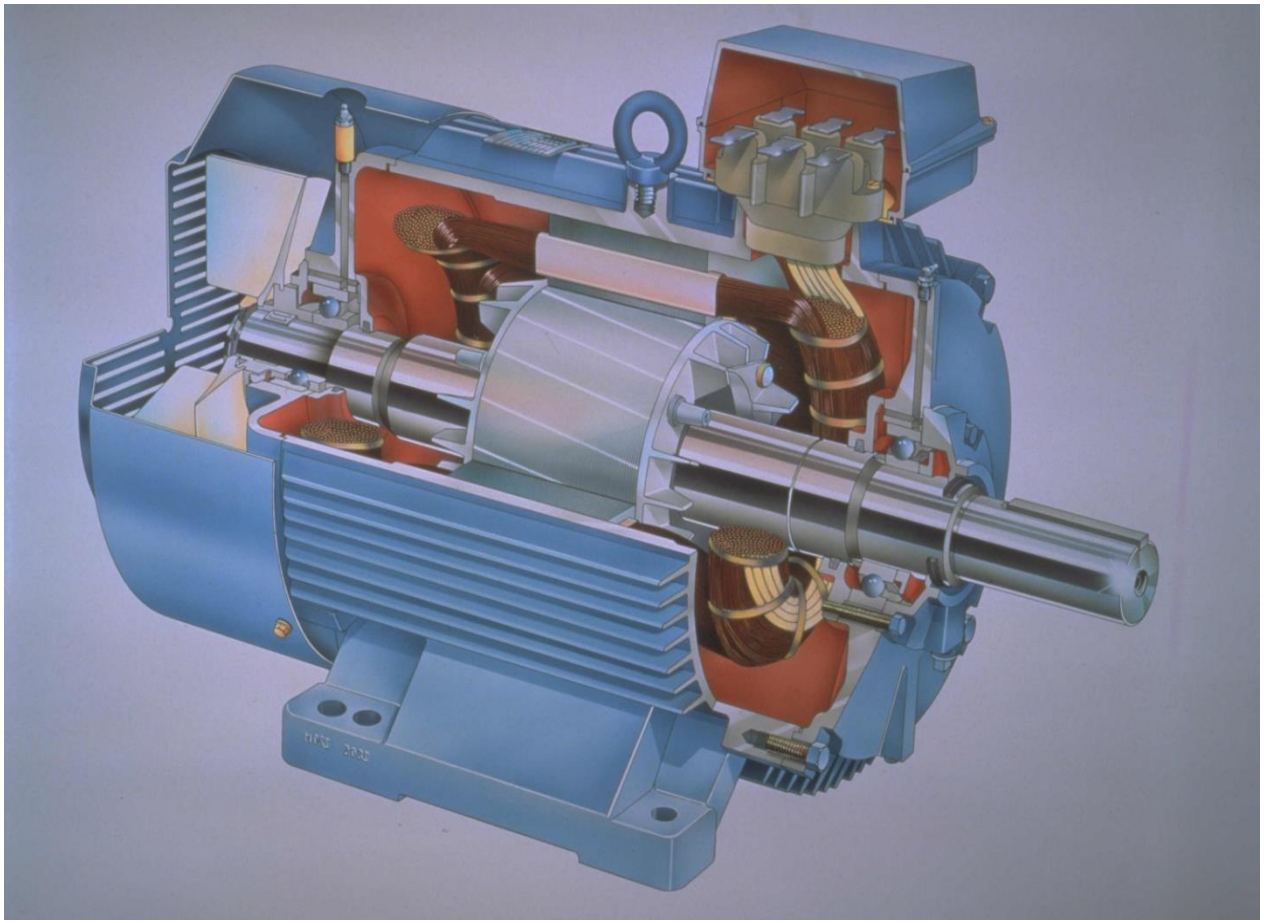
Lecture-39
3-Phase Induction Motor

Lecture delivered by:

