Induction Motor (Asynchronous Motor)

ELECTRICAL MACHINES

Overview of Three-Phase Induction Motor

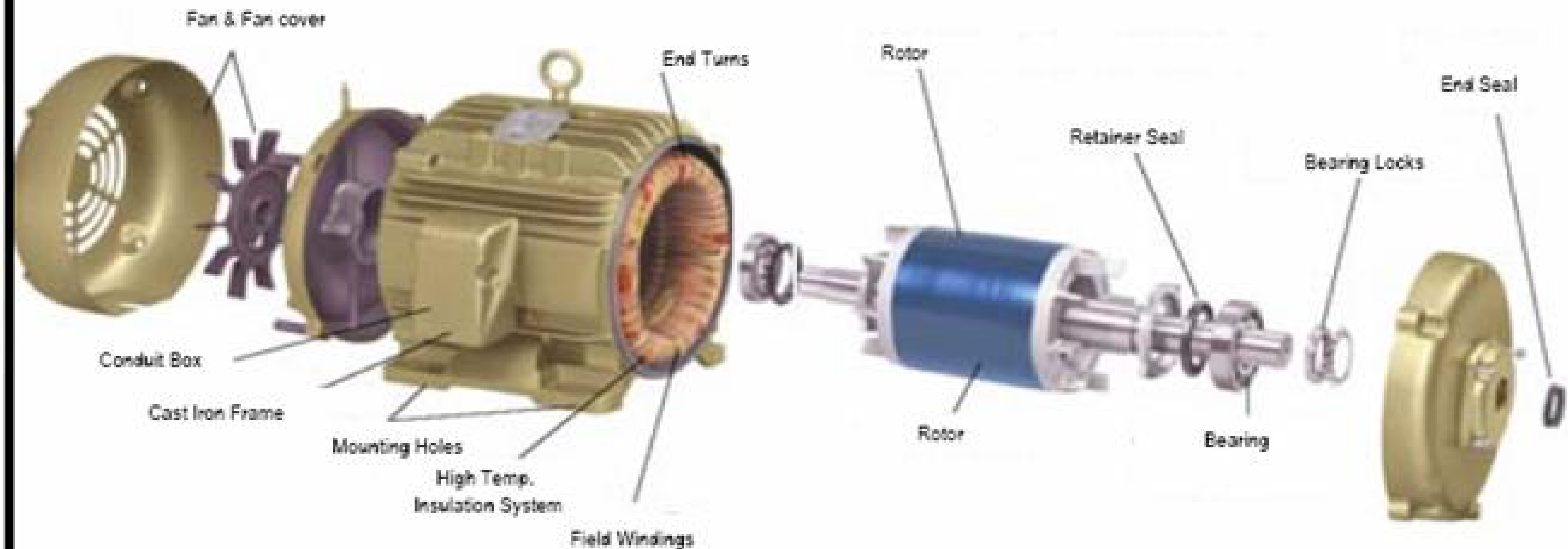
- Induction motors are used worldwide in many residential, commercial, industrial, and utility applications.
- Induction Motors transform electrical energy into mechanical energy.
- It can be part of a pump or fan, or connected to some other form of mechanical equipment such as a winder, conveyor, or mixer.

Introduction

General aspects

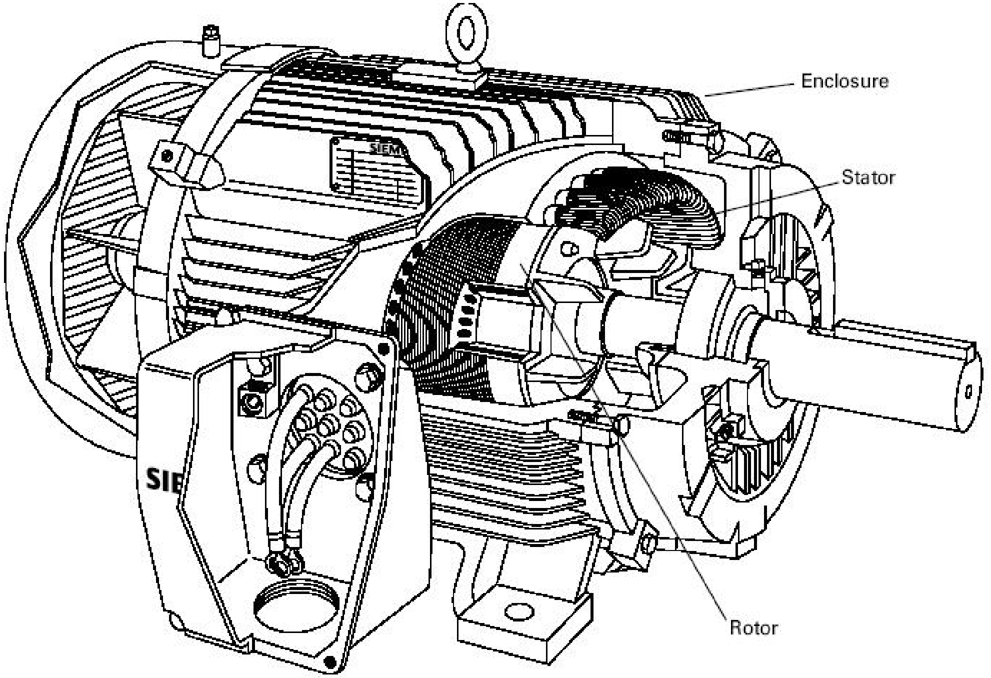
- A induction machine can be used as either a induction generator or a induction motor.
- Induction motors are popularly used in the industry
- Main features: cheap and low maintenance
- Main disadvantages: speed control is not easy

Parts of AC Motor



Construction

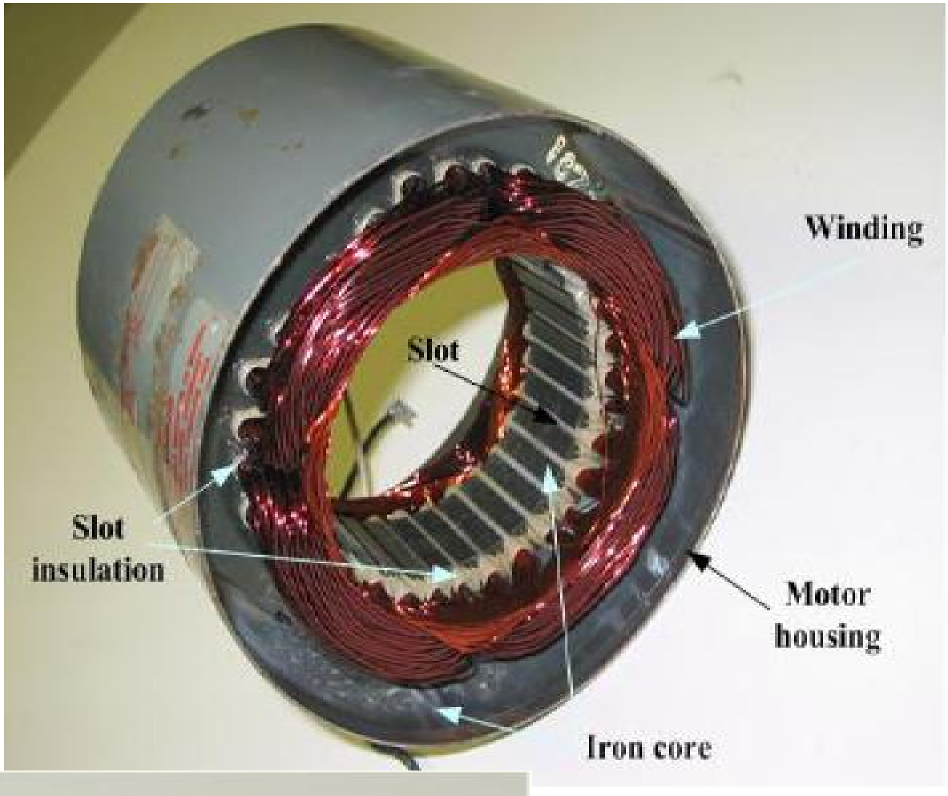
- The three basic parts of an AC motor are the rotor, stator, and enclosure.
- The stator and the rotor are electrical circuits that perform as electromagnets.



