Lecture Notes
Electrical Machines IV
Code: CECE437
Level: Four
Points: 100 = 25+15+60

Course Contents

- **Three phase induction motors:**
  - Introduction.
  - Advantages and disadvantages.
  - Construction.
  - Rotating magnetic field due to 3-phase currents.
  - Principle of operation.
  - Slip, Rotating current frequency, Effect of the slip on the rotor current.
  - Rotor current, Rotor Torque.
  - Starting torque, Condition for maximum starting torque.
  - Effect of change of supply voltage.
  - Motor under load.
  - Torque under running condition.
  - Maximum torque under running conditions.
  - Torque-Slip characteristics.
  - Comparison between transformer and Induction motor.
  - Speed regulation of induction motor.
  - Speed control of induction motor.

Course Contents …

  - Power factor & Power stages in induction motor.
  - Equivalent circuit of 3-phase induction motor.
  - Induction motor ratings.
- **Single phase induction motor:**
  - Self-starting.
  - Capacitor start motor.
  - Equivalent circuit of 1-phase induction motor.
- **Testing methods of three phase induction motor.**

Introduction

- The 3-ph induction motors, the most widely used in industry.
- They run at essentially constant speed from no load to full load.
- We usually prefer DC motors when large speed variations are required.

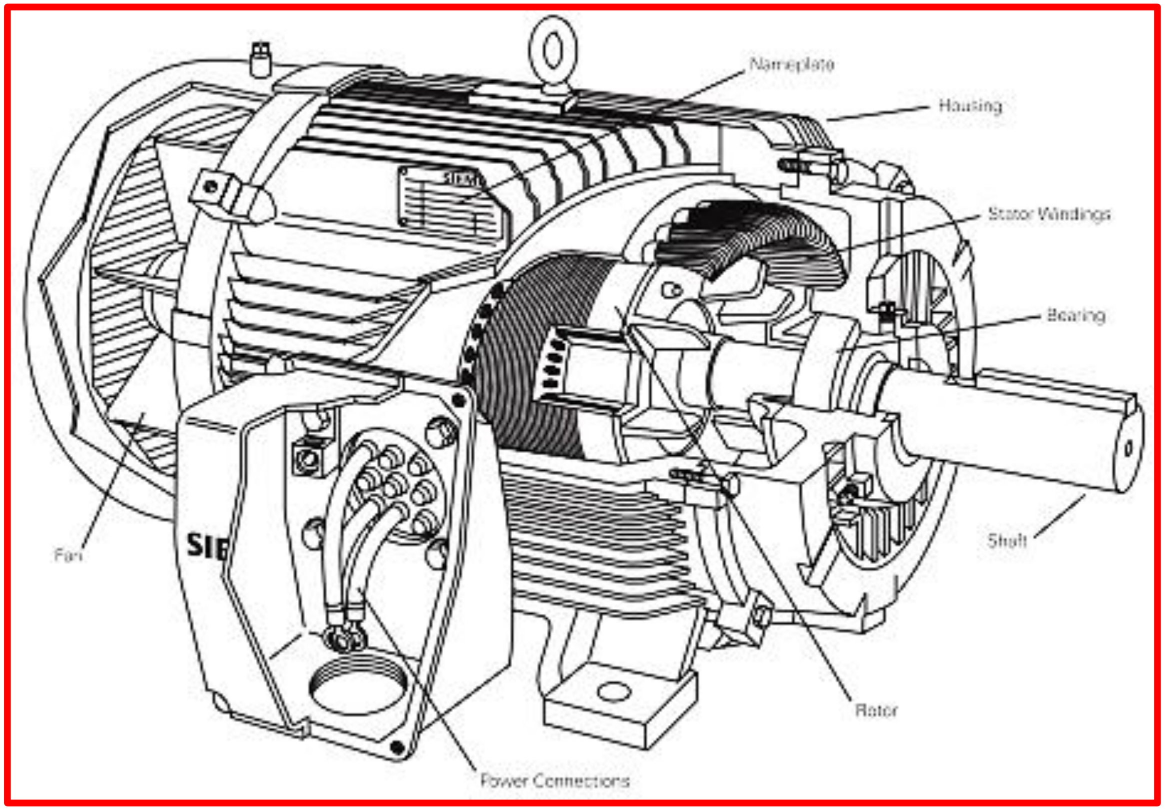


Fig: three phase induction motor

Advantages of 3-phase Induction Motors

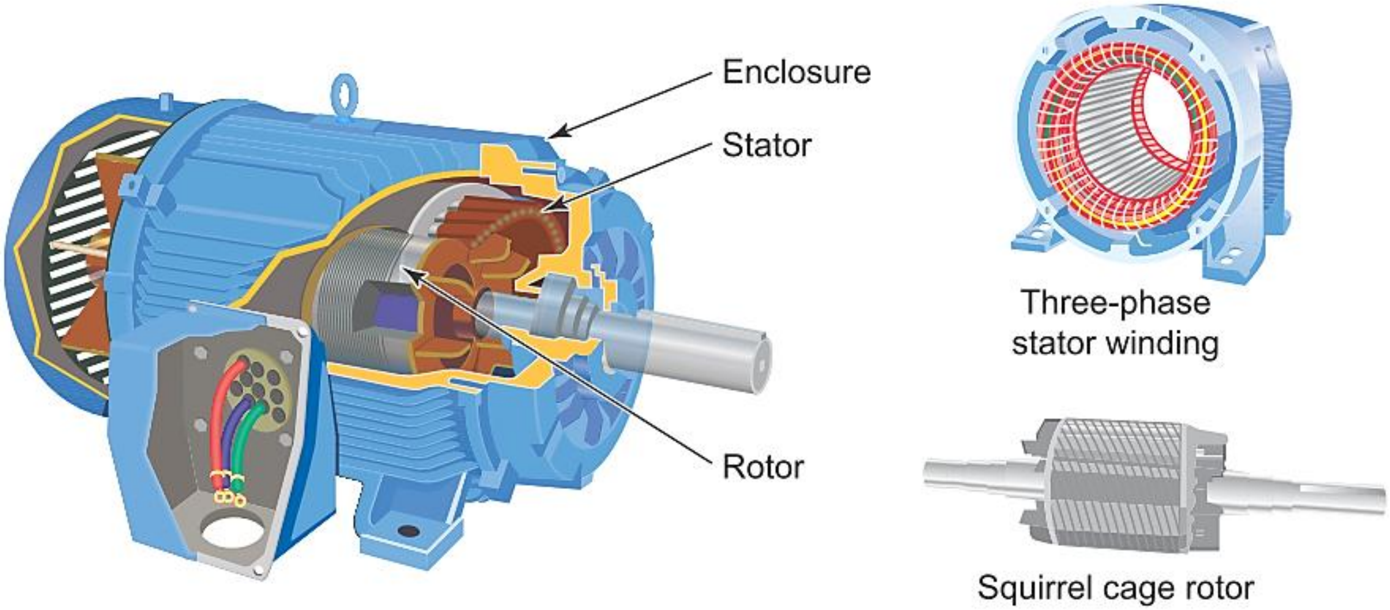
- It has simple and rugged construction.
- It is relatively cheap.
- It requires little maintenance.
- It has high efficiency and good power factor.
- It has self-starting torque.

Disadvantages of 3-phase Induction Motors

- It is essentially has a constant speed and its speed cannot be changed easily.
- Its starting toque is less than that of DC motors.

Construction of 3-phase Induction Motors

- It has two main parts: (i) **Stator**: the stationary part.
  (ii) **Rotor**: the rotating part.
- There is a small air gap between the rotor and stator (0.4 mm to 4 mm) depend on the power of the motor.