THREE-PHASE INDUCTION MOTORS



Topics

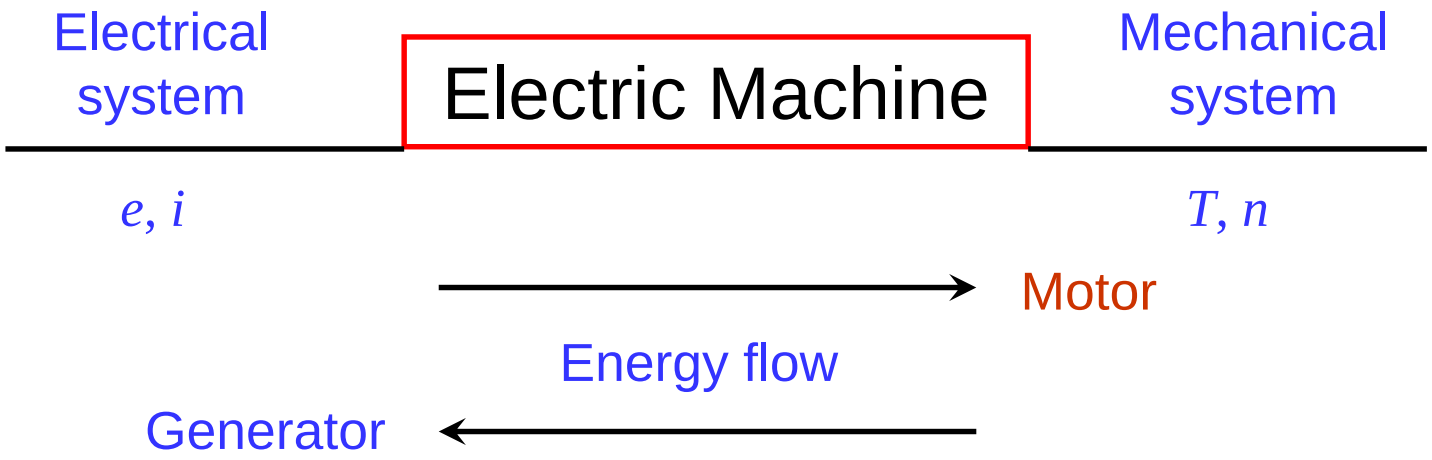
- Induction Motors Introduction
- Classification of Electrical Machines
- Construction details of Electric Machines
- Principle of operation of three phase Induction Motor
- Expressions for Slip, Voltage and Frequency Induced in the Rotor

Objectives

At the end of this lecture, student will be able to:

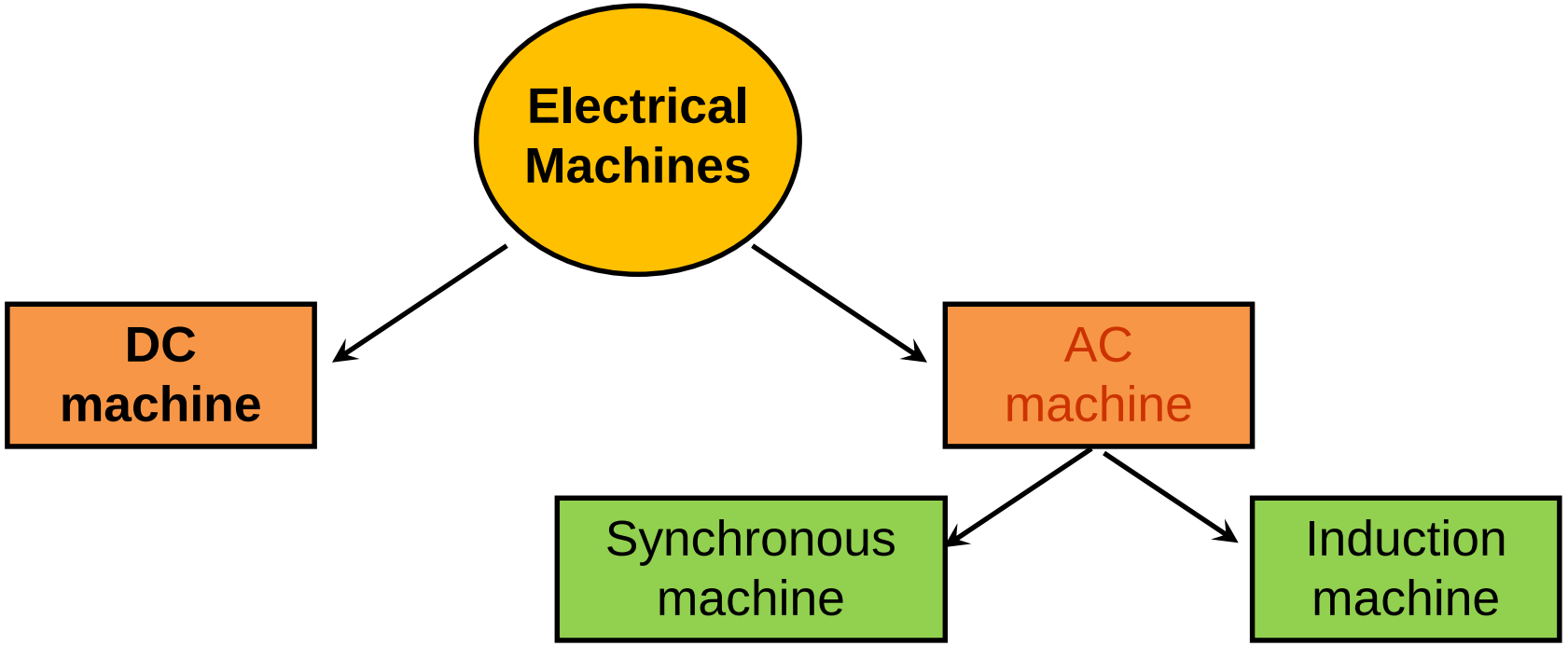
- Explain electromagnetic phenomena in the Electrical Machines
- Discuss the constructional details of Induction Motor
- Describe the principle of operation of 3-phase Induction Motor
- Derive the expressions for Slip, Slip Speed, Voltage and Frequency Induced in the Rotor