Construction

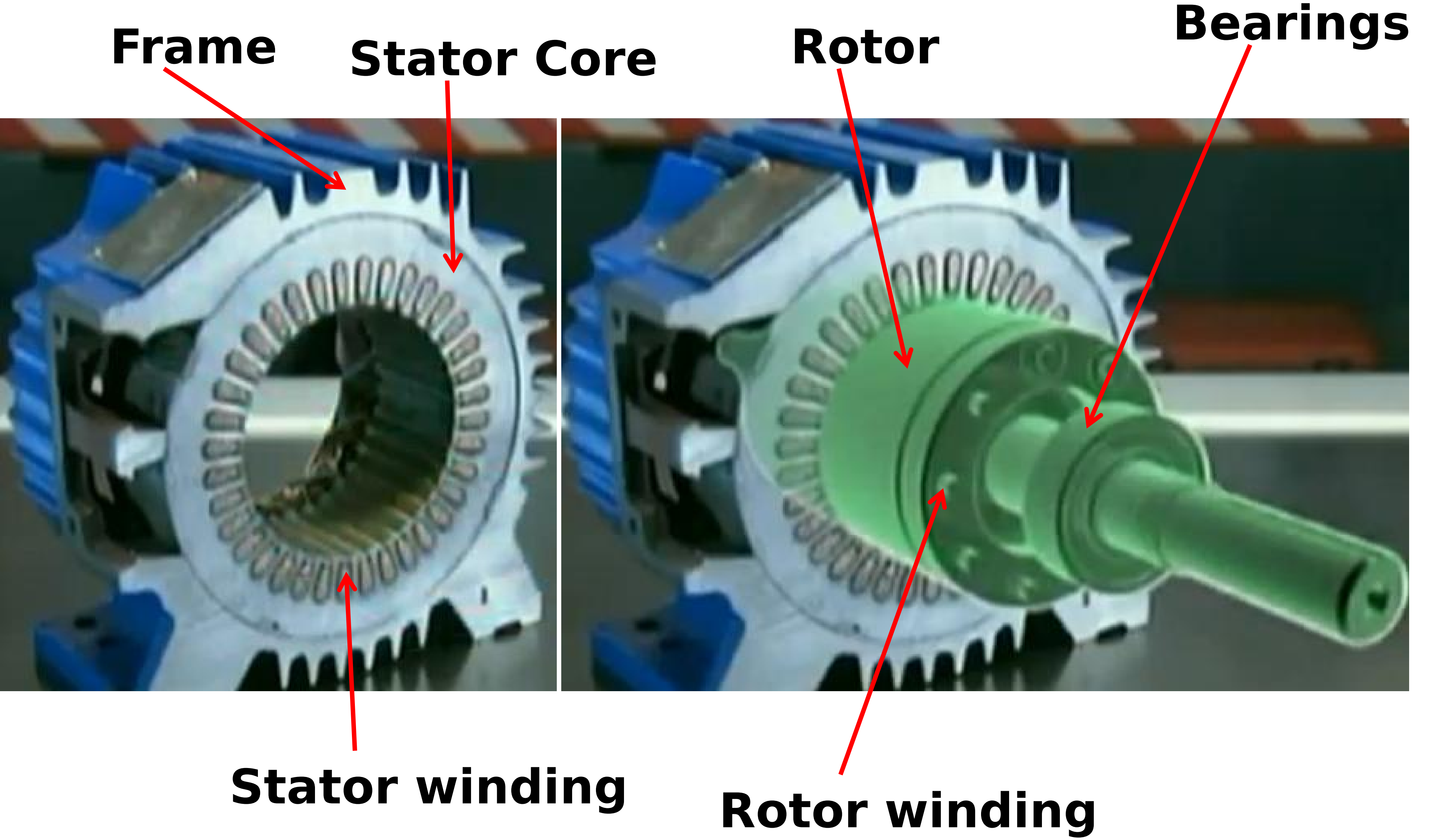
An induction motor has two main parts

1. Stator
2. Rotor



Stator

Parts	Material used	Work	Remarks
Stator Frame	Cast Iron	Provide Support	No Flux Passes
2 End covers	Cast Iron	Provide Support	
Stator Core	Laminated Silicon Steel	Hold windings	Provide flux Path
Distributed winding	Copper	Generate flux	High Conductivity
Bearings		Smooth rotation of shaft	


