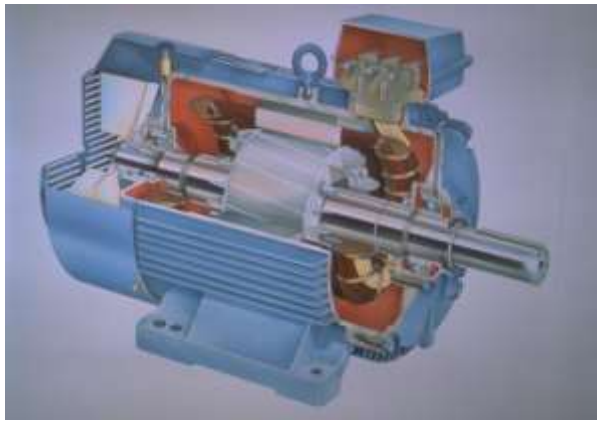
UNIT-III

Fundamentals of Electrical Machines



Lecture 22

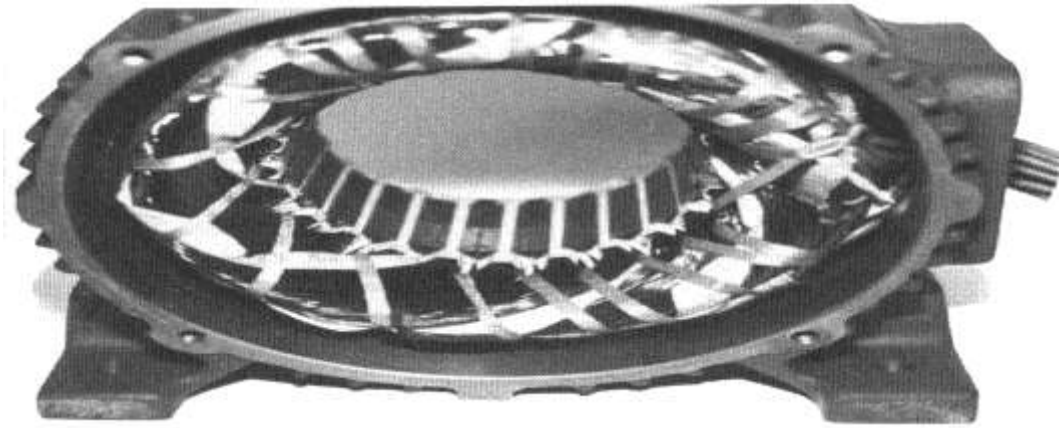
Prepared By:
Krishan Arora
Assistant Professor and Head

Introduction

- Three-phase induction motors are the most common and frequently encountered machines in industry
  - simple design, rugged, low-price, easy maintenance
  - wide range of power ratings: fractional horsepower to 10 MW
  - run essentially as constant speed from no-load to full load
  - Its speed depends on the frequency of the power source
    - not easy to have variable speed control
    - requires a variable-frequency power-electronic drive for optimal speed control

Construction

- An induction motor has two main parts
  - a stationary stator
    - consisting of a steel frame that supports a hollow, cylindrical core
    - core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding



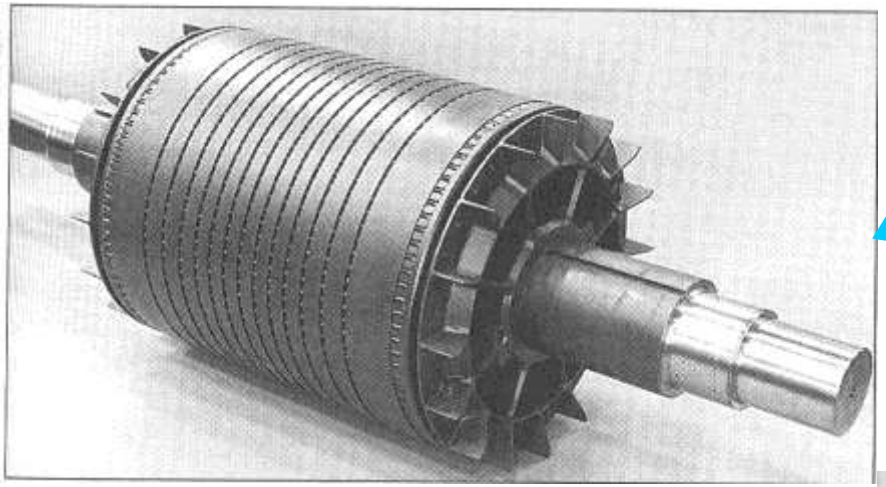
Stator of IM

Construction

- a revolving rotor
  - composed of punched laminations, stacked to create a series of rotor slots, providing space for the rotor winding

