UNIT III- Electrical Motors

1. **Unit III - Topic A**
   - Construction of DC Motor
   - Working Principle of DC Motor
   - Speed-Torque Characteristics
   - Applications of DC Motor
2. **Unit III – Topic B**
   - Construction of Three Phase Induction Motor
   - Working Principle of Three Phase Induction Motor
   - Torque-Slip Characteristics
   - Applications of Three Phase Induction Motor

UNIT-III- Electrical Motors

3. Unit III - Topic C

- Working Principle of Single Phase Induction Motor
- Starting methods of Single Phase Induction Motor
- Applications of Single Phase Induction Motor

Introduction

Electrical machine are of two types

i. AC Machines

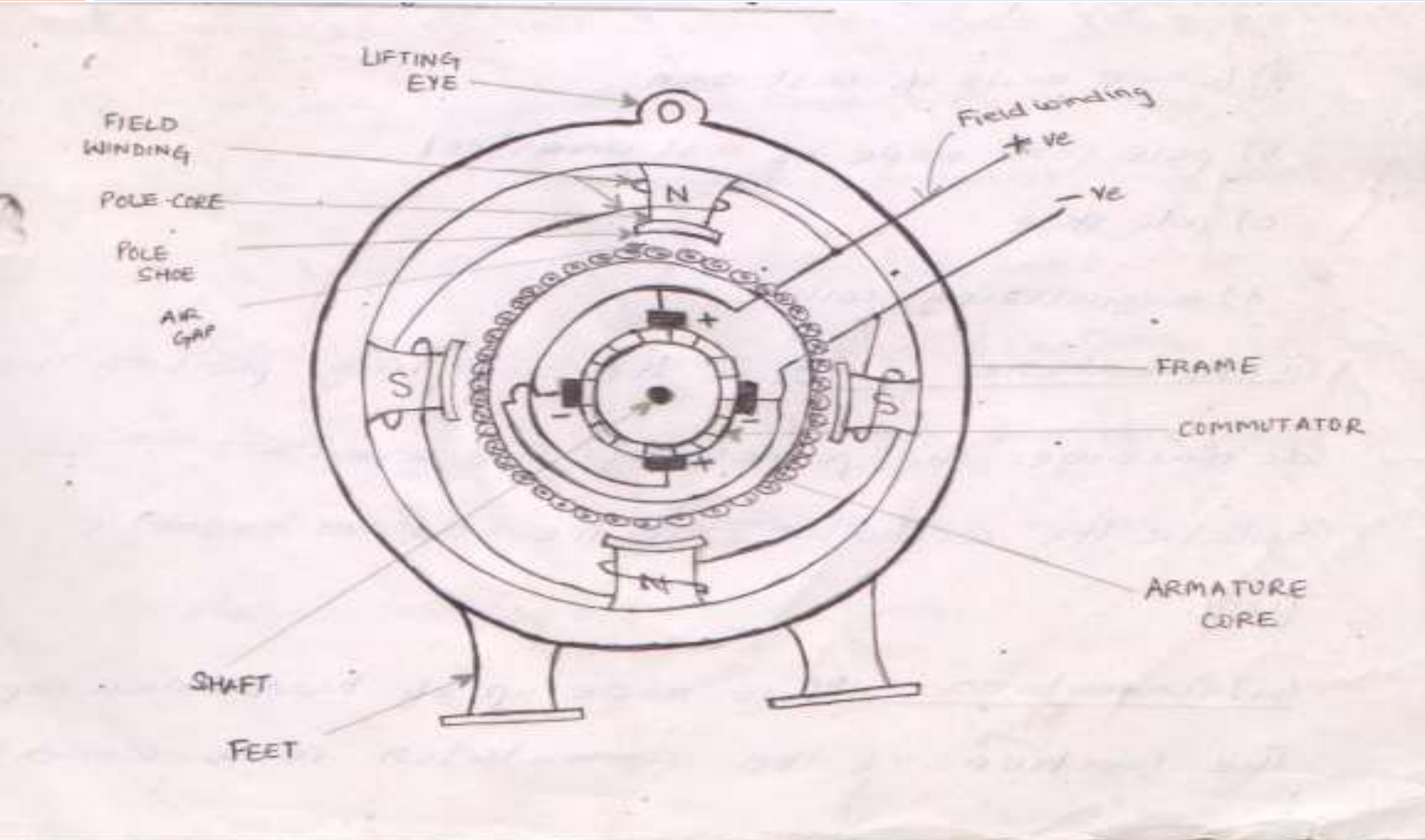
ii. DC Machines

DC machines either convert electrical energy into mechanical energy or mechanical energy into electrical energy. On this basis, dc machines are of two types:

(a) DC Generators (ME to EE)

(b) DC Motors (EE to ME)

Construction of DC Motor



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In construction, DC machine (or dc motor) consists of mainly four parts:

i. Field magnets
ii. armature
iii. Commutator
iv. Brush

Field magnets: The function of the field magnets is to create a uniform magnetic field within which the armature rotates. Electromagnets are preferred on account of its Greater magnetic effect. It has four parts (a) Frame made of cast iron, (b) pole core made of cast steel, (c) pole shoe (d) magnetizing coils

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Armature: It is the rotating part of the dc motor. The purpose of the armature is to rotate the conductors in the uniform magnetic field.

Commutator: It is made up of hard drawn copper. The function of the commutator in a dc motor is to produce unidirectional torque.

Brush: It is made up of copper. The function of the brush is to collect the current from the supply and give it to the armature conductors.

DC Motor

Principle of Operation:

The principle of operation of dc motor is very simple .If a current carrying conductor is placed in a magnetic field, a mechanical force is experienced in the conductor. Hence, the conductor moves in the direction of the force. The magnitude of the mechanical force experienced on the conductor is given by

where,

$$\boxed{F = B\, I_c\, L_c \text{ Newtons}}$$

B = magnetic field strength in Tesla

I_c = Current flowing through the conductor in ampere

L_c= length of the conductor in meter.

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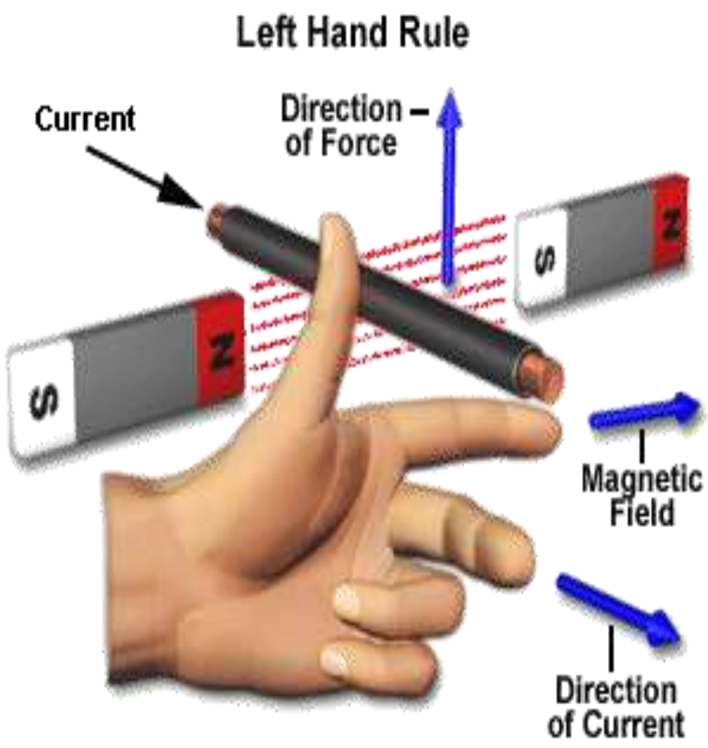
The direction of the mechanical force will be given by **Flemings Left Hand Rule.**

Fleming's Left Hand Rule can be stated as below:

"Extend the thumb, forefinger and middle finger of the left hand at right angles to one another. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb will point in the direction of the force."