Three-phase stator winding

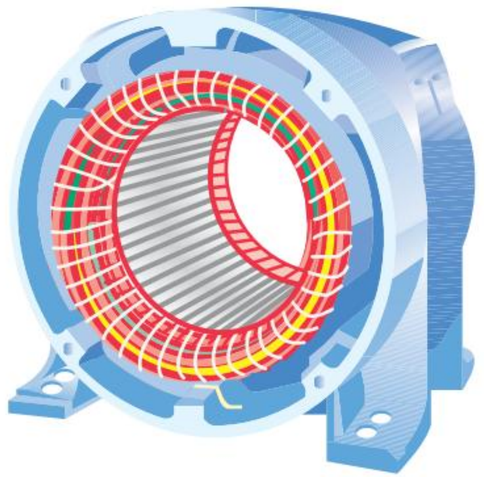
Squirrel cage rotor

Figure 5-35 Squirrel-cage induction motor.

Fig. 1: Three phase squirrel cage induction motor

Construction of 3-phase Induction Motors …

(i) Stator:



Three-phase stator winding

- A hollow cylindrical core made up of thin silicon steel laminations to reduce the hysteresis and eddy current losses.
- Has an even number of slots on the inner periphery.
- Has 3-phase stator windings put in the slots to form Y or Δ connected circuit. The windings configuration determines the number of poles in the induction motor.
- As number of poles decreases, the motor speed increases and vice versa.
- When the 3-phase windings are energized from a 3-phase supply, a rotating magnetic field of constant magnitude is produced. This rotating field induces currents in the rotor by means of electromagnetic induction, then, the rotor rotates.

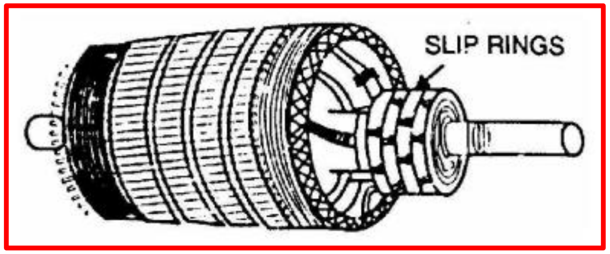
Construction of 3-phase Induction Motors …

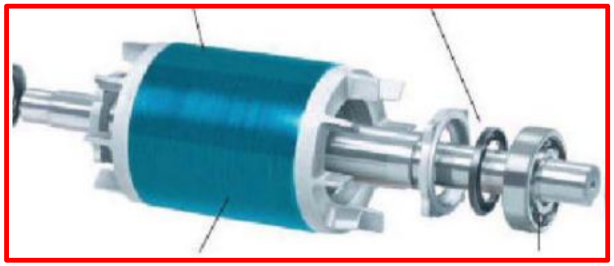
(ii) Rotor:

- A steel laminated core mounted on a shaft. It has slots on its outer periphery, a 3-phase windings are placed in these slots.
- It has two types: [A] Squirrel cage rotor القفص السنجابي
  [B] Wound rotor ملفوف

[A] Squirrel cage rotor type:

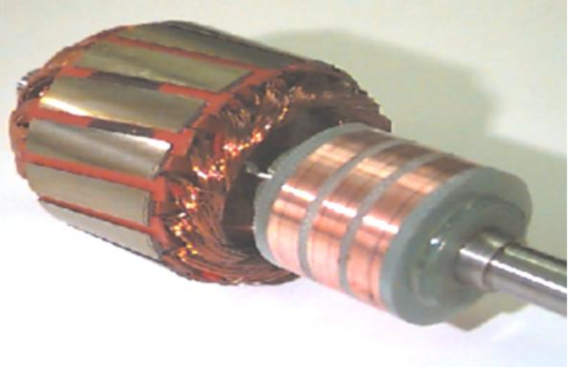
- A laminated cylindrical core having slots on outer periphery, each slot has one bar of AL or Cu bar. These bars are short-circuited at each end by means of slip rings. "hence the name is squirrel cage"
- Not connected to a 3-phase supply, but having currents induced in it by means of electromagnetic induction.
- Simple and rugged construction.
- Low starting torque: (***Why***) {Because: the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to give a large stating torque}.