- Two basic design types depending on the rotor design
  - squirrel-cage: conducting bars laid into slots and shorted at both ends by shorting rings.
  - wound-rotor: complete set of three-phase windings exactly as the stator. Usually Y-connected, the ends of the three rotor wires are connected to 3 slip rings on the rotor shaft. In this way, the rotor circuit is accessible.

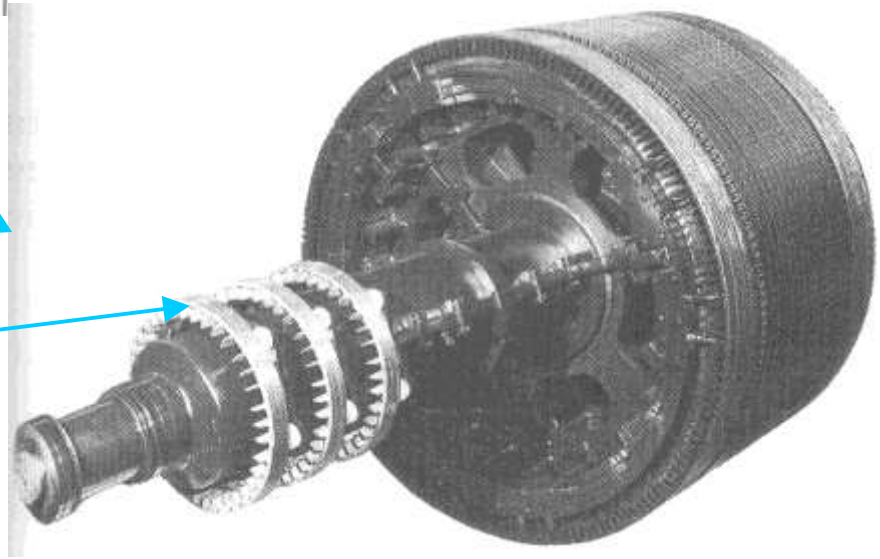
Construction



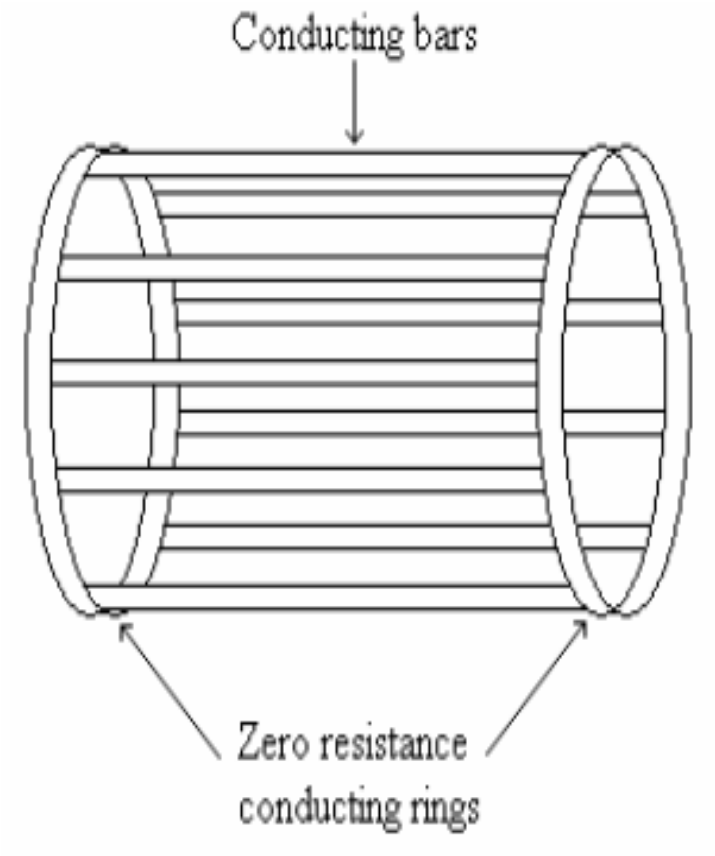
Squirrel cage rotor

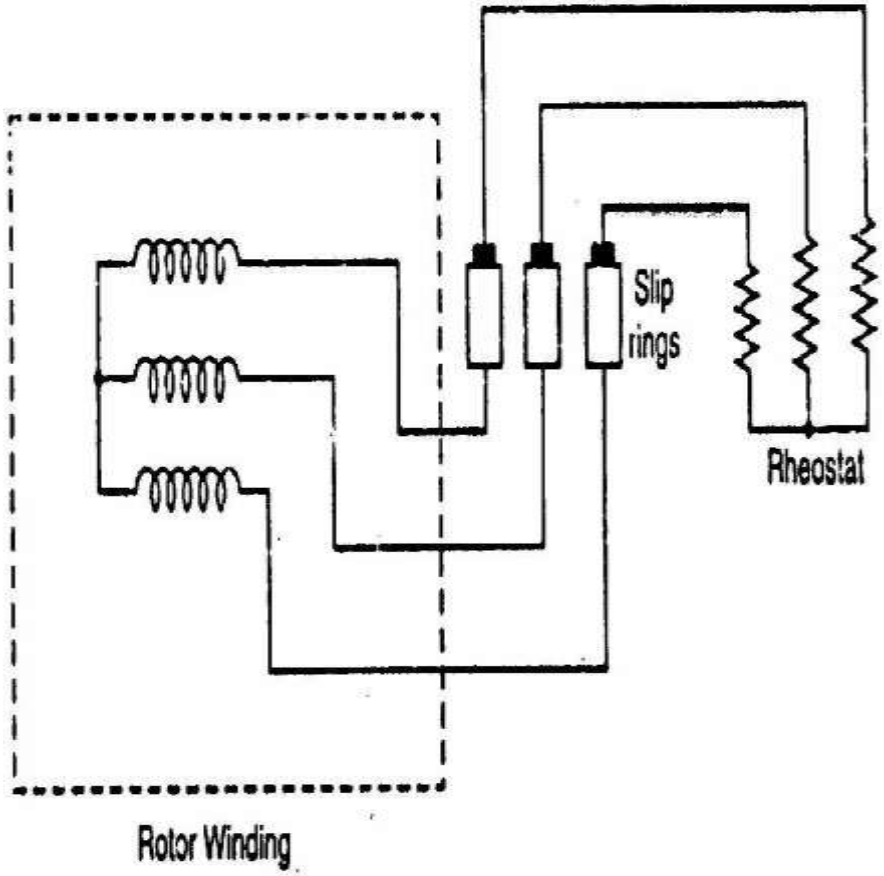
Wound rotor

Notice the
slip rings

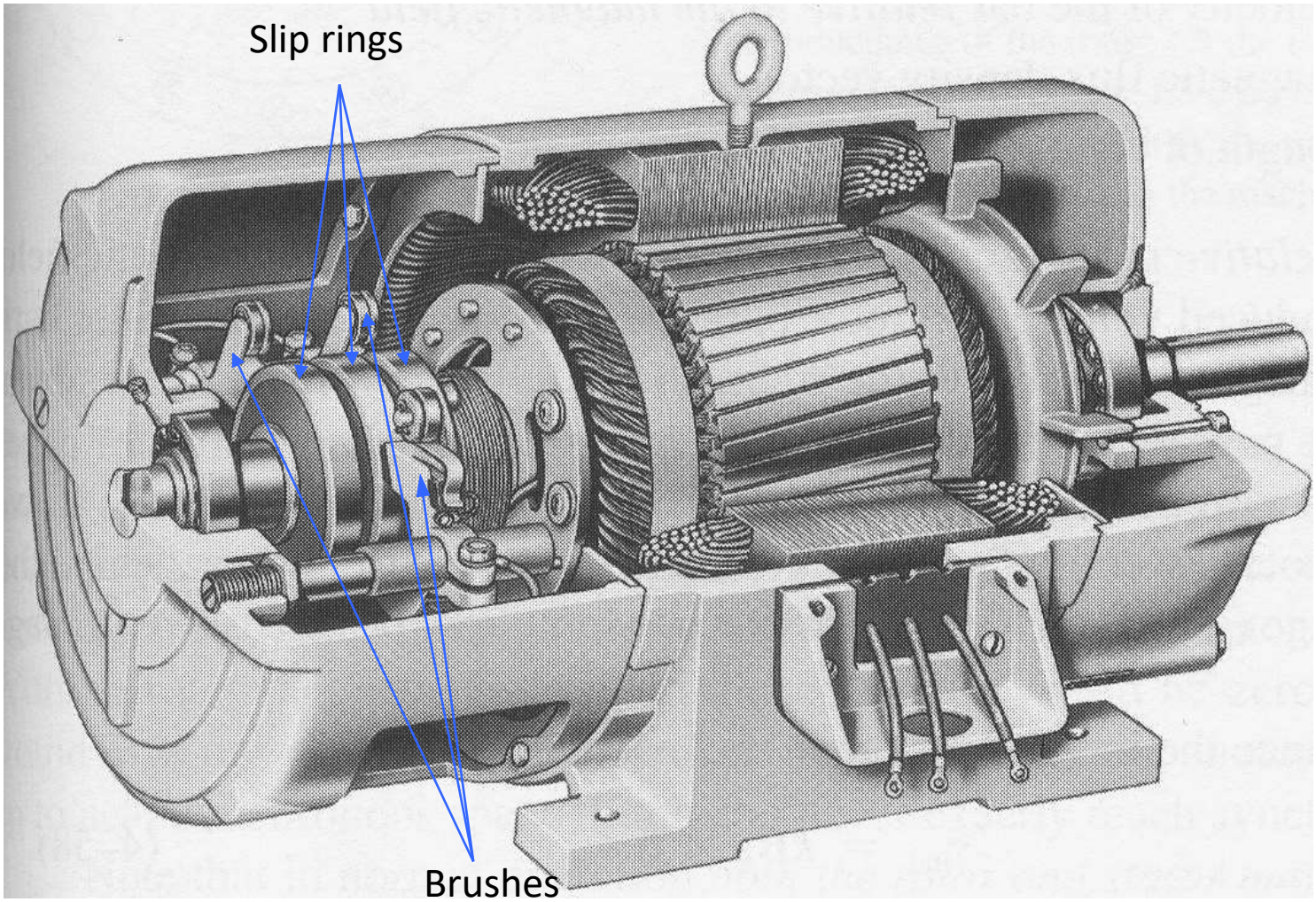


Images


Conducting bars
Zero resistance
conducting rings


Slip
rings
Rheostat
Rotor Winding

Construction



Cutaway in a typical wound-rotor IM. Notice the brushes and the slip rings