Frame
Stator Core
Rotor
Bearings
Stator winding
Rotor winding

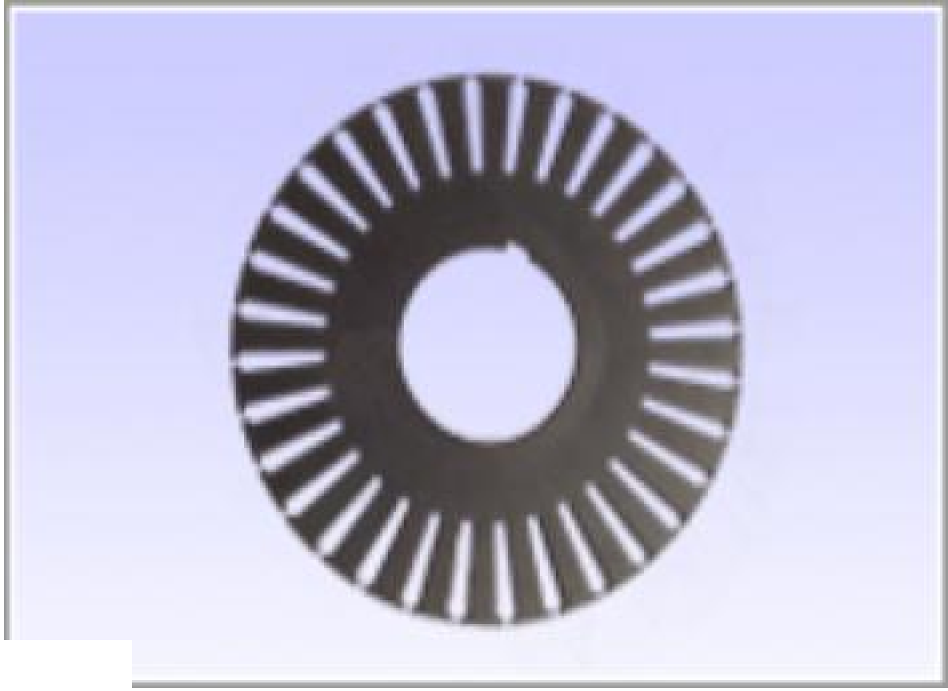

www.stator-rotor.com

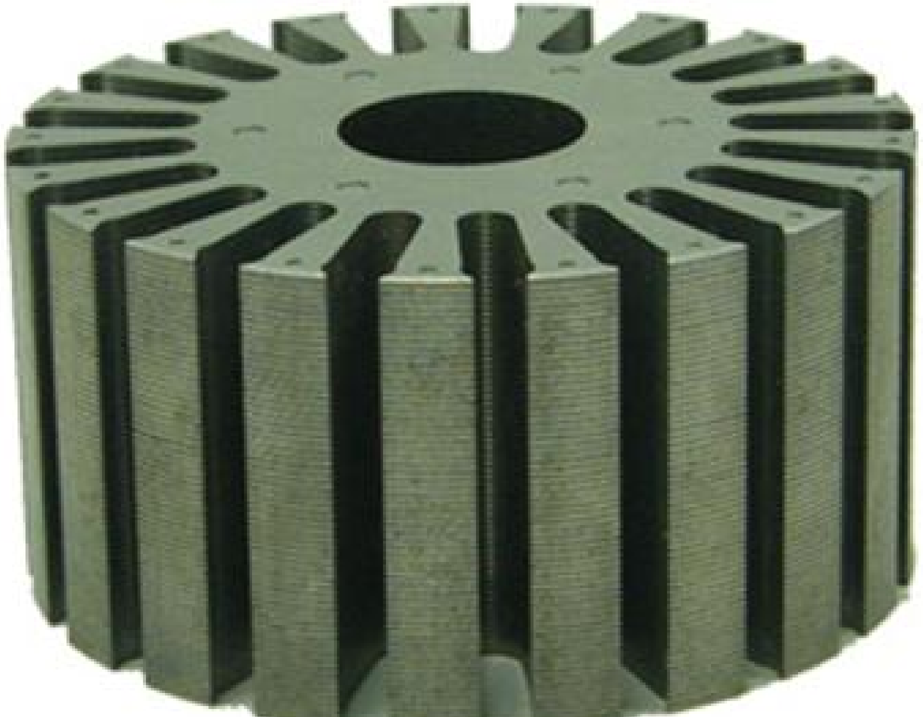
www.stator-rotor.com

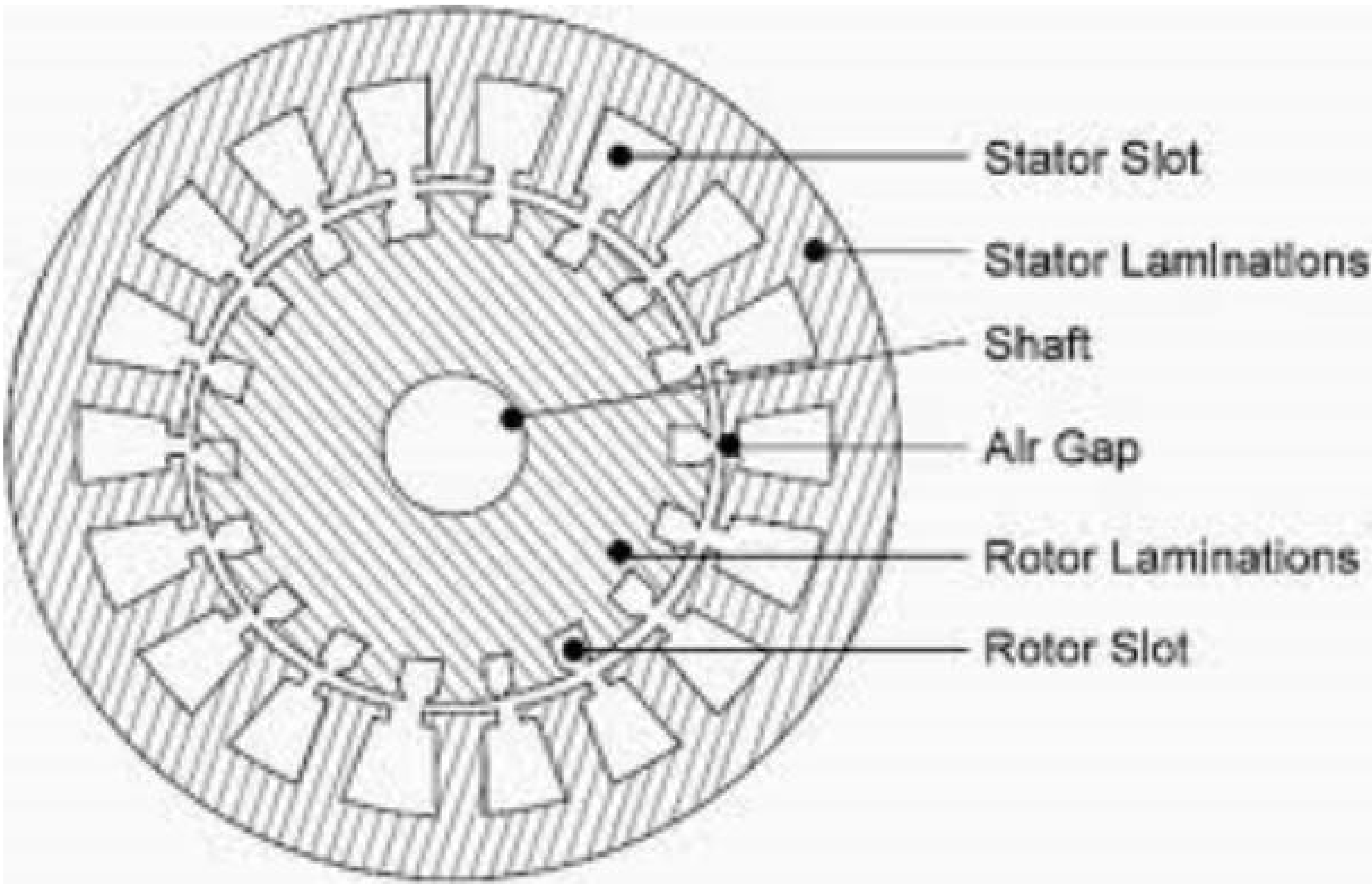
380 V
www.stator-rotor.com


Rotor

(Laminations)

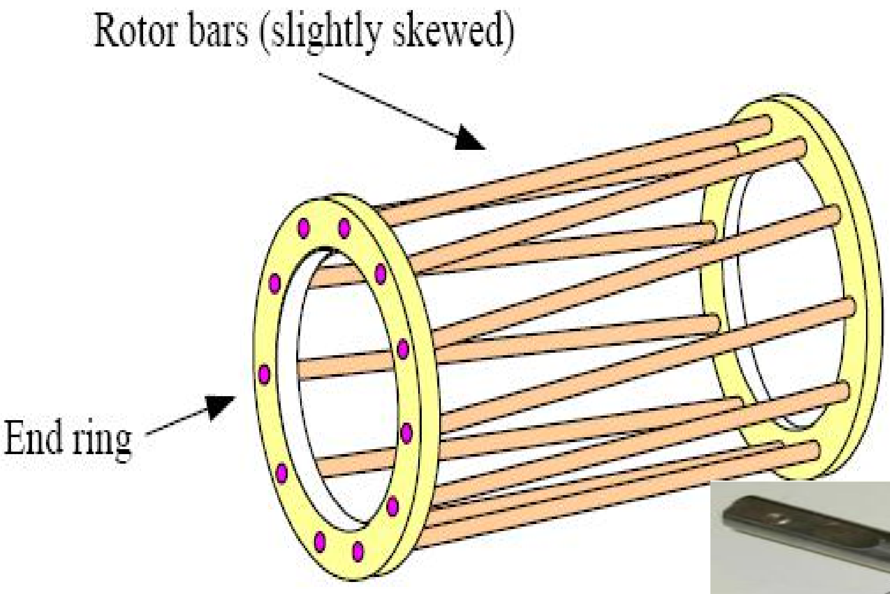


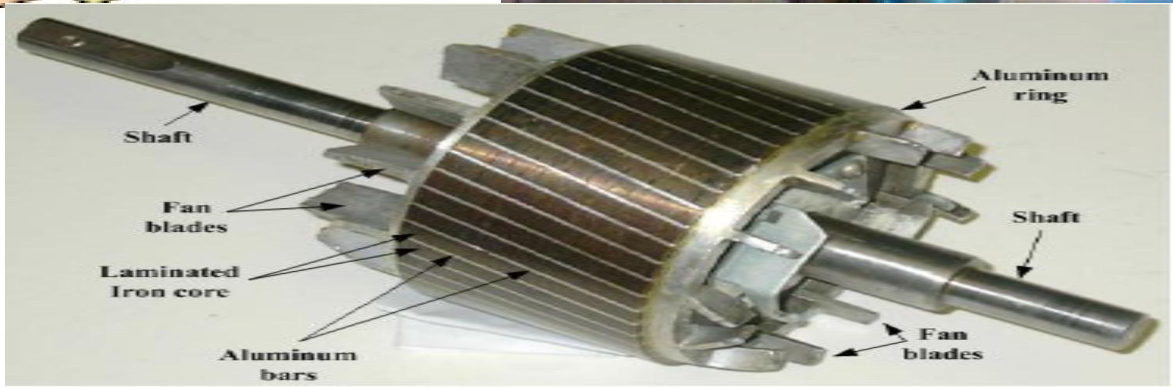



Stator Slot
Stator Laminations
Shaft
Air Gap
Rotor Laminations
Rotor Slot

Rotor

Types:
1. Squirrel-cage rotor
2. wound-rotor





Construction (Rotor construction)

- Induction motor types:
  - **Squirrel cage type:**

    Rotor winding is composed of copper bars embedded in the rotor slots and shorted at both end by end rings