ELECTROMECHANICAL ENERGY CONVERSION



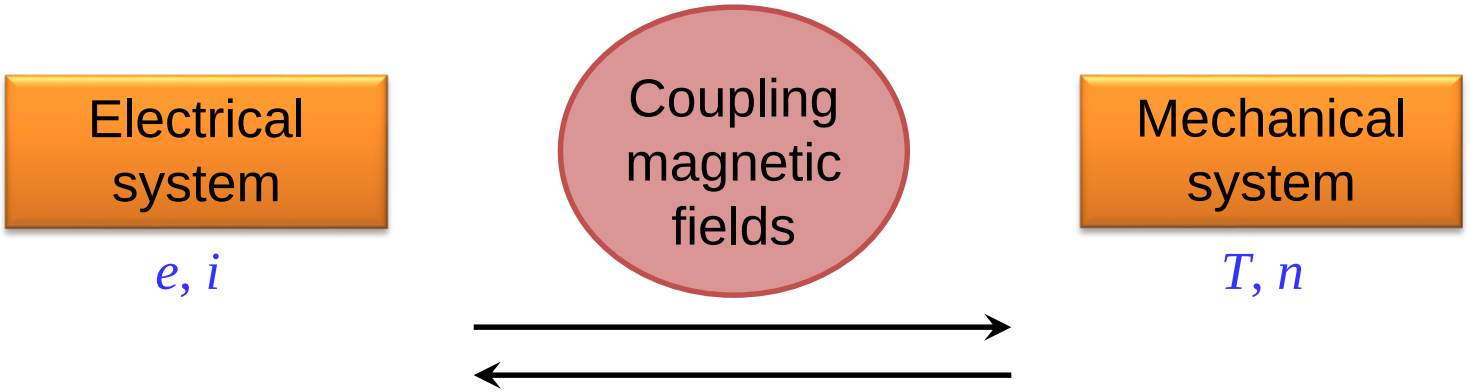
- An electrical machine is link between an electrical system and a mechanical system.
- Conversion from mechanical to electrical: generator
- Conversion from electrical to mechanical: motor

Classification of Electrical Machines



- Machines are called AC machines (generators or motors) if the electrical system is AC.
- DC machines (generators or motors) if the electrical system is DC.

Electromagnetic Phenomena in the Electric Machines



•When a conductor moves in a magnetic field, voltage is induced in the conductor.