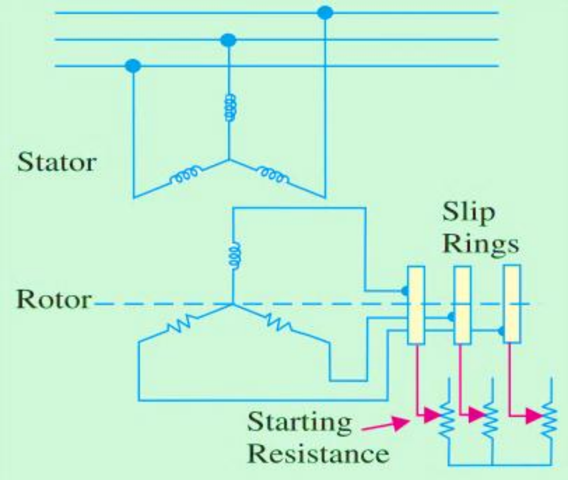




- Construction of 3-phase Induction Motors …

[B] Wound rotor type:





- A laminated cylindrical core having slots on outer periphery to carry 3-phase windings "Y-connected".
- The open end of the 3-phase windings are jointed to insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring.
- The brushes are connected to a 3-phase Y-connected rheostat.
  - Has large starting torque. (***Why***) {Because: at starting, the external resistances are included in the rotor circuit to give high starting torque. These resistances are gradually reduced to zero as the motor runs up to the required speed}.

When the motor reach the normal speed; the external resistances are short-circuited, so that the wound rotor runs like a squirrel cage type.

Rotating Magnetic Field Due to 3-phase Currents

- When the 3-phase **stator** winding are energized from a 3-phase supply, a rotating magnetic field is produced, and this field has poles goes on shifting their positions around the stator.
- For the reason of rotation, it is called "*a rotating magnetic field*".
- **(Magnitude of rotating field) = 1.5 * (Maximum flux due to any phase)**

$$= 1.5 * \phi_m$$

How the rotating magnetic field is produced?

Answer: consider a 2-pole, 3-phase winding as shown in Fig. 6. The three phases of the stator X, Y and Z are energized from a 3-phase source and currents in these phases are I_x, I_y and I_z.

- Referring to Fig. 7, the fluxes by these currents are given by:

$$\boxed{\begin{aligned} \phi_x &= \phi_m \sin \omega t \\ \phi_y &= \phi_m \sin(\omega t - 120^\circ) \\ \phi_z &= \phi_m \sin(\omega t - 240^\circ) \end{aligned}}$$

- Fig. 8 shows the phasor diagram of the three phase fluxes.