Types of DC Motors

DC Motors can be of the following types:

i. DC Shunt Motor

ii. DC Series Motor

iii. DC Compound Motor

   (a) Short Shunt Compound Motors or Long Shunt compound motors.

   (b) Cumulative Compound Motors or Differential compound motors.

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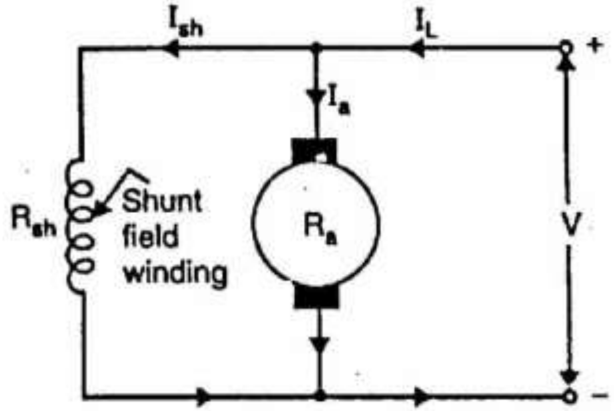
i. DC Shunt Motor:

Here, the field winding is connected in parallel with the armature as shown in the Fig. The current through the shunt field winding is not the same as the armature current.



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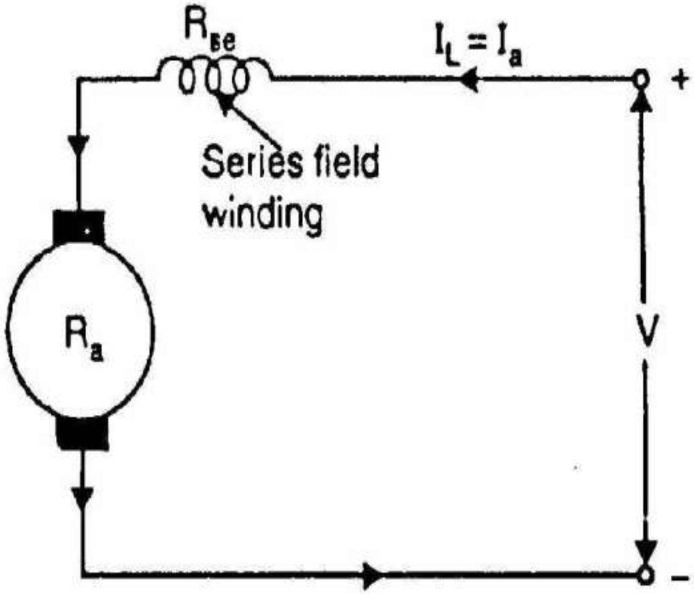
ii. DC Series Motor:

Here, the field winding is connected in series with the armature as shown in the fig. Therefore, series field winding carries the armature current. Here, the current passing through a series field winding is the same as the armature current



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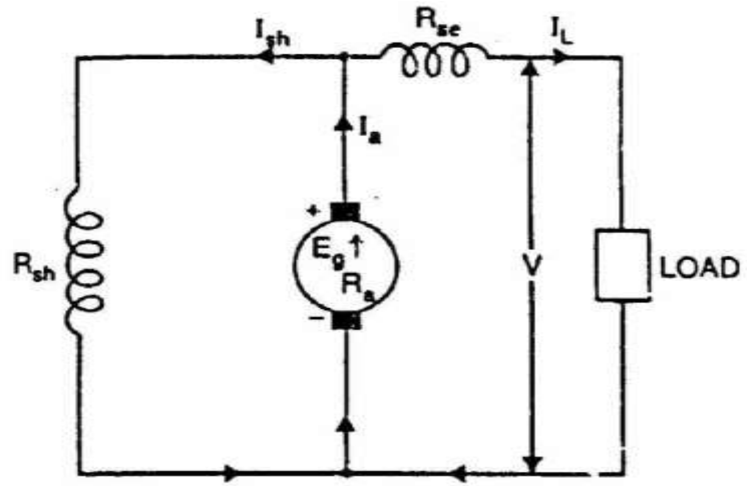
iii. Cumulative Compound motor:

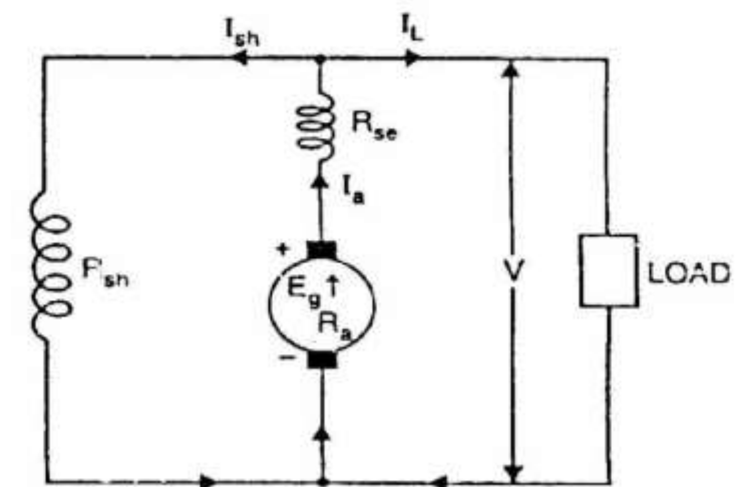
(a) Short Shunt Compound Motors

Here, shunt field winding is in parallel with the armature winding.



Long Shunt Compound Motors:

Here, shunt field winding is in paralle with both series field and armature winding.



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(b)Cumulative compound motors or Differential compound motors:

Cumulative compound motors: Here, the flux of the series field winding assists the flux produced due to shunt field winding.

Differential compound motors: : Here, the flux of the series field winding opposes the flux produced due to shunt field winding

Characteristics of DC Motors

(i) Torque and Armature Current Characteristics(T_q/I_a)

(electrical characteristics of the motor)

(ii) Speed and armature current characteristics (N/I_a)

(iii) Speed and torque characteristics (N/T_a)

(mechanical characteristics of the motor)

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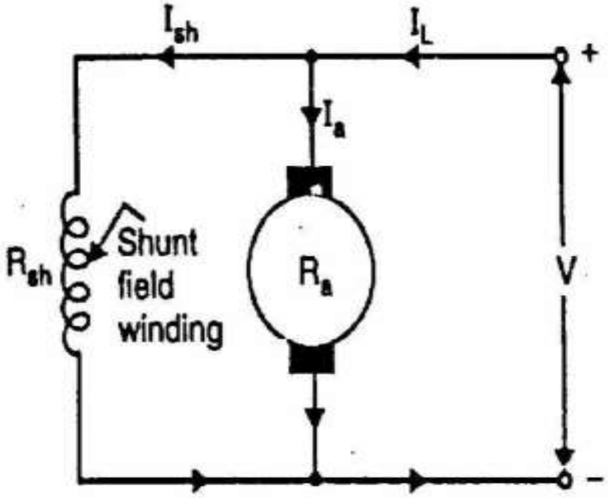
1. Characteristics of DC Shunt Motor

The Fig shows the connections of dc shunt motor. Here, the field current I_{sh} is constant. Since the field winding is in parallel with the supply voltage V which is assumed constant, **the flux in a dc shunt motor is constant.**



