system for AC two-phase induction motor is shown in the figure below. In this, the reference input at which the motor shaft has to maintain at a certain position is given to the rotor of synchro generator as mechanical input theta. This rotor is connected to the electrical input at rated voltage at a fixed frequency.

The three stator terminals of a synchro generator are connected correspondingly to the terminals of control transformer. The angular position of the two-phase motor is transmitted to the rotor of control transformer through gear train arrangement and it represents the control condition alpha.

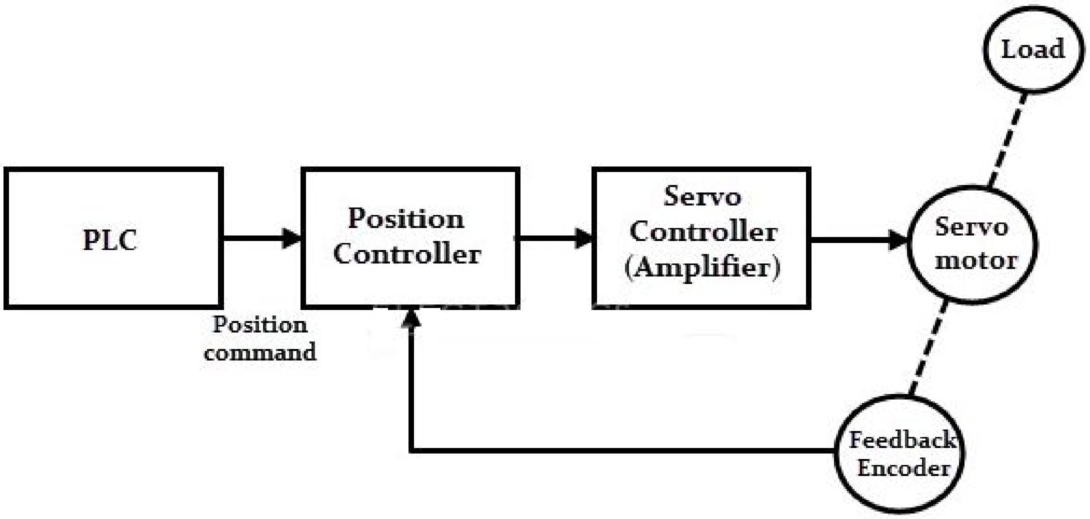


Initially, there exist a difference between the synchro generator shaft position and control transformer shaft position. This error is reflected as the voltage across the control transformer. This error voltage is applied to the servo amplifier and then to the control phase of the motor.

With the control voltage, the rotor of the motor rotates in required direction till the error becomes zero. This is how the desired shaft position is ensured in AC servo motors.

Alternatively, modern AC servo drives are embedded controllers like PLCs, microprocessors and microcontrollers to achieve variable frequency and variable voltage in order to drive the motor.

Mostly, pulse width modulation and Proportional-Integral-Derivative (PID) techniques are used to control the desired frequency and voltage. The block diagram of AC servo motor system using programmable logic controllers, position and servo controllers is given below.

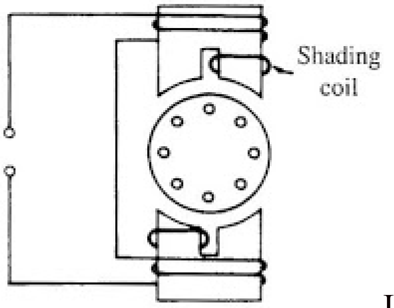


Difference between the DC and A

DC Servo Motor	AC Servo Motor
It delivers high power output	Delivers low output of about 0.5 W to 100 W
It has more stability problems	It has less stable problems
It requires frequent maintenance due to the presence of commutator	It requires less maintenance due to the absence of commutator
It provides high efficiency	The efficiency of AC servo motor is less and is about 5 to 20%
The life of DC servo motor depends on the life on brush life	The life of AC servo motor depends on bearing life
It includes permanent magnet in its construction	The synchronous type AC servo motor uses permanent magnet while induction type doesn’t require it.
These motors are used for high power applications	These motors are used for low power applications

Shaded pole motor;

Shaded pole motor is a split-phase type single phase induction motor. The shaded pole motor is very popular for ratings below 0.05 HP (~ 40 W) because of its extremely simple construction.