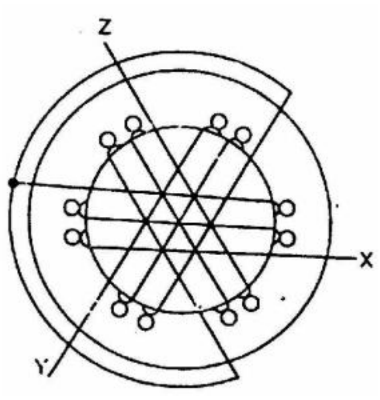


Fig. 6

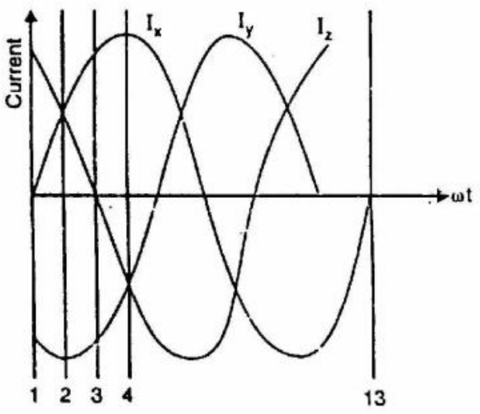


Fig. 7

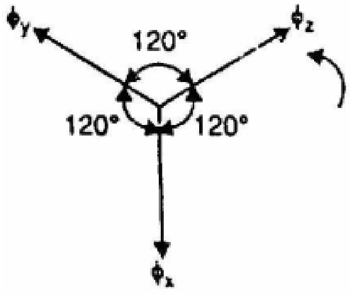
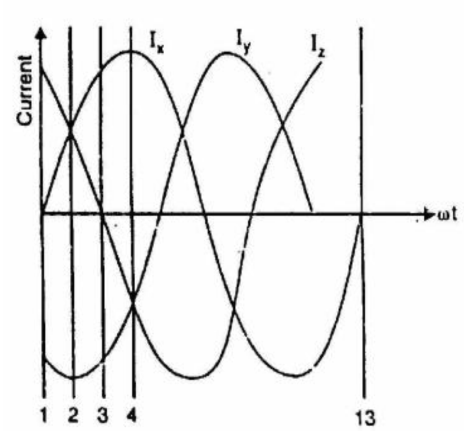


Fig. 8

- We shall now prove that this 3-phase supply produces a rotating field of constant magnitude equal to 1.5Φ_m .



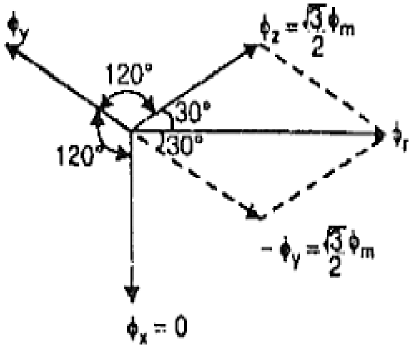
For position no. 1 in Fig.7: [I_x= 0, I_y and I_z are equal and opposite]. This establishes a flux as shown in Fig 9.1.

at $\omega t = 0$;

$$\phi_x = 0$$

$$\phi_y = \phi_m \sin(-120°) = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_z = \phi_m \sin(-240°) = \frac{\sqrt{3}}{2}\phi_m$$



$$\text{Resultant flux,} \quad \phi_r = 2\times\frac{\sqrt{3}}{2}\phi_m \cos\frac{60°}{2} = 2\times\frac{\sqrt{3}}{2}\phi_m\times\frac{\sqrt{3}}{2} = 1.5\ \phi_m$$

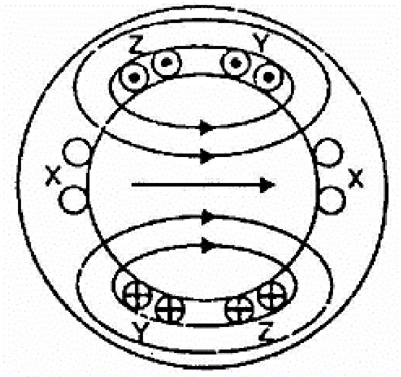
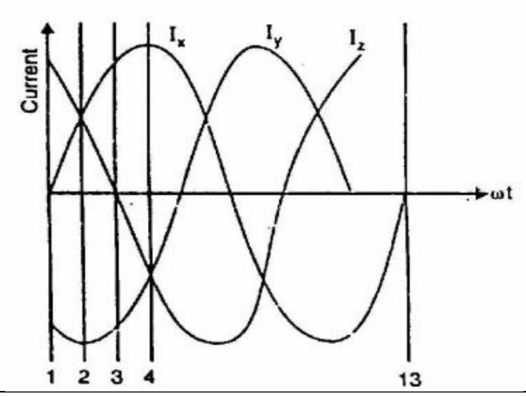


Fig. 9.1



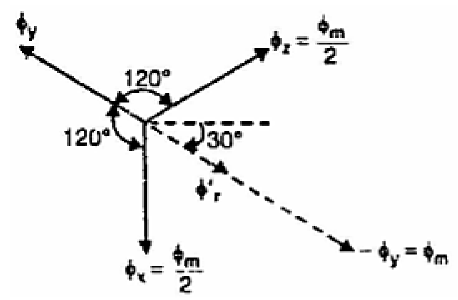
For position no. 2 in Fig.7: The current is maximum (negative) in φ_y phase Y and 0.5 maximum (positive) in phases X and Z. This establishes a flux as shown in Fig 9.2.