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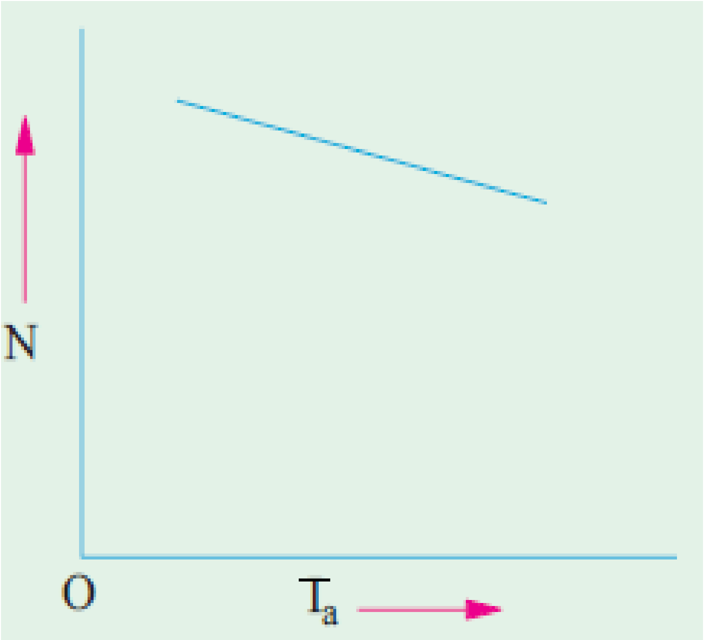
Speed – Torque Characteristic:

This characteristic can be obtained by plotting the values of N and T_a for various armature currents. It can be seen that the speed falls somewhat as the load increases.



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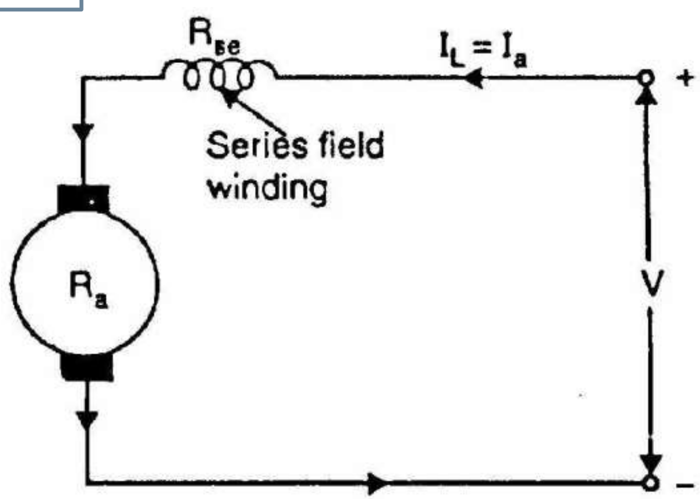
2. Characteristics of DC Series Motors

The fig shows the connections of dc series motor. Here, the field current I_{se} is same as that of armature current. If the mechanical load on the motor increases, the armature current increases and hence the field current. **Hence The flux in a dc series motor is directly proportional to the armature current.**

$$\boxed{\phi \propto I_a}$$



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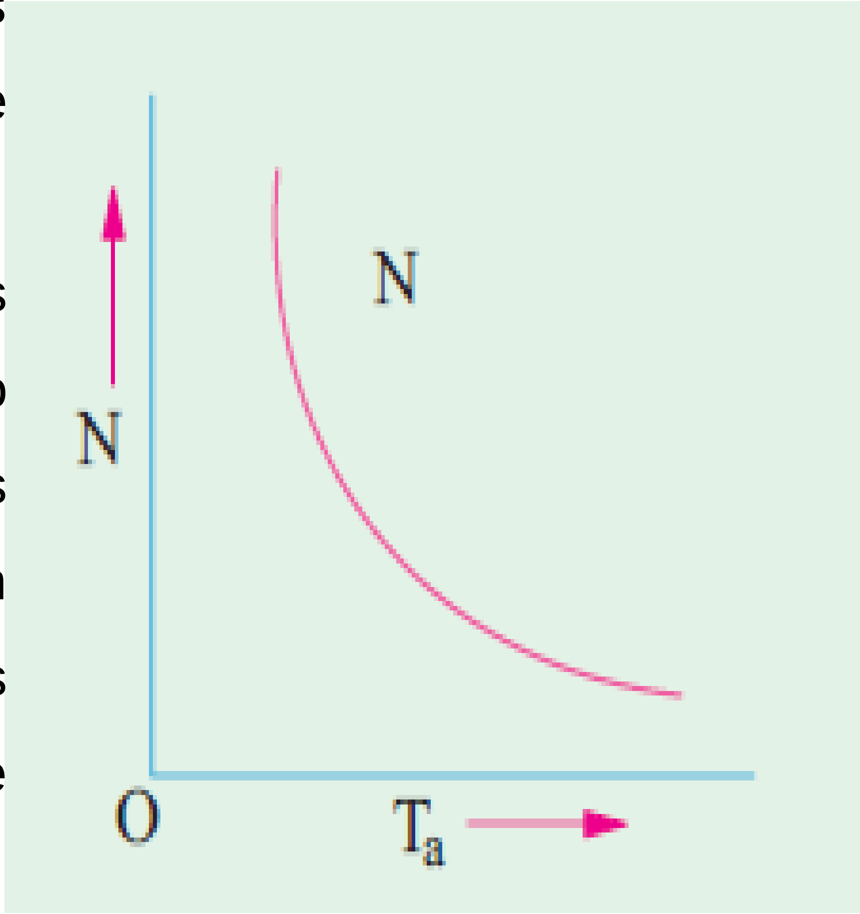
Speed – Torque Characteristic

It is clear that the series motor develops high torque at low speed and vice versa. This curve is obtained by plotting the values of N and T_a for various armature currents. This curve is so because an increase in torque requires an increase in armature current, which is also the field current. The result is that the flux is strengthened and the speed drops($N \propto \frac{1}{\emptyset}$)



Application of DC Motors

1. Shunt motors:

(i) where the speed is required to remain almost constant from no-load to full-load.

(ii) where the load has to be driven at a number of speeds and any one of which is required to remain nearly constant.

***Industrial use:* *Lathes, drills, boring mills, shapers, spinning and weaving* machines etc.**

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2. Series motors:

(i) where large starting torque is required e.g., in elevators and electric traction.

(ii) where the load is subjected to heavy fluctuations and the speed is automatically required to reduce at high torques and vice-versa.

Industrial use: ***Electric traction, cranes, elevators, air compressors, vacuum*** **cleaners, hair drier etc.**

Contd….

3. Compound motors:

Differential-compound motors are rarely used because of their poor torque characteristics. However, cumulative-compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

Industrial use: *Presses, shears, reciprocating machines etc.*

Three Phase Induction Motor

- Working Principle
- Construction
- Torque – Slip Characteristics
- Applications

Construction of Induction Motor

The three phase induction motor is the most widely used electrical motor. Almost 80% of the mechanical power used by industries is provided by three phase induction motors because of its simple and rugged construction, low cost, good operating characteristics, absence of commutator and good speed regulation. In three phase induction motor the power is transferred from stator to rotor winding through induction.