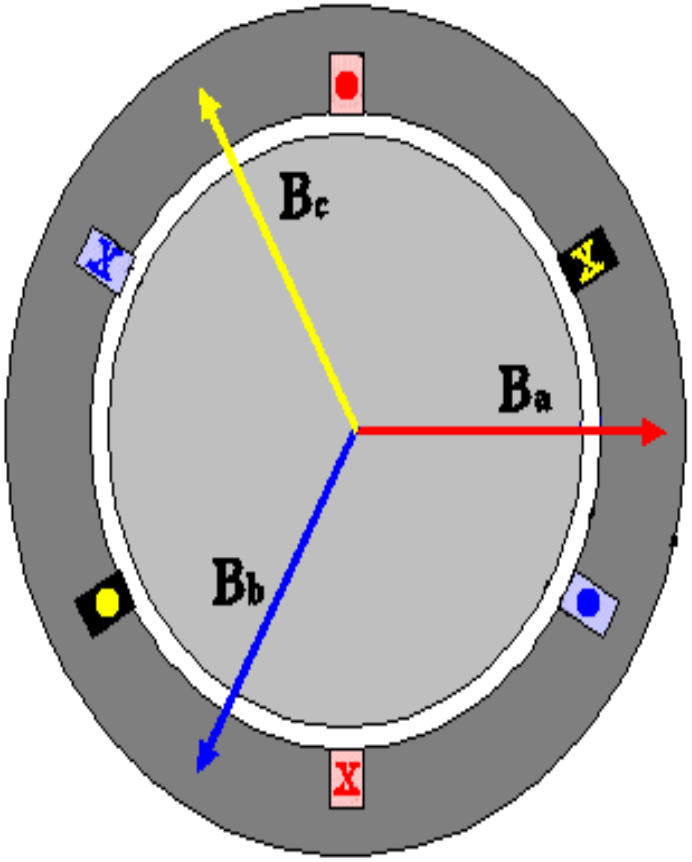
Rotating Magnetic Field

- Balanced three phase windings, i.e. mechanically displaced 120 degrees form each other, fed by balanced three phase source
- A rotating magnetic field with constant magnitude is produced, rotating with a speed

$$n_{sync} \equiv \frac{120 f_e}{P} \quad rpm$$

Where f_e is the supply frequency and