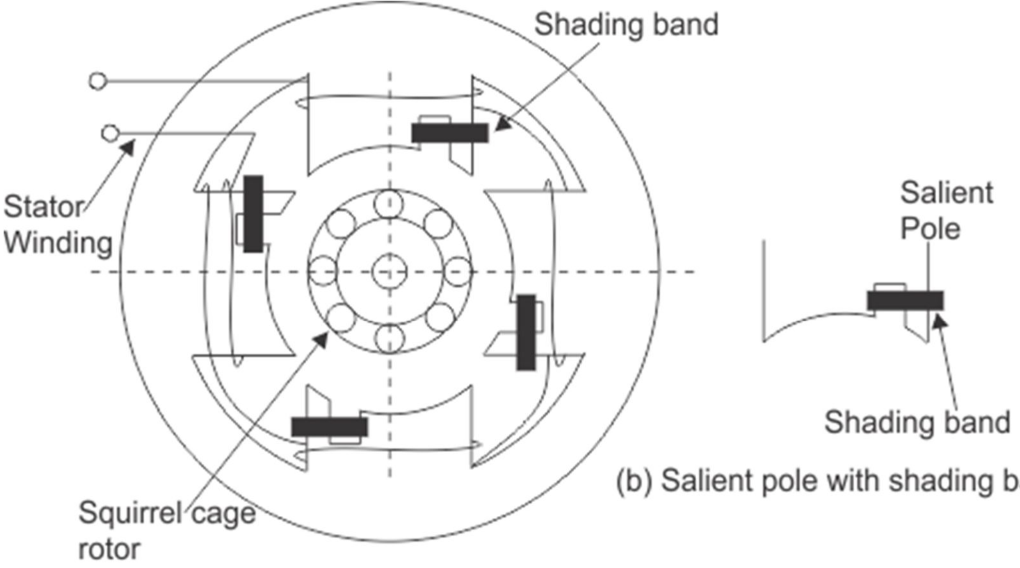


It has salient poles on the stator excited by a single-phase supply and a squirrel cage rotor. A portion of each pole is surrounded by a short-circuited turn of a copper strip called shading coil.

A shaded pole motor and its schematic diagram are shown in the figures above.

Construction of Shaded Pole Induction Motor

A shaded pole motor may be of 2 poles or 4 poles. Here we are considering a 2 pole shaded pole motor. The figures in this article also show a 2 pole motor.



(b) Salient pole with shading band

(a) 4-pole shaded pole construction

Construction of Shaded Pole Induction Motor

Stator

The stator has salient poles. Usually, 2 to 4 poles are used. Each of the poles has its own exciting coil.

A part of each pole is wrapped by a copper coil. The copper coil forms a closed-loop across each pole. This loop is known as the ***shading coil***.

The poles are laminated. A slot is cut across the lamination of the pole. The slot is approximately one-third distance from the edge of the pole. The short-circuited copper coil described above is placed in this slot. So we can call this part as the shaded part and other parts of the pole as unshaded part.

Selecting a 2 poled stator gives a synchronous speed of 3000 rpm while a 4 poled stator speed will be 1500rpm for 50Hz supply.

Rotor

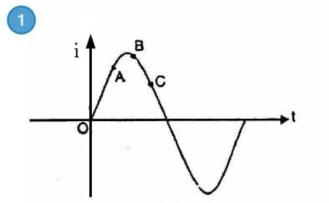
The rotor of shaded pole induction motors is the Squirrel Cage type rotor. The rotor bars are provided with a 60-degree skew. This is to obtain an optimum starting torque and for limiting the torque dip during the run-up.

Airgap length between stator and rotor is of the order **0.25 to 0.5 mm**. Too short air-gap may result in starting-torque variations due to rotor slotting.

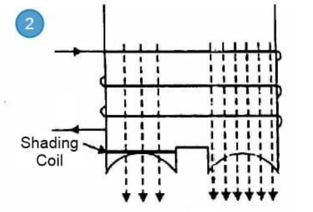
The shaded pole induction motor has no commutator, brushes, collector rings, contactors, capacitors or moving switch parts, so it is relatively cheaper, simpler and extremely rugged in construction and reliable. The absence of a centrifugal switch eliminates the possibility of motor failure due to faulty centrifugal switch mechanisms.

Working of Shaded Pole Induction Motor

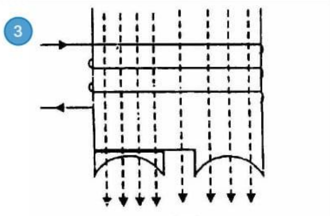
The operation of the motor can be understood by referring to the figure which shows one pole of the motor with a shading coil. Considering a cycle of alternating current (fig 1) applied to the stator winding we will explain the working of shaded pole motor.