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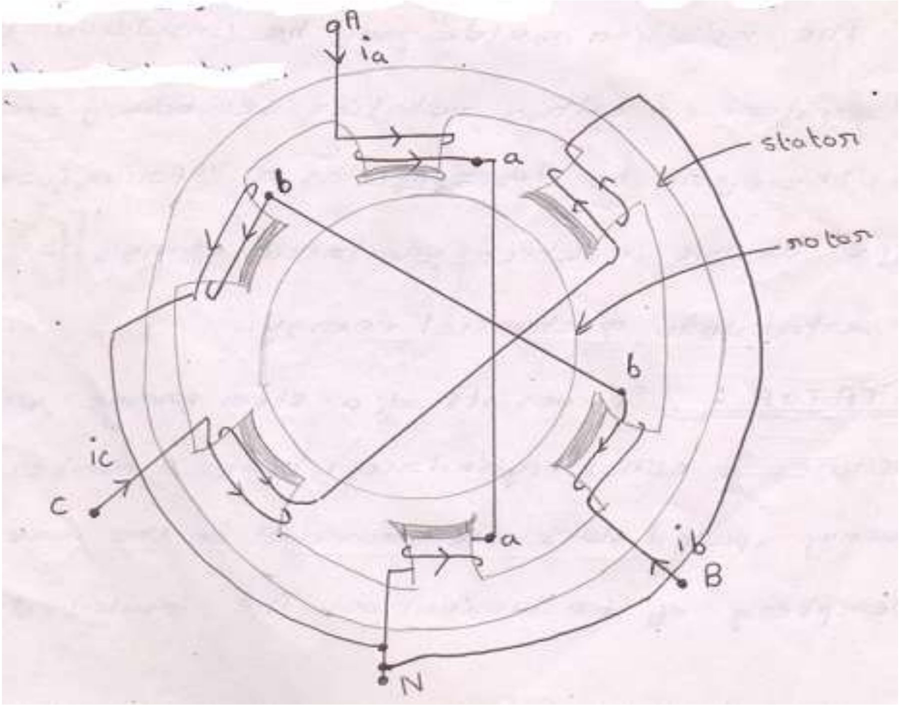
Like any other electrical motor induction motor also have two main parts namely rotor and stator.

Stator: As its name indicates stator is a stationary part of induction motor. A stator winding is placed in the stator of induction motor and the three phase supply is given to it. The three phase stator winding is wound for a definite number of poles as per the requirement of speed.



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Greater the number of poles, lesser is the speed of motor and vice versa. When a 3 phase supply is given to the stator winding, a rotating magnetic field of constant magnitude is produced. This rotating field induces current in the rotor by electromagnetic induction.

Rotor: The rotor is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft.

The rotor of the three phase induction motor are further classified as

i. Squirrel Cage Rotor
ii. Slip Ring Rotor or Wound Rotor.

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Depending upon the type of rotor construction used. Induction motor can be of the following types

i. Squirrel Cage Induction motor

ii. Slip Ring Induction Motor or Wound Induction motor .

Note: The stator of both the types of Induction motor is same.

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Squirrel Cage Induction Rotor: Almost 90 % of induction motors are Provided with squirrel cage rotor because of its simple and robust construction. The rotor of the squirrel cage three phase induction motor is cylindrical in shape and have slots on its periphery. The slots are not made parallel to each other but are bit skewed.

One aluminum or copper conductor is placed in each slot. A both ends of the rotor, the rotor conductors are short circuited by the continuous end rings. The rotor conductors and the end rings forms a complete closed circuit resembling a squirrel cage and hence its name.

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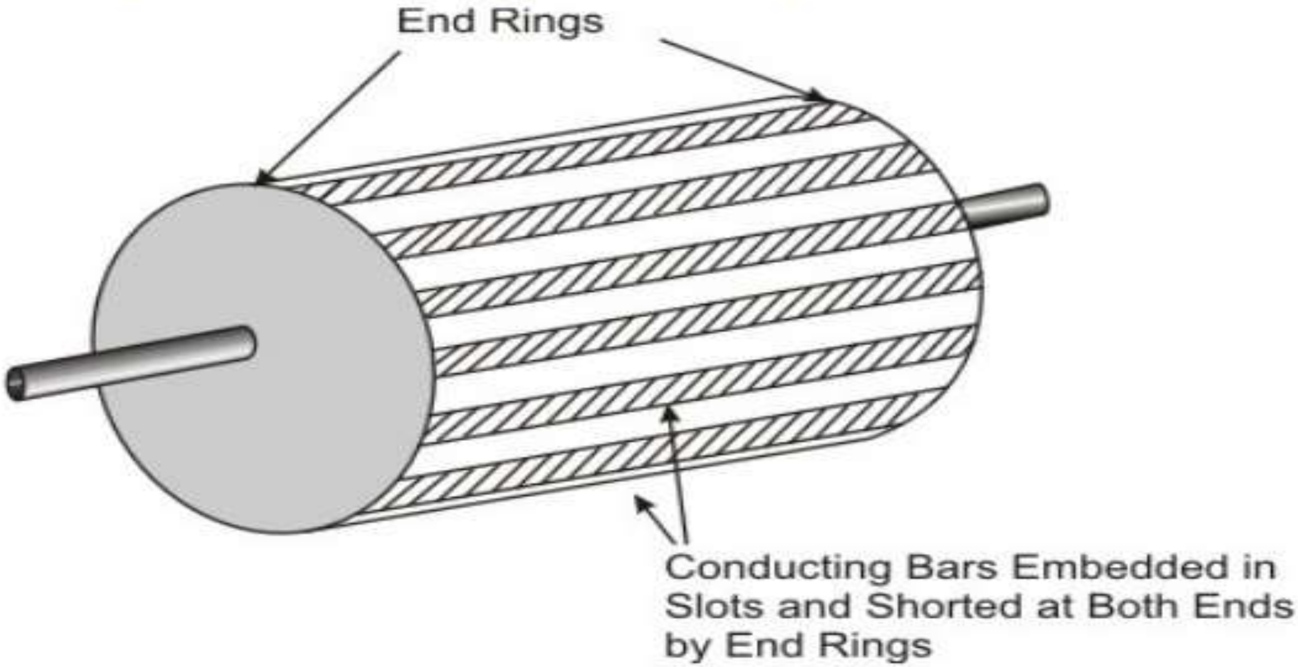
Simple view of squirrel cage induction rotor



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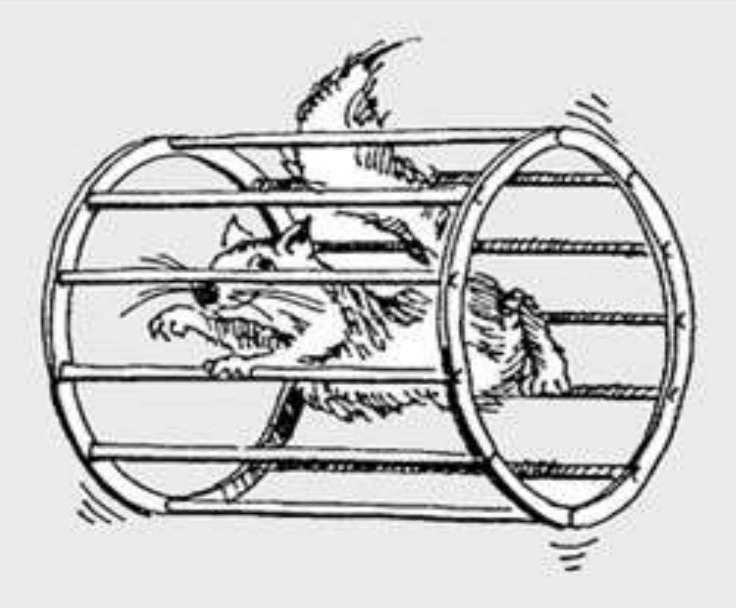
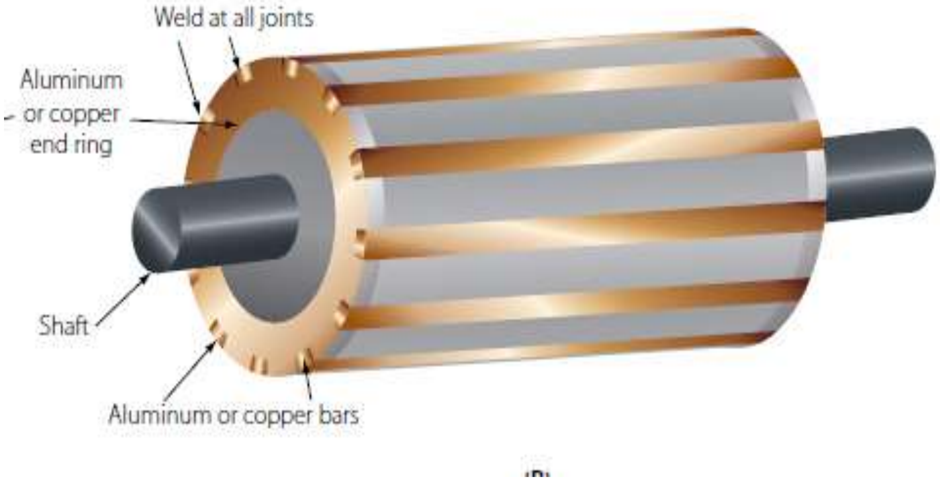
More Images of Squirrel Cage Induction Rotor