at $\omega t = 30$;

$$\phi_x = \phi_m \sin 30^\circ = \frac{\phi_m}{2}$$

$$\phi_y = \phi_m \sin(-90^\circ) = -\phi_m$$

$$\phi_z = \phi_m \sin(-210^\circ) = \frac{\phi_m}{2}$$



Phasor sum of ϕ_x and ϕ_z → $\phi'_r = 2 \times \frac{\phi_m}{2} \cos\frac{120^\circ}{2} = \frac{\phi_m}{2}$

Phasor sum of ϕ'_r and $-\phi_y$ → $\phi_r = \frac{\phi_m}{2} + \phi_m = 1.5\,\phi_m$

Note that resultant flux is displaced 30° clockwise from position 1.

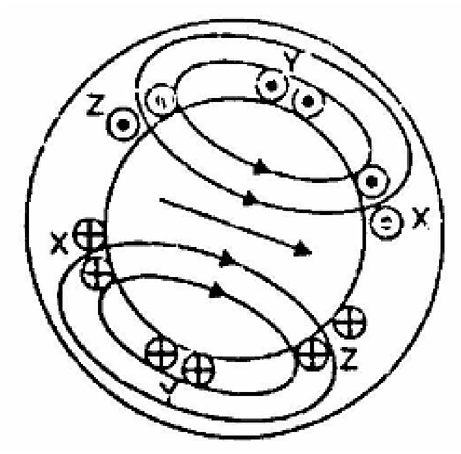
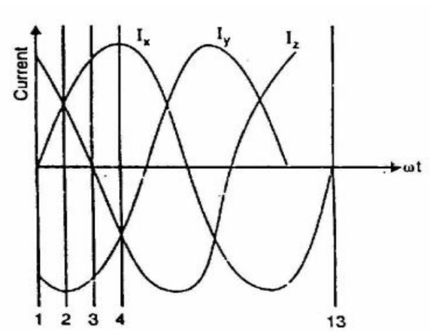


Fig. 9.2



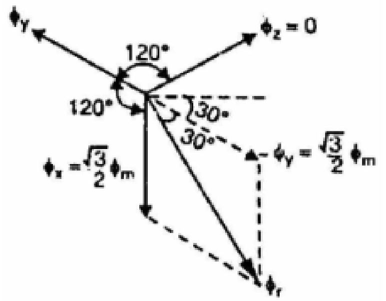
For position no. 3 in Fig.7: current in phase Z is zero and the currents in phases X and Y are equal and opposite (currents in phases X and Y arc 0.866 × max. value). This establishes a flux as shown in Fig 9.3.

at $\omega t = 60$;

$$\phi_x = \phi_m \sin 60^\circ = \frac{\sqrt{3}}{2}\phi_m;$$

$$\phi_y = \phi_m \sin(-60^\circ) = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_z = \phi_m \sin(-180^\circ) = 0$$



$$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos\frac{60^\circ}{2} = 1.5\,\phi_m$$

Note that resultant flux is displaced 60° clockwise from position 1.

And so on… [redacted]

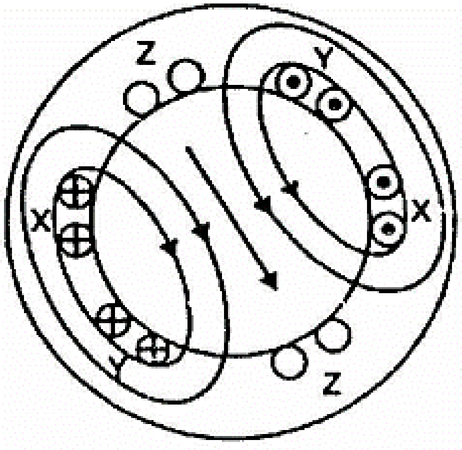


Fig. 9.3