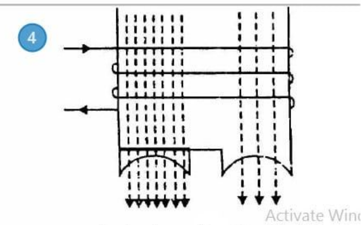
AC cycle applied to the motor



During the portion OA of Cycle



During the portion AB of Cycle



During the portion BC of Cycle

During the portion OA

During the portion OA of the alternating-current cycle [Fig 1], the flux begins to increase and an e.m.f. is induced in the shading coil. The resulting current in the shading coil will be in such a direction (Lenz's law) so as to oppose the change in flux.

Thus the flux in the shaded portion of the pole is weakened while that in the unshaded portion is strengthened as shown in figure 2.

During the portion AB

During the portion AB of the alternating-current cycle, the flux has reached the almost maximum value and is not changing. Consequently, the flux distribution across the pole is uniform [See Fig 3] since no current is flowing in the shading coil.

During the portion BC

As the flux decreases (portion BC of the alternating current cycle), the current is induced in the shading coil so as to oppose the decrease in current. Thus the flux in the shaded portion of the pole is strengthened while that in the unshaded portion is weakened as shown in Fig 4.

The effect of the shading coil is to cause the field flux to shift across the pole face from the unshaded to the shaded portion. This shifting flux is like a rotating weak field moving in the direction from the unshaded portion to the shaded portion of the pole.

The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed. As soon as this torque starts to revolve the rotor, additional torque is produced by single-phase induction-motor action. The motor accelerates to a speed slightly below the synchronous speed and runs as a single-phase induction motor.

Characteristics of Shaded Pole Motors

Some of the important characteristics of shaded pole induction motors are given below. The details of the characteristics of the shaded pole motor will be discussed later.

1. The salient features of this motor are extremely simple construction and absence of centrifugal switch.
2. Since starting torque, efficiency and power factor are very low, these motors are only suitable for low power applications e.g., to drive: (a) small fans (b) toys (c) hair driers (d) desk fans, etc.

Capacitor Start Motors: Diagram & Explanation of How a Capacitor is Used to Start a Single Phase Motor

The single-phase induction motor can be made to be self-starting in numerous ways. One often-used method is the Split Phase motors. Another method is the Capacitor Start Induction Run Motors.

Capacitor-Start Induction-Run Motors

We know about the activity of a capacitor in a pure A.C. Circuit. When a capacitor is so introduced, the voltage lags the current by some phase angle. In these motors, the necessary phase difference between the Is and Im is obtained by introducing a capacitor in series with the starter winding. The capacitor used in these motors are of electrolytic type and usually visible as it is mounted outside the motor as a separate unit. (click on an image to enlarge it).

During starting, as the capacitor is connected in series with the starter winding, the current through the starter winding Is leads the voltage V, which is applied across the circuit. But the current through the main winding Im, still lags the applied voltage V across the circuit. Thus more the difference between the Is and Im, better the resulting rotating magnetic field.

When the motor reaches about 75% of the full load speed, the centrifugal switch S opens and thus disconnecting the starter winding and the capacitor from the main winding. It is important to point out from the phasor diagram that the phase difference between Im and Is is almost 80 degrees as against 30 degrees in a split-phase induction motor. Thus a capacitor-start induction-run motor produces a better rotating magnetic field than the split-phase motors. It is evident from the phasor diagram that the current through the starter winding Is leads the voltage V by a small angle and the current through the main winding Im lags the applied voltage. It is to be appreciated that the resultant current I, is small and is almost in phase with the applied voltage V.

The torque developed by a split-phase induction motor is directly proportional to the sine of the angle between Is avnd Im. Also the angle is 30 degrees in case of split-phase motors. But in the case of capacitor-start induction-run motors, the angle between Is and Im is 80 degrees. It is then obvious that the increase in the angle (from 30 degrees to 80 degrees) alone increases the starting torque to nearly twice the value developed by a standard split-phase induction motor. The speed-torque characteristics curve is exhibiting the starting and running torques of a capacitor-start induction-run motor.

Types of Motors

There are different types of Capacitor-start motors designed and used in various fields. They are as follows:

1. Single-voltage, externally reversible type,
2. Single-voltage, non-reversible type,
3. Single-voltage reversible and with thermostat type,
4. Single-voltage, non-reversible with magnetic switch type,
5. Two-voltage, non-reversible type,
6. Two-voltage, reversible type,
7. Single-voltage, three-lead reversible type,
8. Single-voltage, instantly-reversible type,
9. Two speed type, and
10. Two-speed with two-capacitor type.

These motors can be used for various purposes depending upon the need of the user. The starting, speed/torque characteristics of each of the above motors can be analyzed before employing them in work.