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Slip Ring Induction Rotor: Here three phase winding is also provided in the rotor. The rotor is wound for the same number of poles as the stator. The rotor winding is star or delta connected but star connection is always preferred. The three finish terminals are connected together to form a star and the three start terminals are brought out and connected to three slip rings . The slip rings are mounted on the rotor shaft. The slip rings are connected further to three star connected external resistors with the help of brushes.

The purpose of the external resistors is for starting and speed control. At the time of starting, the entire resistance is included in the rotor

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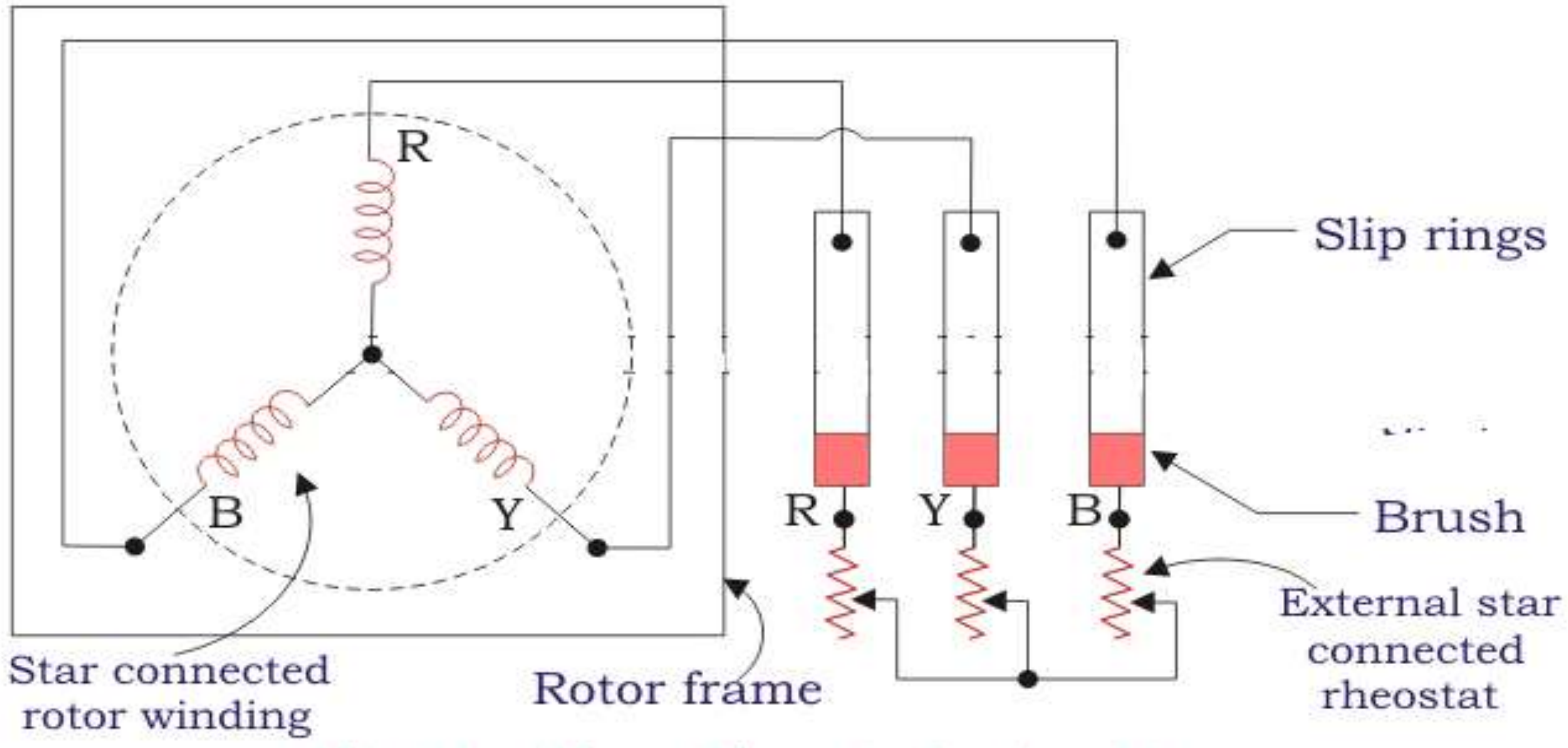
circuit and this resistances is gradually cut out as the motor picks up the speed.



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Slip Rings: **Slip ring** is an electromechanical device that allows the transmission of electrical signals from a stationary to a rotating structure.

Working Principle of Three Phase Induction Motor

In a DC motor, supply is needed to be given to the stator winding as well as to the rotor winding. But in an **induction motor** only the stator winding is fed with an AC supply.

The principle of operation of three phase induction motor can be explained with the help of the following points:

- When a 3 phase supply is given to the stator winding of a three phase induction motor, a rotating magnetic field is set up which rotates around the stator at synchronous speed(N_s=120f/P)

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- The rotating field passes through the air gap and cuts the rotor conductors which are yet stationary and hence emf is induced in the rotor conductors. Since the rotor conductors are short circuited, current starts flowing in the rotor conductors.
- The current carrying rotor conductors are placed in the magnetic field produced by the stator. Consequently, mechanical force acts on the rotor conductors.

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The sum of all the mechanical forces due to all the rotor conductors produces a torque which tends to move the rotor in the same direction as the rotating field.

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Synchronous Speed : The speed at which the revolving flux rotates is called the synchronous speed(N_s=120f/P)

Slip: We have seen that the rotor rapidly accelerates in the direction of the rotating field. In practice, the rotor never reaches the speed of the stator flux. If it dis, there would be no relative speed between the stator field and the rotor conductors, no induced rotor currents, and, therefore, no torque to drive the rotor. The friction and the windage would definitely cause the rotor to slow down. Hence the rotor speed (N_r) is always less than the stator speed(N_s).

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The difference between the synchronous speed N_s of the rotating stator field and the actual rotor speed N_r is called slip. It is actually expressed as percentage of synchronous speed.

i.e., Slip, s = $\frac{N_s - N_r}{N_s}$ **x 100%**

- **The quantity (N_s- N_r) is also called slip speed.**
- **When the rotor is stationary(i.e., N_r = 0), slip is 1 or 100%**

Torque Slip Characteristics

- Torque of an induction motor being due to interaction of stator and rotor fields, depends upon strength of those field and phase relation between them.
- Torque is directly proportional to:

  (i) Rotor current

  (ii) Stator flux /pole φ

  (iii) Power factor of rotor circuit, $\cos\phi_2$

  i.e., Torque $\propto I_2 \phi \cos\phi_2$

Also Rotor emf E_2 at standstill is directly proportional to ϕ.

$$\boxed{\text{i.e., } T \propto I_2 E_2 \cos\phi_2}$$

Contd…..