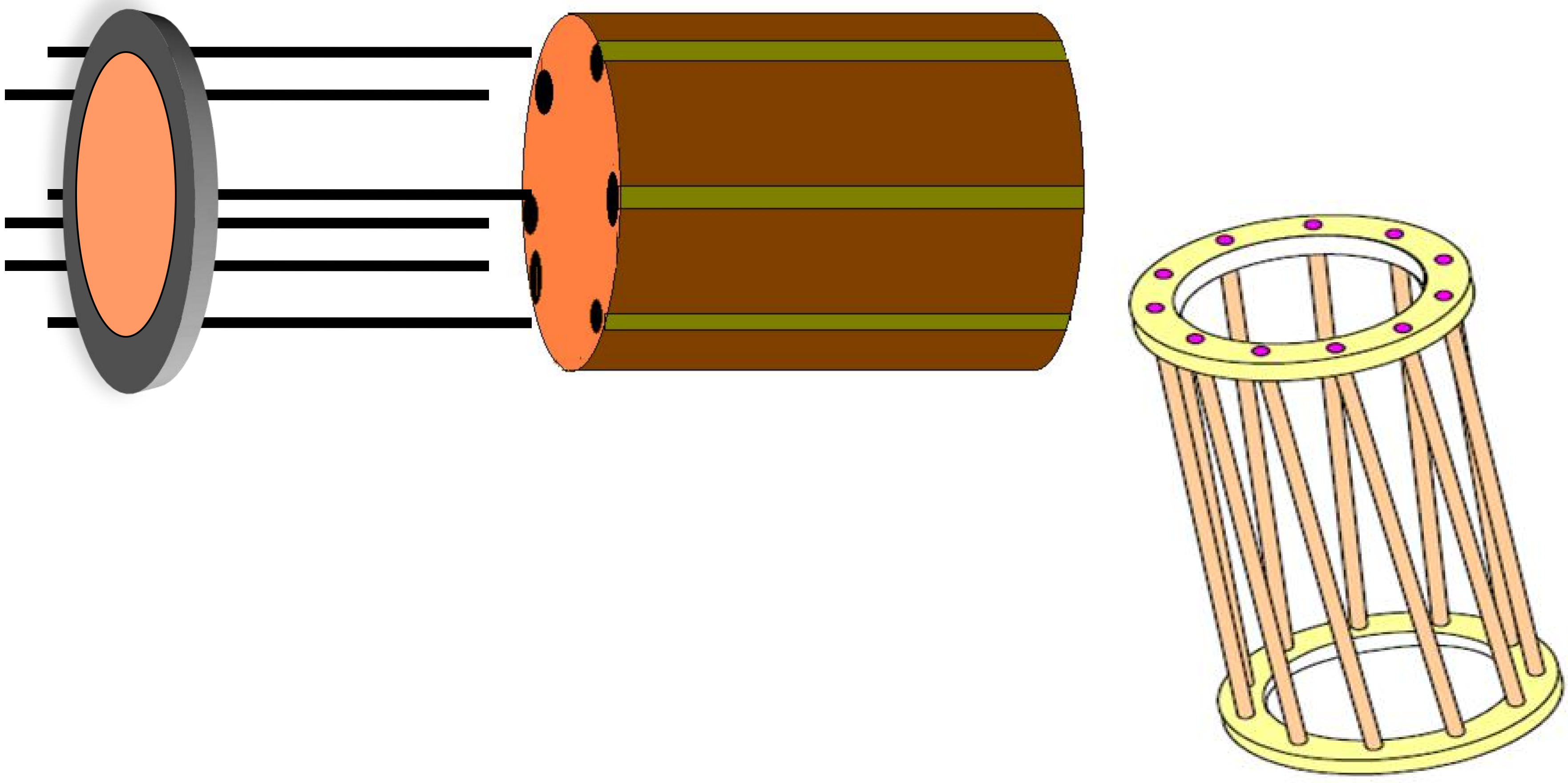
    Simple, low cost, robust, low maintenance

  - **Wound rotor type:**

    Rotor winding is wound by wires. The winding terminals can be connected to external circuits through slip rings and brushes.

    Easy to control speed, more expensive.

Squirrel-cage rotor



Squirrel Cage Rotor

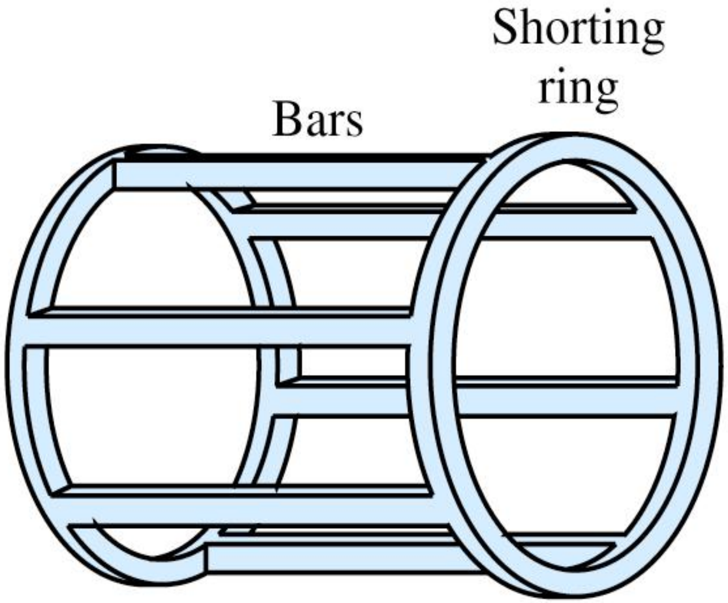
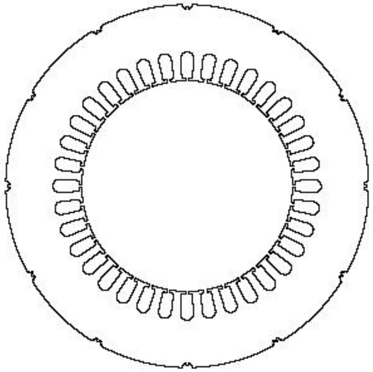
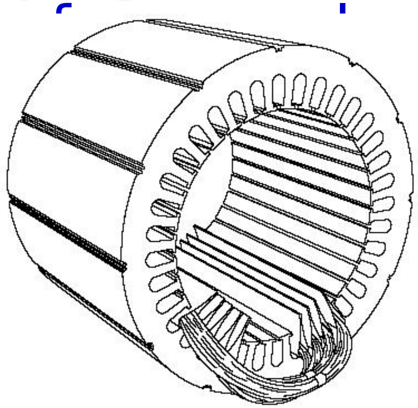


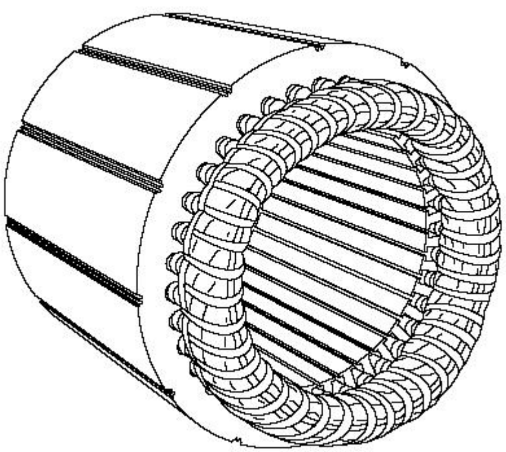
Figure 17.6 The rotor conductors of a squirrel-cage induction machine are aluminum bars connected to rings that short the ends together. These conductors are formed by casting molten aluminum into slots in the laminated iron rotor.

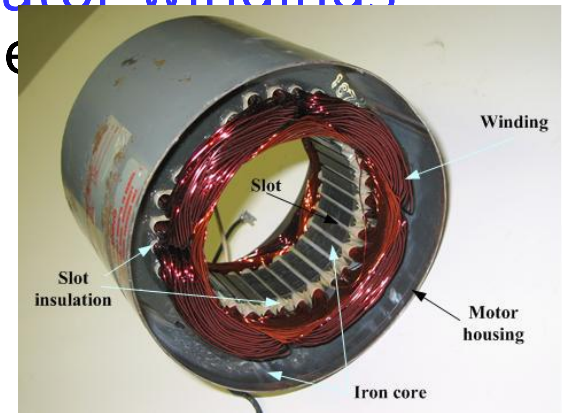
Construction (Stator construction)

- The stator is the stationary electrical part of the motor.
- The stator core of a National Electrical Manufacturers Association (NEMA) motor is made up of several hundred thin laminations.
- Stator laminations are stacked together forming a hollow cylinder. Coils of insulated wire are inserted into slots of the stator core.
- Electromagnetism is the principle behind motor operation. Each grouping of coils, together with the steel core it surrounds tromagnet. The stator windings are conne o the power source