P is the no. of poles and n_{sync} is called the synchronous speed in *rpm* (revolutions per minute)



Synchronous speed

P	50 Hz	60 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

Quick Quiz (Poll 1)

- Induction motors have the advantage of

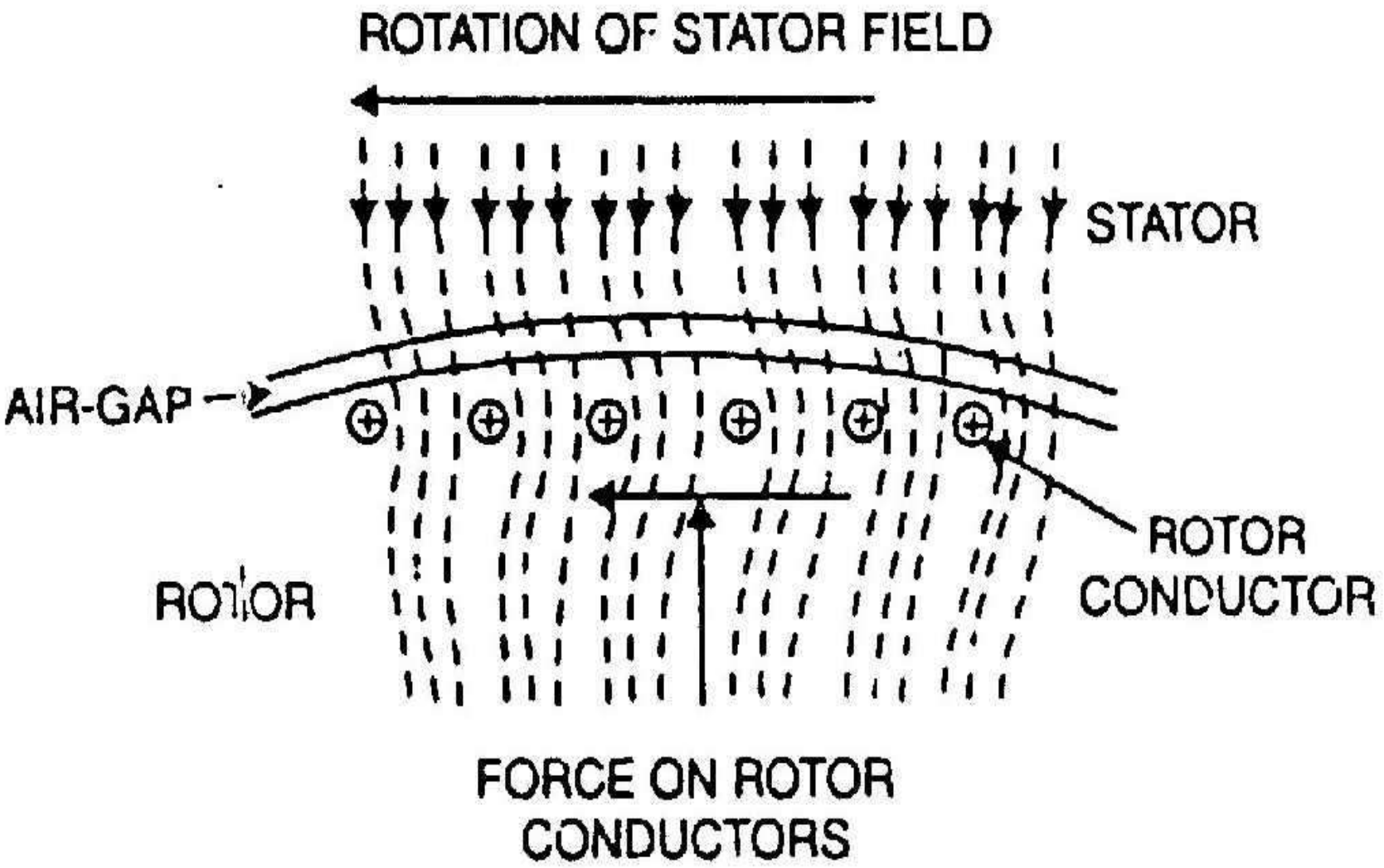
A. Less Maintenance
B. Less cost
C. Simple in construction
D. All of the above