Also,

$$Rotor\ current, I_2 = \frac{sE_2}{\sqrt{R_2^2 \ + \ (sX_2)^2}}$$

$$Power\ factor\ of\ rotor\ current, \cos\emptyset_2 = \frac{R_2}{\sqrt{R_2^2 \ + \ (sX_2)^2}}$$

Therefore, $T = KE_2 \frac{sE_2}{\sqrt{R_2^2 + s^2X_2^2}} \times \frac{R_2}{\sqrt{R_2^2 + s^2X_2^2}} = \frac{KsR_2E_2^2}{R_2^2 + s^2X_2^2}$ ……….2

Therefore, electromagnetic torque developed in a three phase induction motor is given by Equation 2

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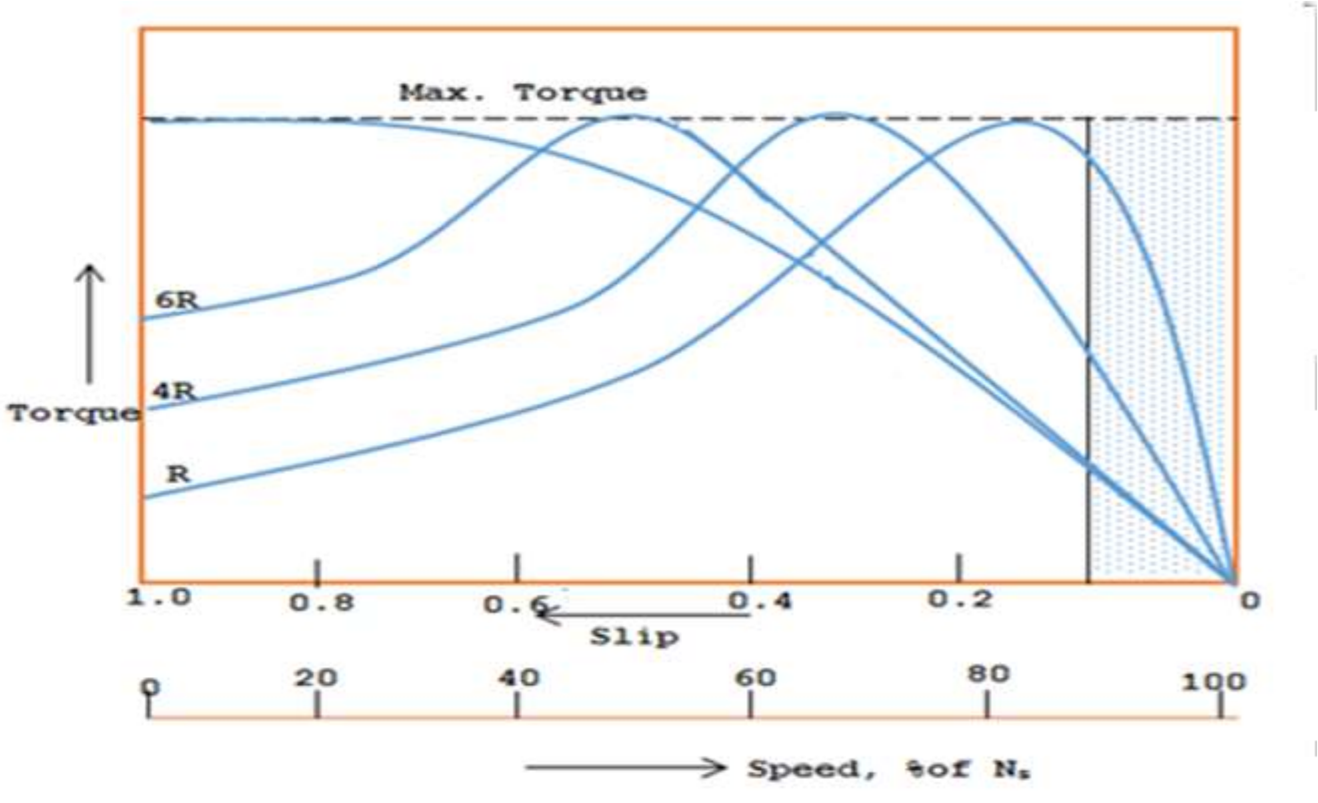
The variation of torque with slip, or speed, of an induction motor can be plotted from the equation of torque given in eq. 2. for different values of slip s.



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Under normal operating condition, the rotor revolves in the direction of the rotating field produced by the stator currents. As such, the slip varies from 1 at standstill to 0 at synchronous speed.

Effect of Rotor Resistance: As the rotor resistance is increased, the maximum torque remains the same, but the slip at which maximum torque occurs goes on decreasing.

Applications of Three Phase Induction Motor

Slip Ring Induction Motor: These motors are used in places where high starting torque is required(also starting current should be low) such as pumps, fan, compressors and lifts.

Squirrel Cage Induction Motor: They find their applications under various circumstances as follows:

(a) Low starting torque with normal starting current, eg: fans and centrifugal pumps

(b) Normal torque with normal starting current, eg: fans, blowers, centrifugal pumps

(c) High torque with low starting current:eg: conveyers, crushes, reciprocating pumps

(d) High torque with medium and high slip, eg: punches, die stamping

Single Phase Induction Motor

Working principle: A single phase induction motor consists of a single phase winding on the stator and a squirrel cage winding on the rotor. Since single phase supply is given to to the stator winding of a single phase induction motor, it does not produce a rotating magnetic field. Hence a single phase induction motor is inherently not self starting and requires a special means to start.

If however, the rotor of a single phase induction motor is rotated by an auxiliary means and the starting device is then removed, the motor continues to rotate in the direction in which it is started.

Starting Methods of Single Phase Induction Motor

Single Phase Induction Motor can be classified according to the auxiliary means used to start the motor.

i. Split Phase Motor
ii. Capacitor start Motor
iii. Capacitor start capacitor run motor
iv. Shaded Pole Motor