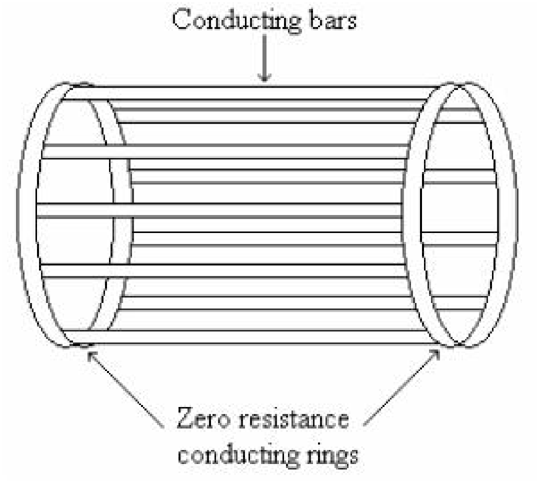


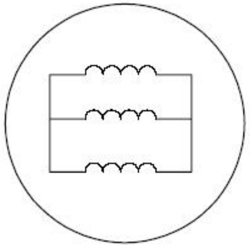


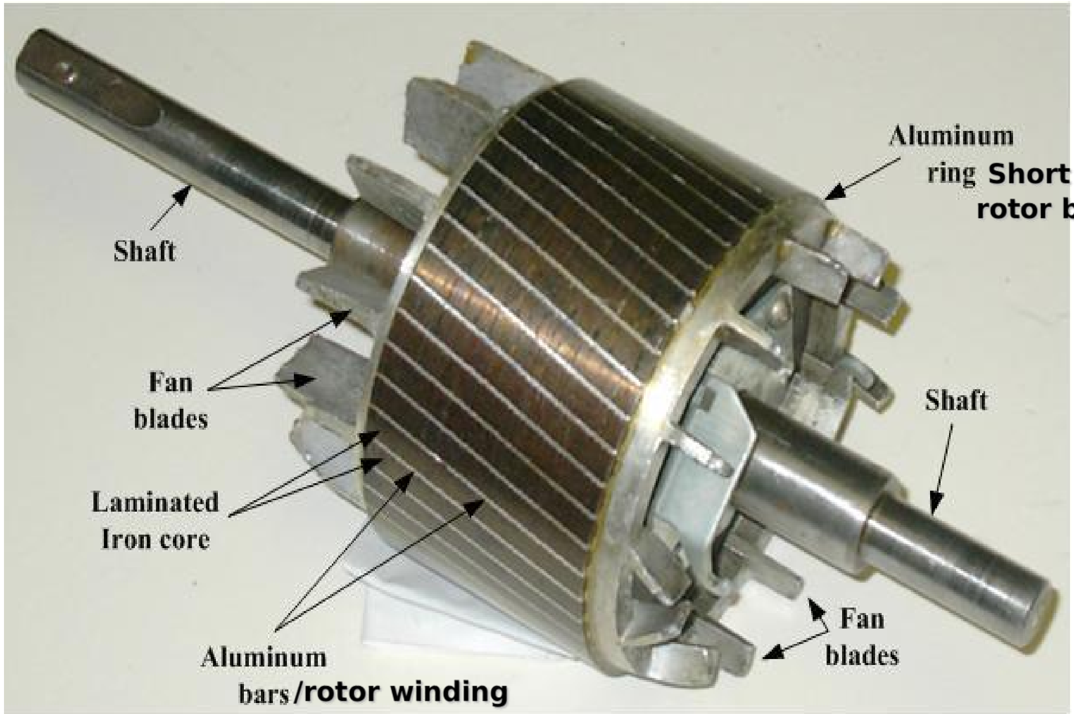


Construction (Rotor construction)