•When a current-carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

Applications of AC Rotating Machines

Asynchronous (Induction) Machines:

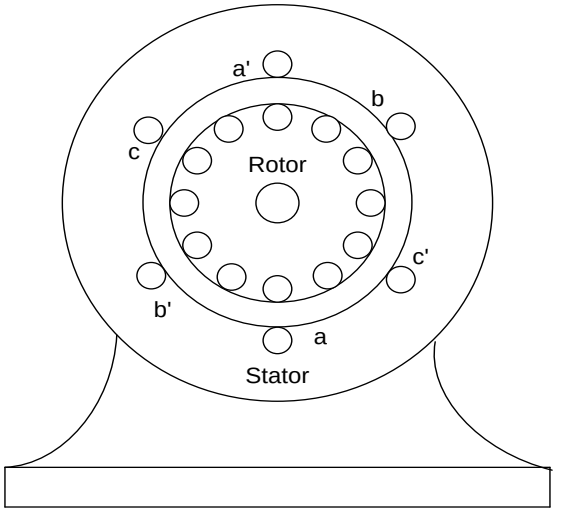
- **Induction Motors:** Most widely used electrical motors in both domestic and industrial applications.
- **Induction Generators:** Due to lack of a separate field excitation, these machines are rarely used as generators.

Synchronous Machines:

- **Synchronous Generators:** A primary source of electrical energy
- **Synchronous Motors:** Used as as power factor compensators (synchronous condensers)

Electric Machines Basic Structure

The structure of an electric machine has two major components, stator and rotor, separated by the air gap.

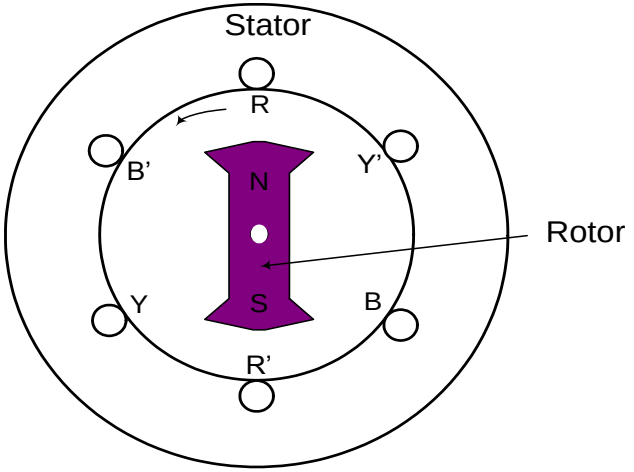


- **Stator:**

Does not move and normally is the outer frame of the machine.

- **Rotor:**

Is free to move and normally is the inner part of the machine.