Split Phase Single Phase Induction Motor

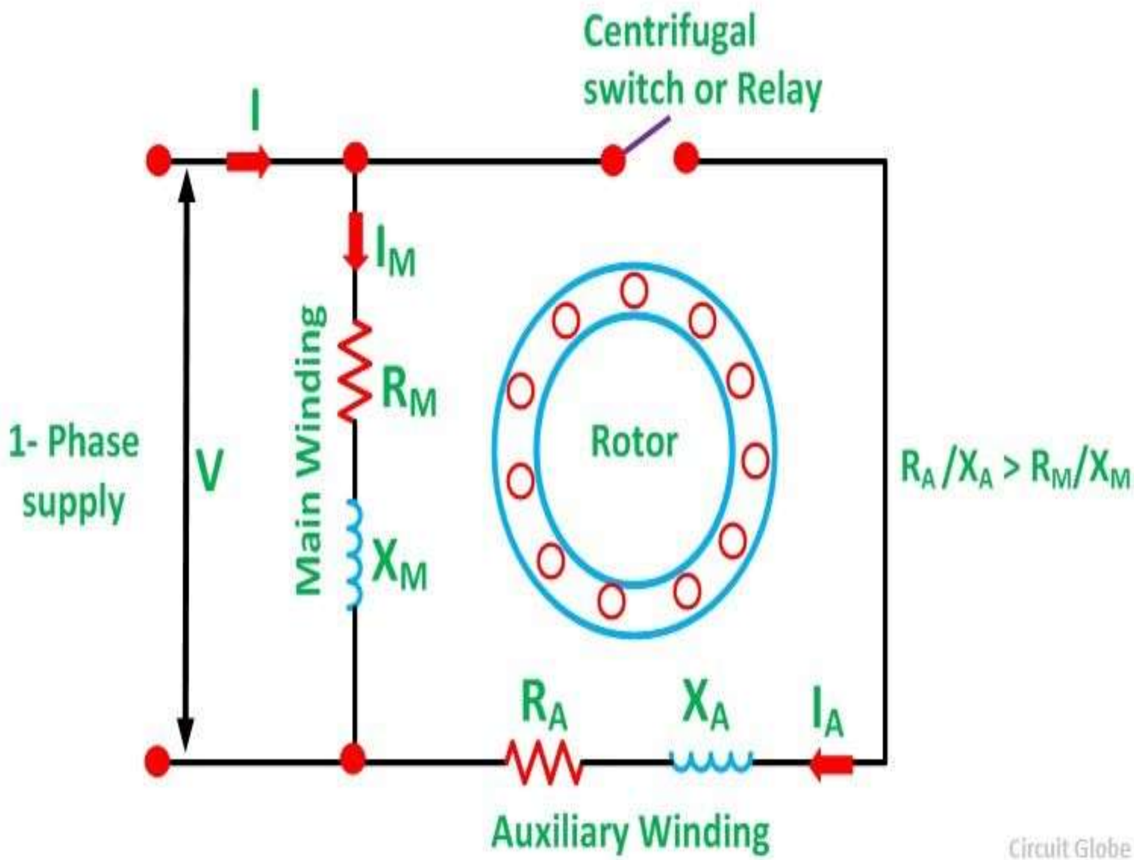

Fig.(a) Connection Diagram

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The **Split Phase Induction Motor** is also known as a **Resistance Start Motor**. It has a single cage rotor, and its stator has two windings known as main winding and starting winding. The main winding has very low resistance and a high inductive reactance whereas the starting winding has high resistance and low inductive reactance. The connection diagram of the motor is as shown in fig (a). At the starting of the motor both the windings are connected in parallel. As soon as the motor reaches the speed of about 70 to 80 % of the synchronous speed the starting winding is disconnected automatically from the supply mains with the help of the centrifugal switch.

Applications of Single Phase Induction Motor

Applications of single phase induction motors include washing machines, fans, mixer grinders, pumps, compressors, etc

Capacitor Start Single Phase Induction Motor

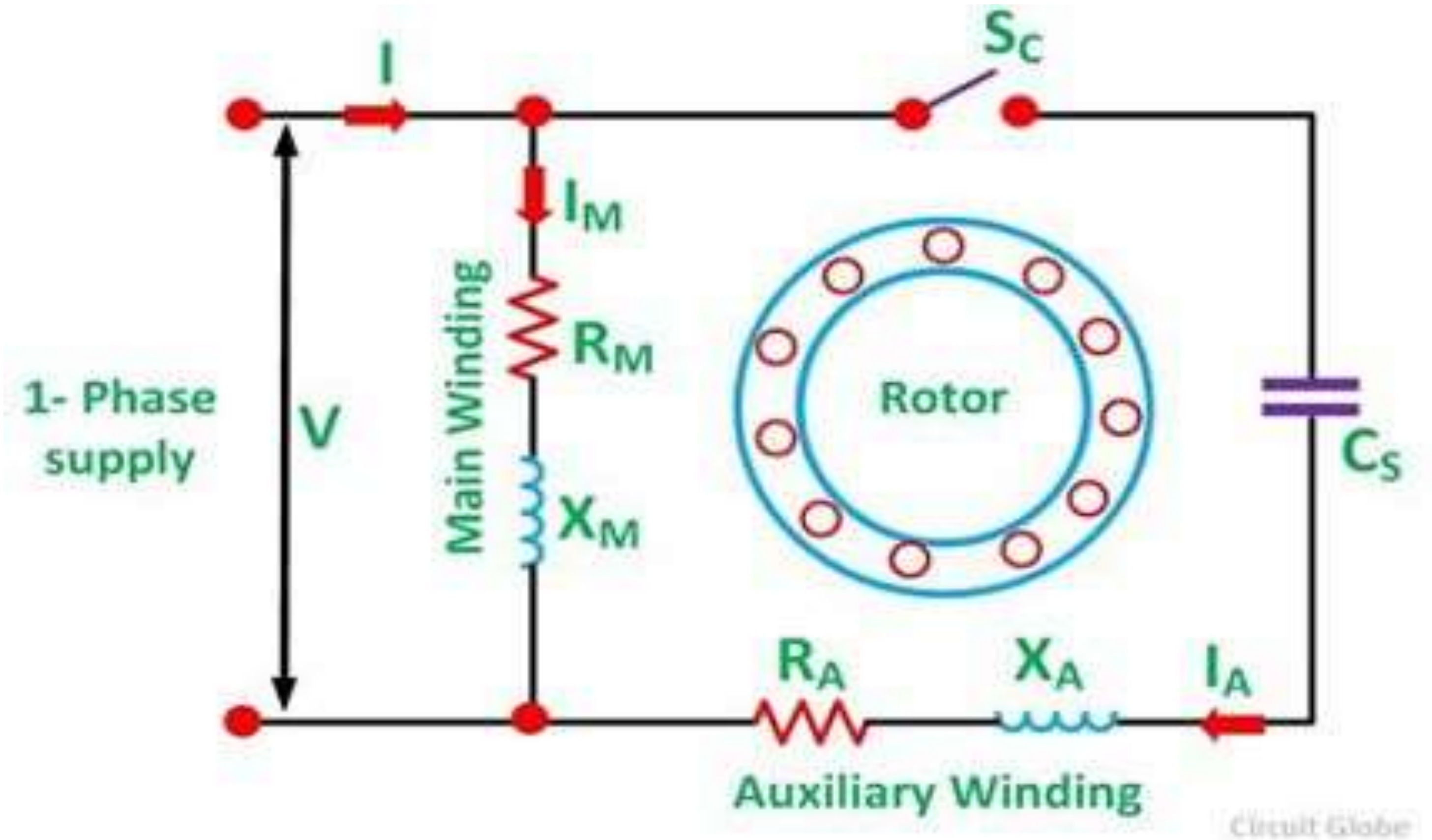
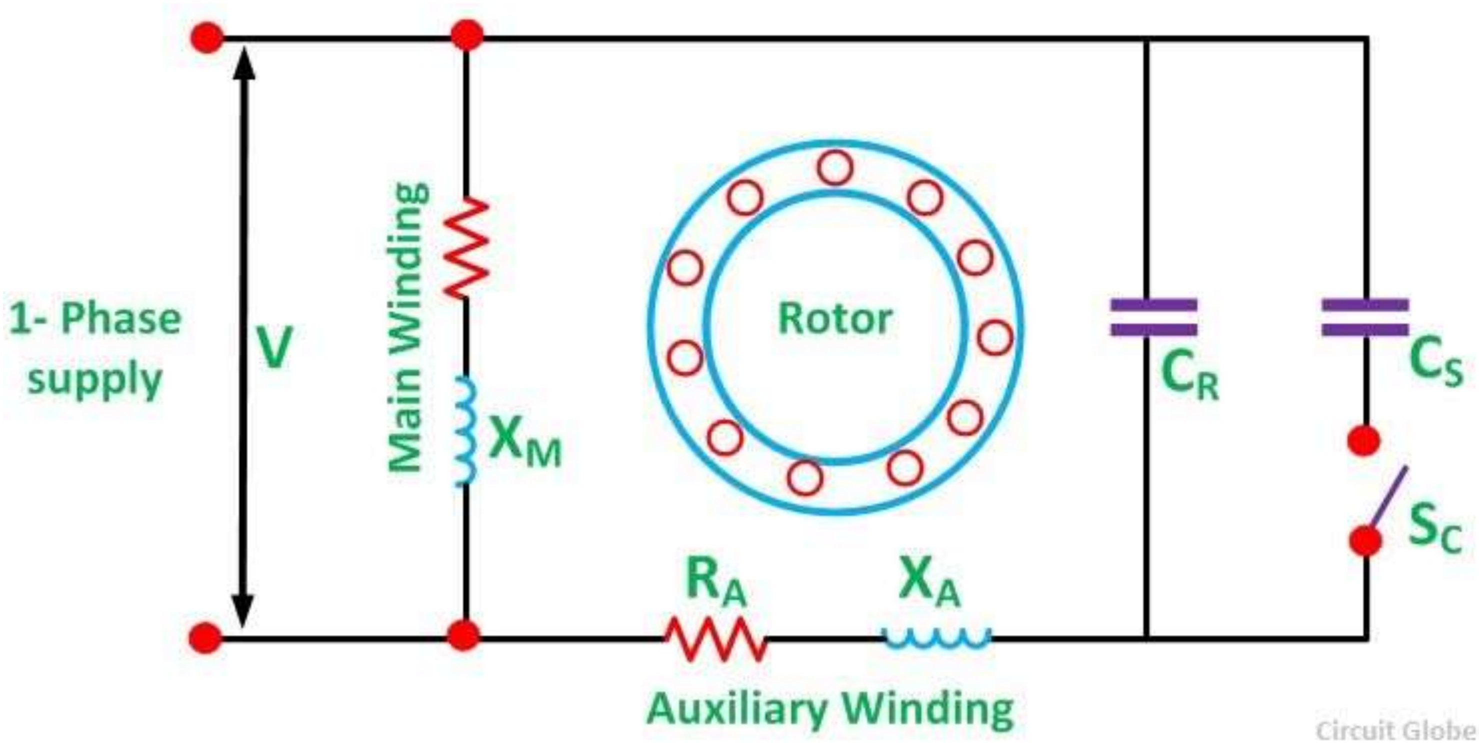