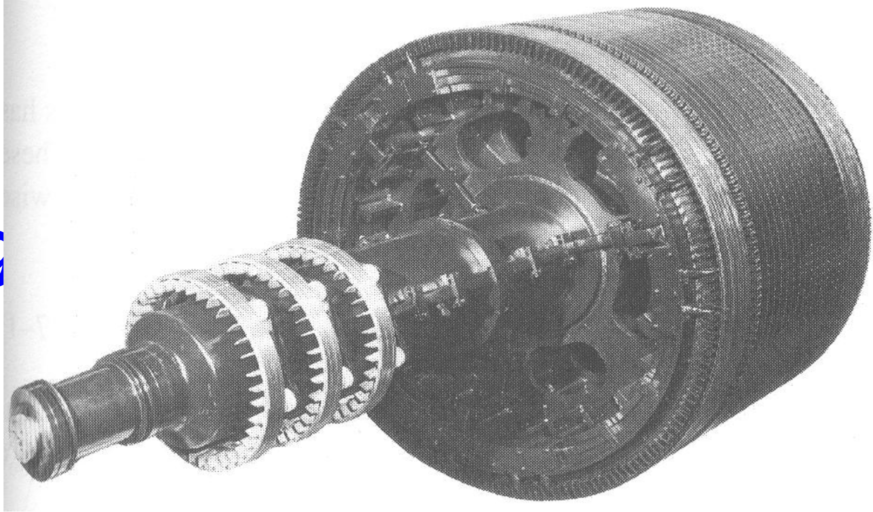
Squirrel-Cage Rotor

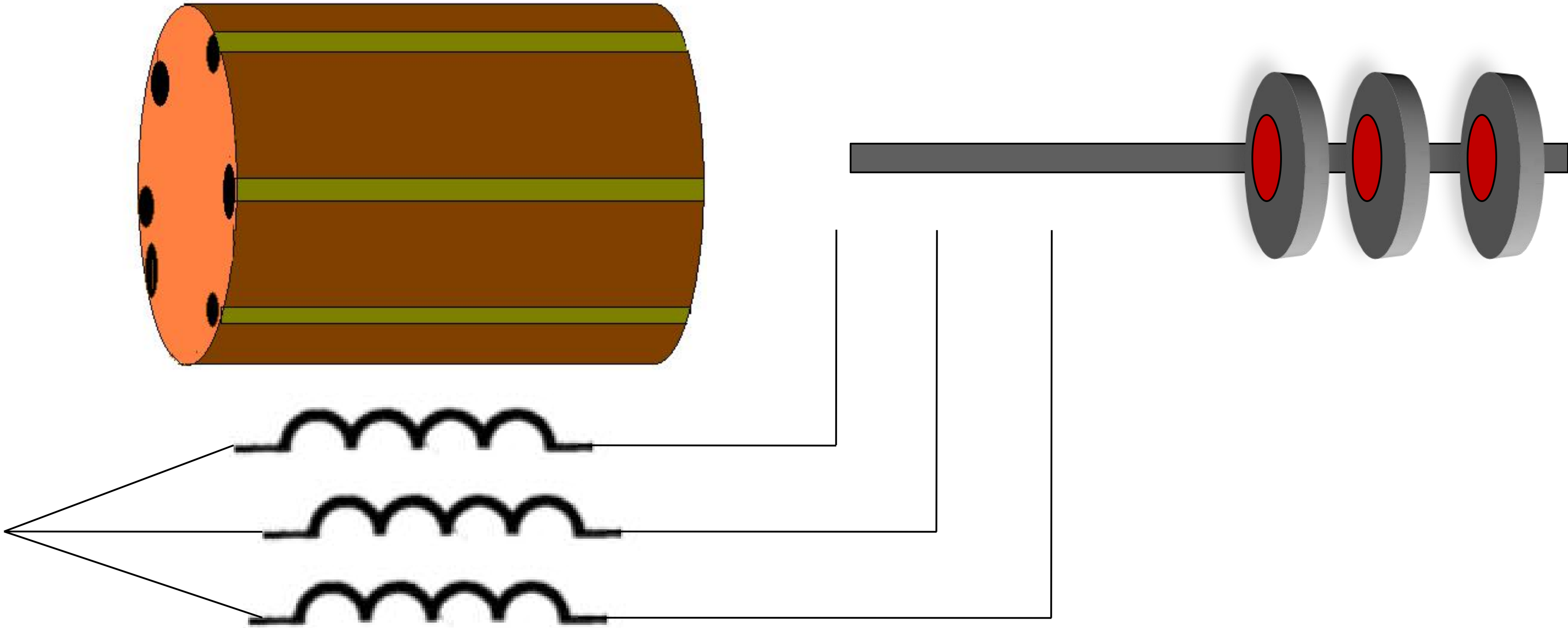






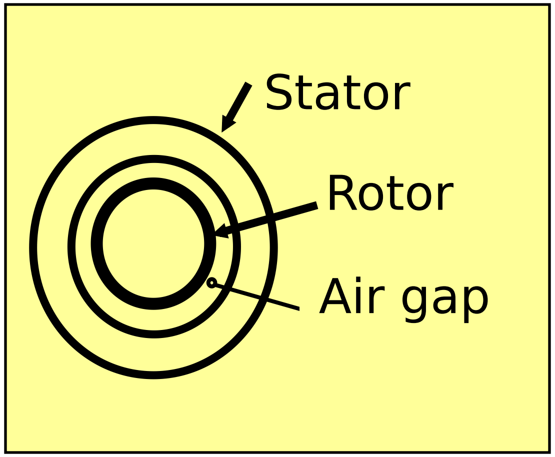
Wound-rotor(Slip Ring





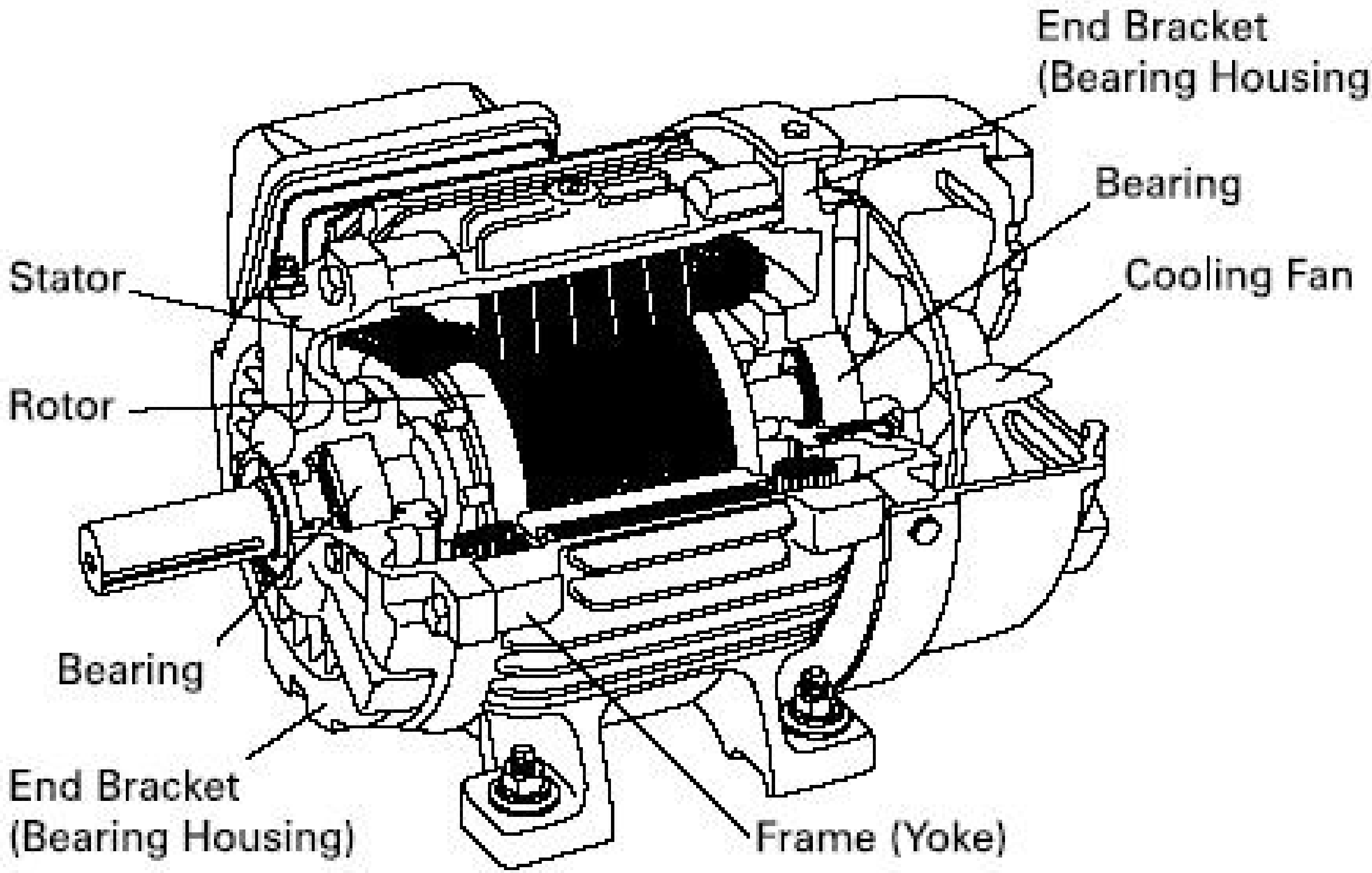
Construction (Enclosure)

- The enclosure consists of a frame (or yoke) and two end brackets (or bearing housings). The stator is mounted inside the frame. The rotor fits inside the stator with a slight air gap separating it from the stator. There is **NO** direct physical connection between the rotor and the stator.



- The enclosure also protects the electrical and operating parts of the motor from harmful effects of the environment in which the motor operates.
- Bearings, mounted on the shaft, support the rotor and allow it to turn.
- A fan, also mounted on the shaft, is used on the motor shown below for

Construction (Enclosure)



Difference Between Slip ring and Squirrel Cage IM

Slip ring or phase wound Induction motor	Squirrel cage induction motor
Construction is complicated due to presence of slip ring and brushes	Construction is very simple
The rotor winding is similar to the stator winding	The rotor consists of rotor bars which are permanently shorted with the help of end rings
We can easily add rotor resistance by using slip ring and brushes	Since the rotor bars are permanently shorted, its not possible to add external resistance
Due to presence of external resistance high starting torque can be obtained	Staring torque is low and cannot be improved
Slip ring and brushes are present	Slip ring and brushes are absent
Frequent maintenance is required due to presence of brushes	Less maintenance is required
The construction is complicated and the presence of brushes and slip ring makes the motor more costly	The construction is simple and robust and it is cheap as compared to slip ring induction motor

Difference Between Slip ring and Squirrel Cage IM

Slip ring or phase wound Induction motor	Squirrel cage induction motor
This motor is rarely used only 10 % industry uses slip ring induction motor	Due to its simple construction and low cost. The squirrel cage induction motor is widely used
Rotor copper losses are high and hence less efficiency	Less rotor copper losses and hence high efficiency
Speed control by rotor resistance method is possible	Speed control by rotor resistance method is not possible
Slip ring induction motor are used where high starting torque is required i.e in hoists, cranes, elevator etc	Squirrel cage induction motor is used in lathes, drilling machine, fan, blower printing machines etc

Rotating Magnetic Field

- When a 3 phase stator winding is connected to a 3 phase voltage supply, 3 phase current will flow in the windings, which also will induced 3 phase flux in the stator.
- These flux will rotate at a speed called a Synchronous Speed, n_s. The flux is called as Rotating magnetic Field
- Synchronous s[illegible]d of rotating flux

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

- Where; p = is the number of poles, and
  f = the frequency of supply

Principle of operation

- Three phase windings of stator are connected to three phase supply, so three phase magnetic fluxes are produced. Due to combination of three phase fluxes rotating magnetic flux is generated.
- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings.
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings.
- The rotor current produces another magnetic field.
- A torque is produced as a result of the interaction of those two magnetic fields

$$\tau_{ind} = kB_R \times B_s$$

Where τ_{ind} is the induced torque and B_R and B_S are the magnetic flux densities of the rotor and the stator respectively

Induction motor speed

- At what speed will the IM run?
  - Can the IM run at the synchronous speed, why?
  - If rotor runs at the synchronous speed, which is the same speed of the rotating magnetic field, then the rotor will appear stationary to the rotating magnetic field and the rotating magnetic field will not cut the rotor. So, no induced current will flow in the rotor and no rotor magnetic flux will be produced so no torque is generated and the rotor speed will fall below the synchronous speed
  - When the speed falls, the rotating magnetic field will cut the rotor windings and a torque is produced

Slip and Rotor Speed

1. Slip *s*

- The rotor speed of an Induction machine is different from the speed of Rotating magnetic field. The % difference of the speed is called slip.

$$s = \frac{n_s - n_r}{n_s} \quad OR \quad n_r = n_s(1 - s)$$

- Where; n_s = synchronous speed (rpm)

  n_r = mechanical speed of rotor (rpm)

- under normal operating conditions, s= 0.01 ~ 0.05, which is very small and the actual speed is very close to synchronous speed.
- Note that : s is not negligible

$$s = (n_s - n)\text{rpm}$$

Effect of slip in rotor parameters

$Note\ :$

$\underline{At\ \ stator}\ :\quad n_s = \frac{120\ f}{p}$

$$‘ \quad f = \frac{n_s\, p}{120} \qquad .....(\ i\ )$$

$\underline{At\ \ Rotor}\ :\quad n_s - n_r = \frac{120\ f}{p}$

$$‘ \quad f_r = \frac{(n_s - n_r)\, p}{120} \qquad .....(\ ii\ )$$

$\underline{(ii)\ \partial\ (i)}\ :\quad f_r = s.f$

Slip and Rotor Speed

- **Rotor Speed**
  - When the rotor move at rotor speed, $n_{r\ (rps)}$, the stator flux will circulate the rotor conductor at a speed of $(n_s - n_r)$ per second. Hence, the frequency of the rotor is written as:

    - $$f_r = (n_s - n_r)p$$
      $$= sf$$

    - Where; s = slip
      f = supply frequency

Slip may be expressed as a percentage:

$$S\% = \frac{N_{sync} - N_m}{N_{sync}} \times 100$$

Where *s* is the *slip*

Notice that : if the rotor runs at synchronous speed

$s = 0$

if the rotor is stationary

$s = 1$

Induction Motor Speed = Rotor speed

$$S = \frac{N_{sync} - N_m}{N_{sync}} = \frac{\omega_{sync} - \omega_m}{\omega_{sync}}$$

$$N_m = N_{sync}(1 - S)$$

$$N_m = \frac{120\, f}{p}(1 - S)$$

Effect of Slip on magnitude of rotor induced EMF

When rotor is at standstill s=1, relative speed is max amd
max. emf get induced in the rotor, Let this emf is E2

As the rotor gains speed, the relative speed b/w rotor and RMF decreases and hence induced emf in rotor also
Decreases as it is proportional to speed (Ns-N),
let this e

$$\frac{E_{2r}}{E_2} = \frac{N_s - N}{N_s}$$

$$\frac{E_{2r}}{E_2} = s$$

$$E_{2r} = sE_2$$

Principle of Operation

- **Torque producing mechanism**

  When a 3 phase stator winding is connected to a 3 phase voltage supply, 3 phase current will flow in the windings, hence the stator is energized.