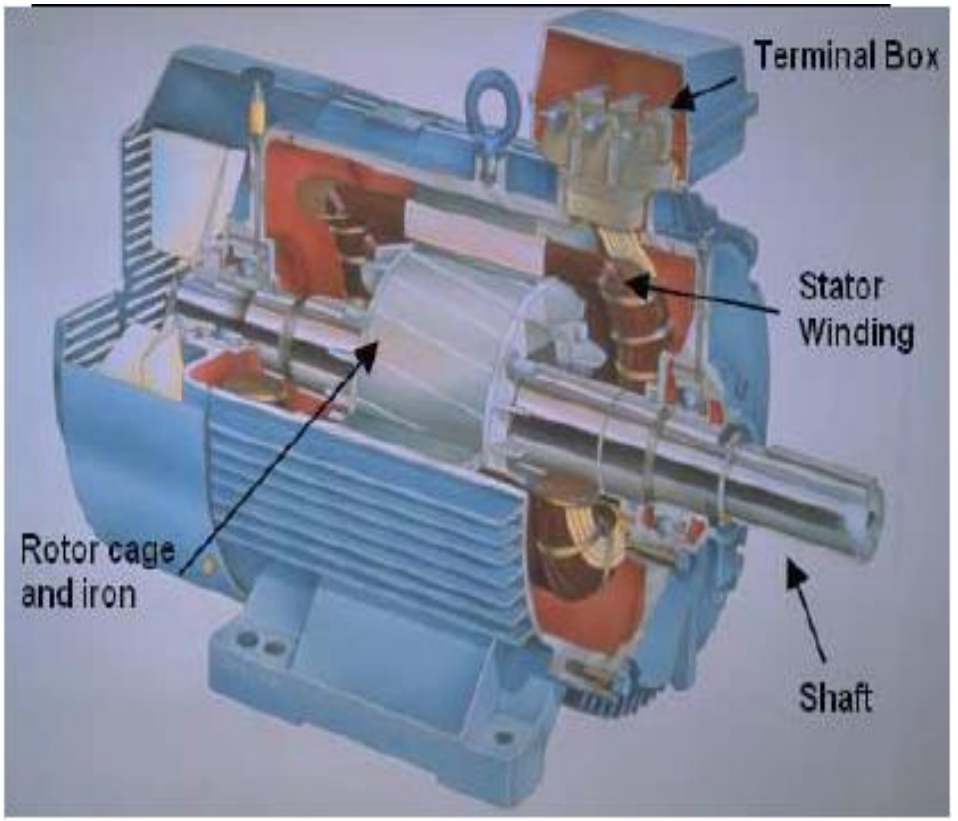


Both rotor and stator are made of ferromagnetic materials.

Constructional details of Induction Motor

General

- Induction machine has a stator and a rotor like other type of motors.
- Types of rotors in Induction machine :
  1-squirrel-cage winding,
  2-Wound-rotor
- Both three-phase and single-phase motors are widely used.



Construction of Induction Motor

IM Application

- For industrial applications, the three-phase induction motor is used to drive machines

Construction (Rotor construction)

- Types of rotors in Induction machine

Squirrel cage rotor.

Wound rotor

- Motors employed squirrel cage rotor are called squirrel cage induction motor.
- Motors employed wound rotor are called wound motors or slip ring motors.

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

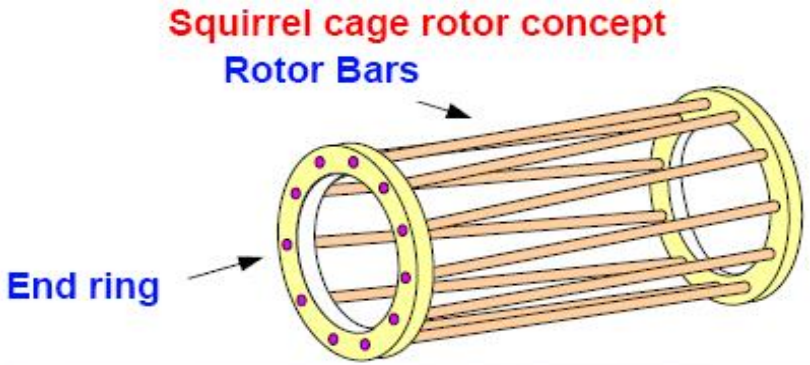
❖ **Wound rotor type:**

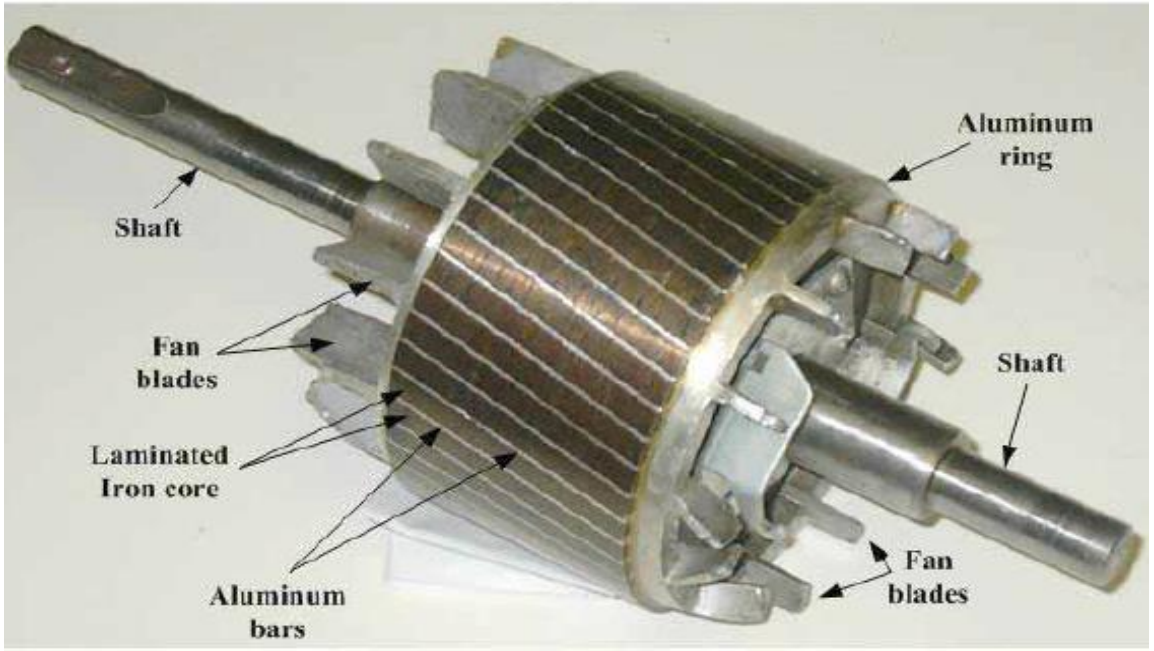
➢ Rotor winding is wound by wires. The winding terminals can be connected to external circuits through slip rings and brushes.