Principle of operation

- 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


ROTATION OF STATOR FIELD
STATOR
AIR-GAP
ROTOR
ROTOR CONDUCTOR
FORCE ON ROTOR CONDUCTORS

Induction motor speed

- So, the IM will always run at a speed lower than the synchronous speed
- The difference between the motor speed and the synchronous speed is called the *Slip*

$$n_{slip} = n_{sync} - n_m$$

Where n_{slip}= slip speed

n_{sync}= speed of the magnetic field

n_m = mechanical shaft speed of the motor

The 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)
s = slip

Slip may be expressed as a percentage by multiplying the above eq. by 100, notice that the slip is a ratio and doesn't have units

Rotor Frequency

- The frequency of the voltage induced in the rotor is given by

$$f_r = \frac{P \times n}{120}$$

Where f_r = the rotor frequency (Hz)

P = number of stator poles

n = slip speed (rpm)

$$f_r = \frac{P \times (n_s - n_m)}{120}$$

$$= \frac{P \times sn_s}{120} = sf_e$$

Induction Motors and Transformers

- Both IM and transformer works on the principle of induced voltage
  - Transformer: voltage applied to the primary windings produce an induced voltage in the secondary windings
  - Induction motor: voltage applied to the stator windings produce an induced voltage in the rotor windings
  - The difference is that, in the case of the induction motor, the secondary windings can move
  - Due to the rotation of the rotor (the secondary winding of the IM), the induced voltage in it does not have the same frequency of the stator (the primary) voltage

- **Advantages of Three-Phase Induction Motor**: These **motors** are self-starting and use no capacitor, start winding, centrifugal switch or other starting device.

APPLICATIONS

- **Three-phase** AC **induction motors** are widely used in industrial and Commercial **applications**.

APPLICATION OF three phase INDUCTION MOTOR

- **Squirrel cage induction motor**
- Squirrel cage induction motors are simple and rugged in construction, are relatively cheap and require little maintenance. Hence, squirrel cage induction motors are preferred in most of the industrial applications such as in
- Lathes
- Drilling machines
- Agricultural and industrial pumps
- Industrial drives.

Quick Quiz (Poll 2)

- A 50 Hz, 3-phase induction motor has a full load speed of 1440 r.p.m. The number of poles in the motor is

a) 2 pole

b) 4 pole

c) 6 pole

d) 8 pole

Explanation

- **P = 120f/N**
- = 120 x 50/ 1400
- **= 4.28**
- **The number of poles should be even and the whole number. Therefore the number of poles must be 4.**

Quick Quiz (Poll 3)

- A three phase, 50 Hz, 4 pole induction motor has a full load speed of 1440 rpm. The full load slip will be

a) 3%

b) 5%

c) 4%

d) 2%

Explanation

- $\mathbf{N_s = 120f/P}$
  $= 120 \times 50/4$
  $= 1500$

  and slip is equal to
  $\mathbf{s = N_s - N_r/N_s}$
  $= 1500 - 1440/1500$
  $= \mathbf{4\%}$