Fig.(a) Connection Diagram

The capacitor start motor has a cage rotor and has two windings on the stator. They are known as the main winding and the auxiliary or the starting winding. The two windings are placed 90 degrees apart. A capacitor C_S is connected in series with the starting winding. A centrifugal switch S_C is also connected in the circuit.

As the motor approaches its rated speed, the auxiliary winding and the starting capacitor is disconnected automatically by the centrifugal switch provided on the shaft of the motor.

Capacitor Start Capacitor Run Single Phase Induction Motor

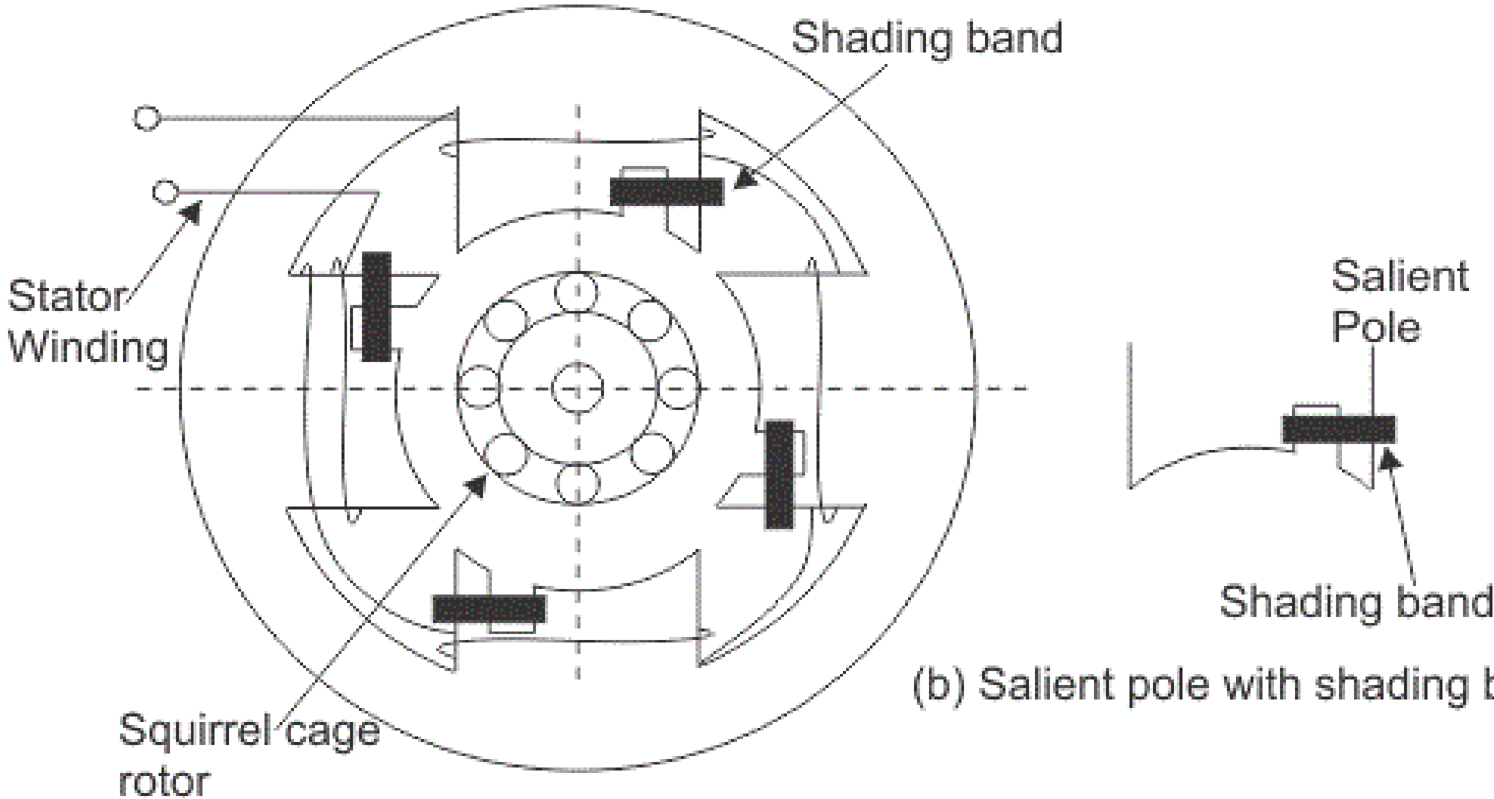


The **Capacitor Start Capacitor Run Motor** has a cage rotor, and its stator has two windings known as Main and Auxiliary Windings. The two windings are displaced 90 degrees in space. There are two capacitors in this method one is used at the time of the starting and is known as starting capacitor. The other one is used for continuous running of the motor and is known as RUN capacitor

There are two capacitors in this motor represented by C_S and C_R. At the starting, the two capacitors are connected in parallel.

As the motor reaches the synchronous speed, the starting capacitor Cs is disconnected from the circuit by a centrifugal switch Sc. The capacitor C_R is connected permanently in the circuit and thus it is known as RUN Capacitor.

Shaded-Pole Single Phase Induction Motor



(b) Salient pole with shading band

4-pole shaded pole construction

Features of Shaded Pole Induction Motor

- No auxiliary winding
- Has salient poles
- Each pole is split into two – one portion is surrounded by a short circuited coil called shading ring
- The flux produced by the shaded portion of the pole is displaced in time from the flux produced by the unshaded portion.
- The two fluxes interacts with each other which produces a force which starts the motor.

ALL THE BEST!!!!!