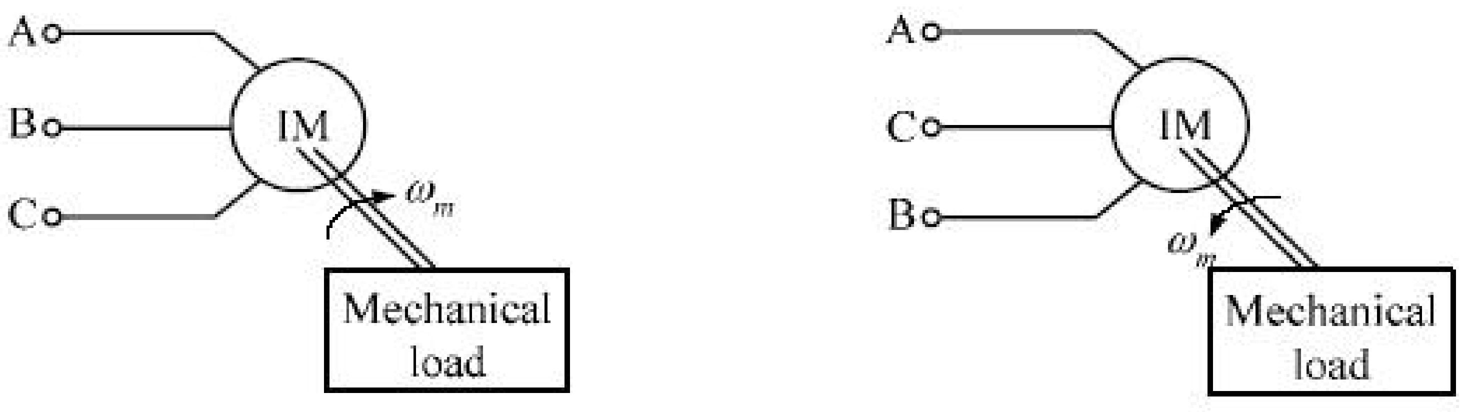
  A rotating flux Φ is produced in the air gap. The flux Φ induces a voltage E_a in the rotor winding (like a transformer).

  The induced voltage produces rotor current, if rotor circuit is closed.

  The rotor current interacts with the flux Φ, producing torque. The rotor rotates in the direction of the rotating flux.

Direction of Rotor Rotates

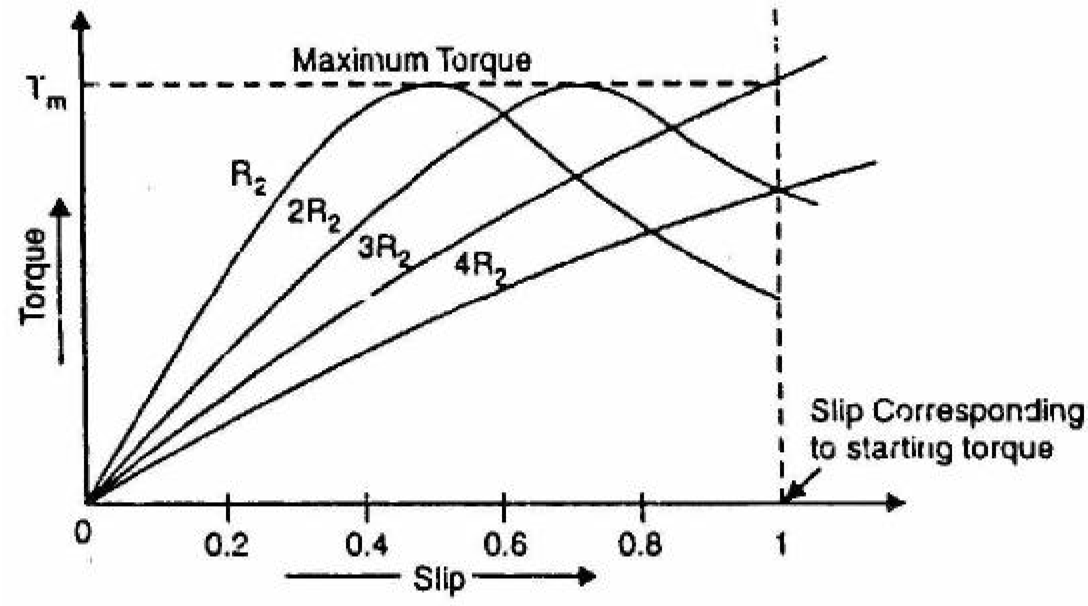
- Q: How to change the direction of
- rotation?
- • A: Change the phase sequence of the
- power supply.



Torque-Slip Characteristics

The motor torque under running conditions is given by

$$T = \frac{K_2 \; s \, R_2}{R_2^2 + s^2 \; X_2^2}$$



Torque-Slip Characteristics

(i) At s = 0, T = 0 so that torque-slip curve starts from the origin.

(ii) At normal speed, slip is small so that s X_2 is negligible as compared to R_2.

$$\therefore \quad T \propto s/R_2$$

$$\propto s$$

- Hence torque slip curve is a straight line from zero slip to a slip that corresponds to full-load.

(iii) As slip increases beyond full-load slip, the torque increases and becomes maximum at s = R_2/X_2. This maximum torque in an induction motor is called pull-out torque or break-down torque. Its value is at least twice the full-load value when the motor is operated at rated voltage and frequency.

Torque-Slip Characteristics

- To the Max Torque $(sX_2)^2$ increases so fast so that R_2 can be neglected form the equation.

$$\therefore \quad T \propto s/s^2 X_2^2$$

- Thus the tor $\propto 1/s$ sely proportional to slip. Hence torque–slip curve is a rectangular hyperbola.

(v) The maximum torque remains the same and is independent of the value of rotor resistance. Therefore, the addition of resistance to the rotor circuit does not change the value of maximum torque but it only changes the value of slip at which maximum torque occurs.

Power Stages in an Induction Motor

- The input electric power fed to the stator of the motor is converted into mechanical power at the shaft of the motor. The various losses during the energy conversion are:

- **Fixed losses**

  (i) Stator iron loss

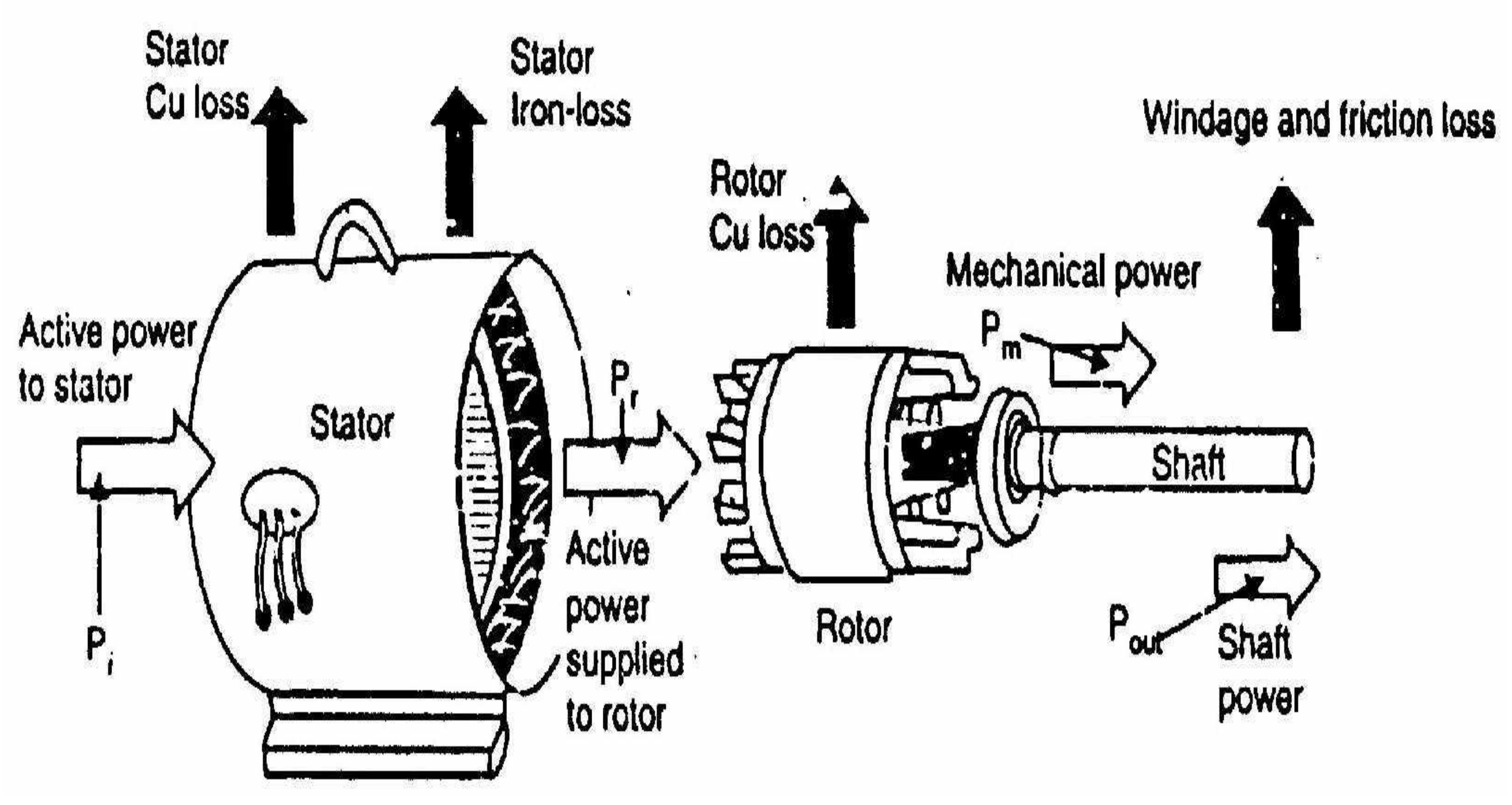
  (ii) Friction and windage loss

- **Variable losses**

  (i) Stator copper loss

  (ii) Rotor copper loss

Power Stages in IM



Power Stages in IM

(i) Stator input, Pi = Stator output + Stator losses

= Stator output + Stator Iron loss + Stator Cu loss

(ii) Rotor input, Pr = Stator output

- It is because stator output is entirely transferred to the rotor through airgap by electromagnetic induction.

(iii) Mechanical power available, Pm = Pr - Rotor Cu loss

- This mechanical power available is the gross rotor output and will produce a gross torque Tg.

(iv) Mechanical power at shaft, Pout = Pm - Friction and windage loss

- Mechanical power available at the shaft produces a shaft torque Tsh.

Pm - Pout = Friction and windage loss

Induction Motor Torque

- The mechanical power P available from any electric motor can be expresse[d as]

$$P = \frac{2\pi N T}{60} \quad \text{watts}$$

- where N = speed of the motor in r.p.m.

  T = torque developed in N-m

$$\therefore \qquad T = \frac{60}{2\pi}\frac{P}{N} = 9.55\frac{P}{N} \ \text{N - m}$$

If the gross output of the rotor of an induction motor is Pm and its speed is N r.p.m., then gross torque T developed is given by:

$$T_g = 9.55\frac{P_m}{N} \ \text{N - m}$$

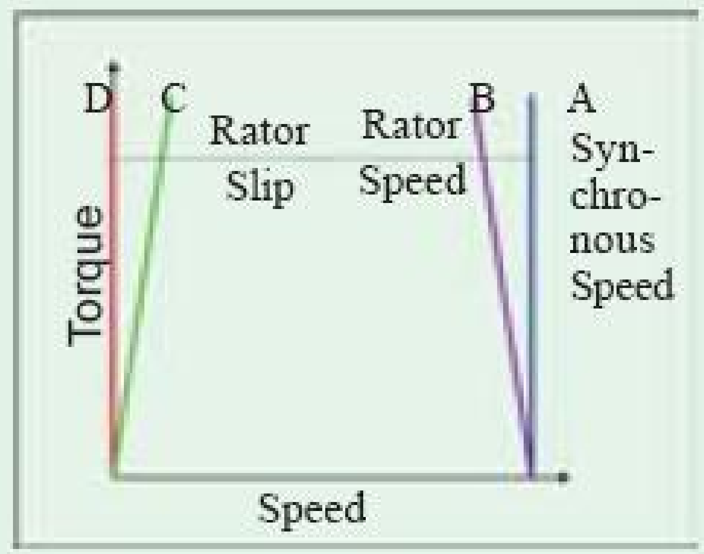
$$\text{Similarly,} \qquad T_{sh} = 9.55\frac{P_{out}}{N} \ \text{N - m}$$

Measurement of Slip

(i) By actual measurement of Slip

This method requires measurement of Actual motor speed N and calculation of Ns.Then slip is calculated by using equation

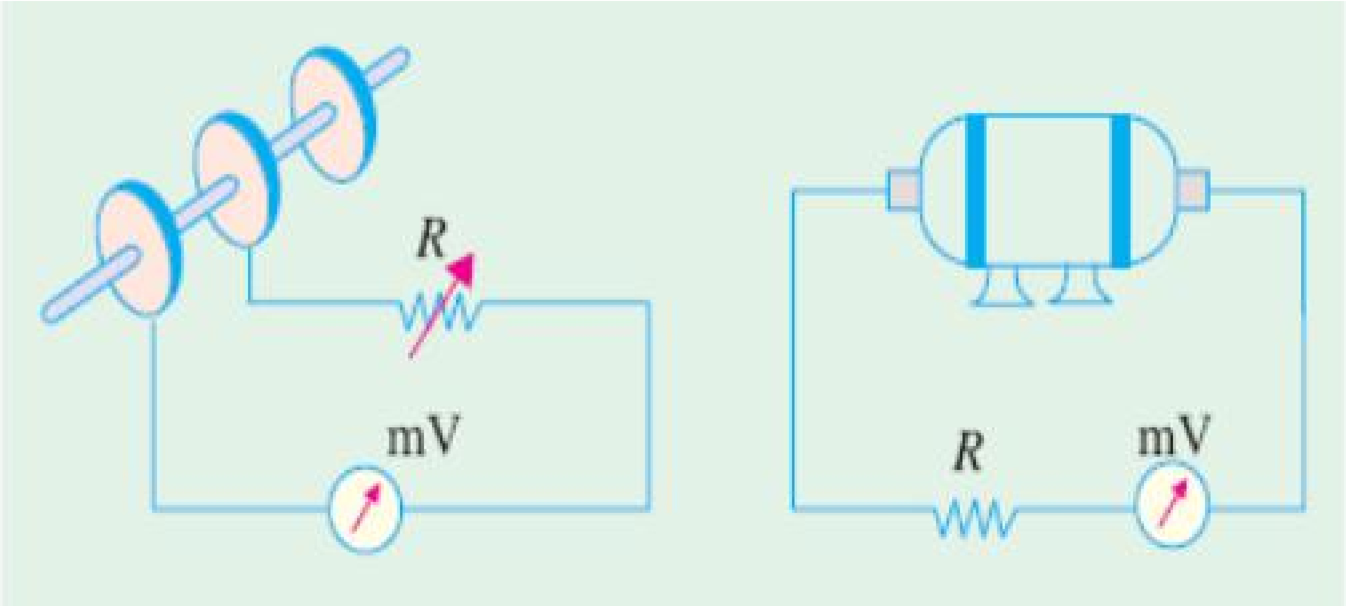
$$s = (N_s - N) \times 100 / N_s$$



The speed curve of an induction motor. The slip is the difference in rotor speed relative to that of the synchronous speed. CD = AD - BD = AB.

Measurement of Slip

(ii) By comparing rotor and stator supply frequency



Measurement of Slip

(iii) Stroboscopic method.

- A circular metallic disc is taken and painted with alternatively black and white segments.
- The painted disc is mounted on the end of the shaft and illuminated by means of neon filled stroboscopic lamp.