➢ Easy to control speed, more expensive.

Squirrel-Cage Rotor

- Rotor is from laminated iron core with slots.

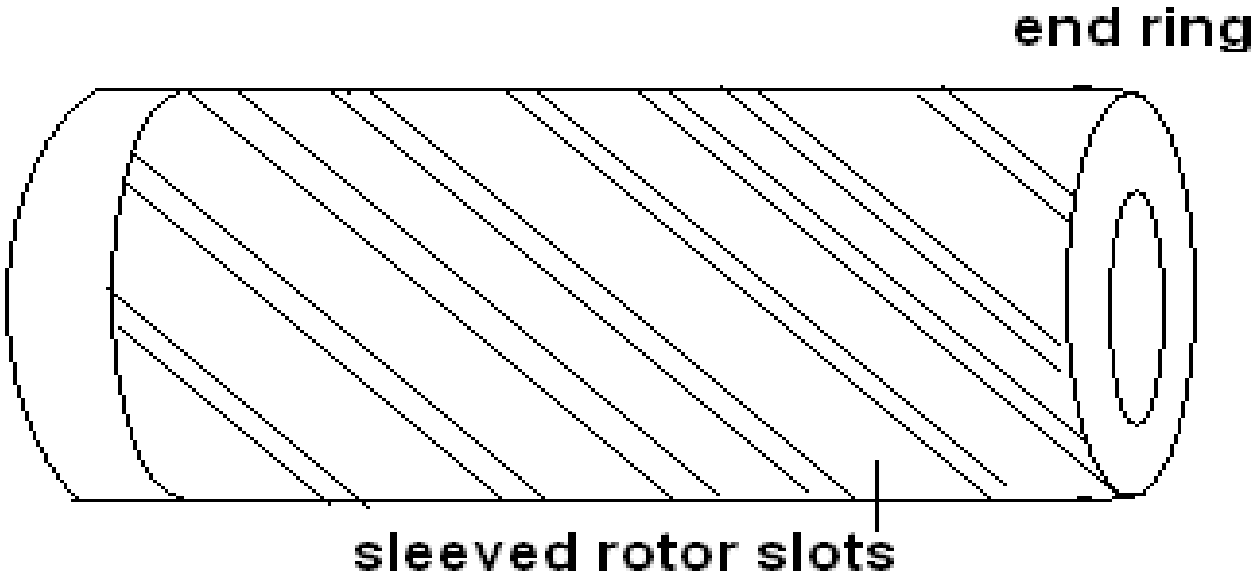




Squirrel cage rotor Construction Details

- It has most rugged construction
- The rotor consists of a cylindrical laminated cone.
- The conductors consists of heavy balls of copper, aluminium or alloy.
- It resembles a squirrel case, hence the name squirrel case rotor.
- The rotor slots are given a slight skew to Make the motor run quickly by reducing magnetic hum.

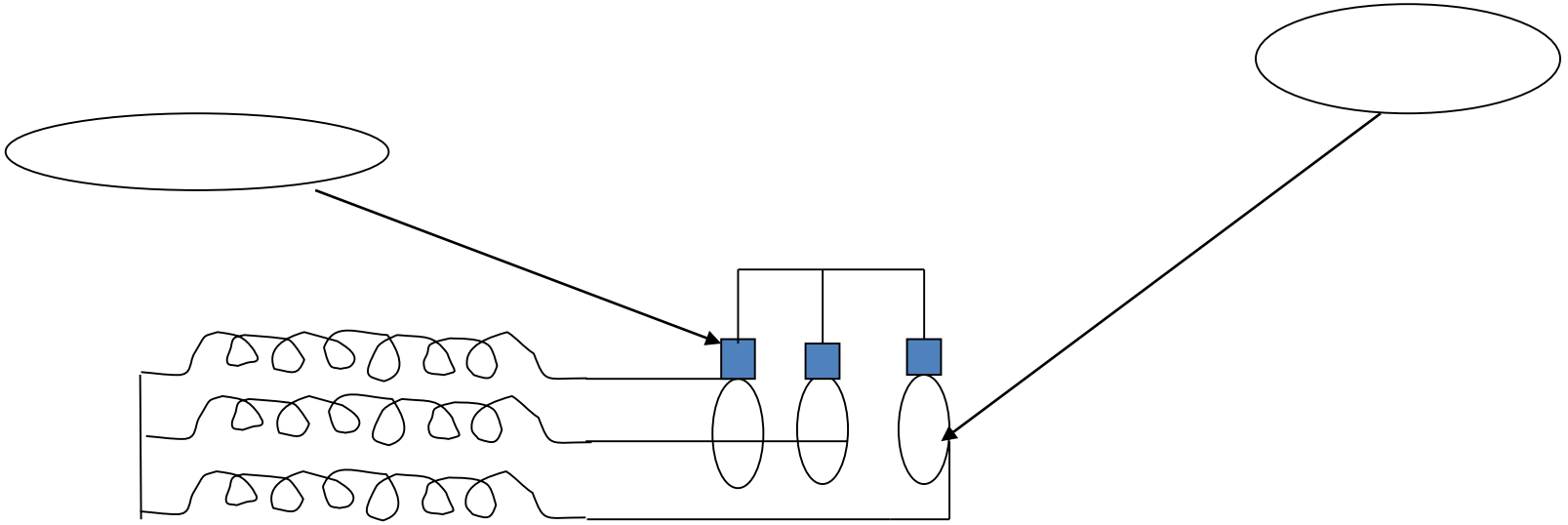
Squirrel cage rotor



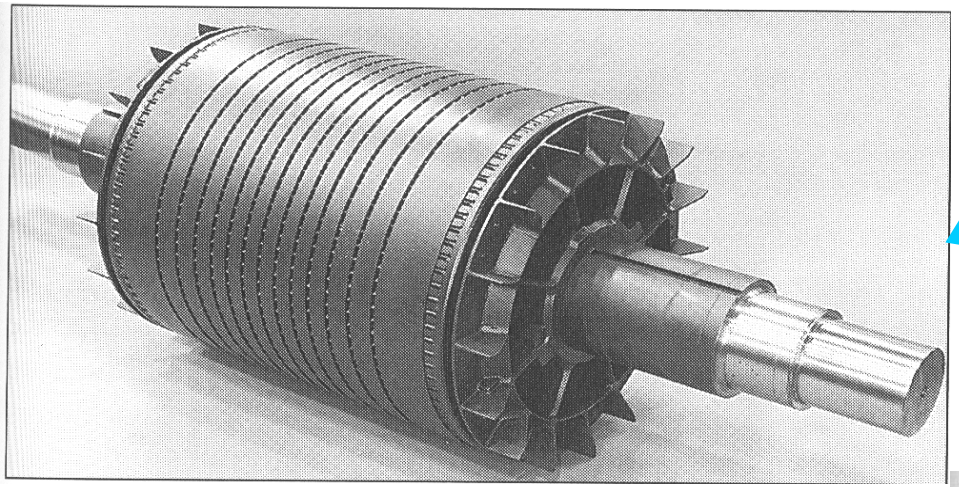
Slip Ring Rotor

- Rotor contains windings similar to stator.

- Connections from rotor are brought out using slip rings that
- are rotating with the rotor and carbon brushes that are static.



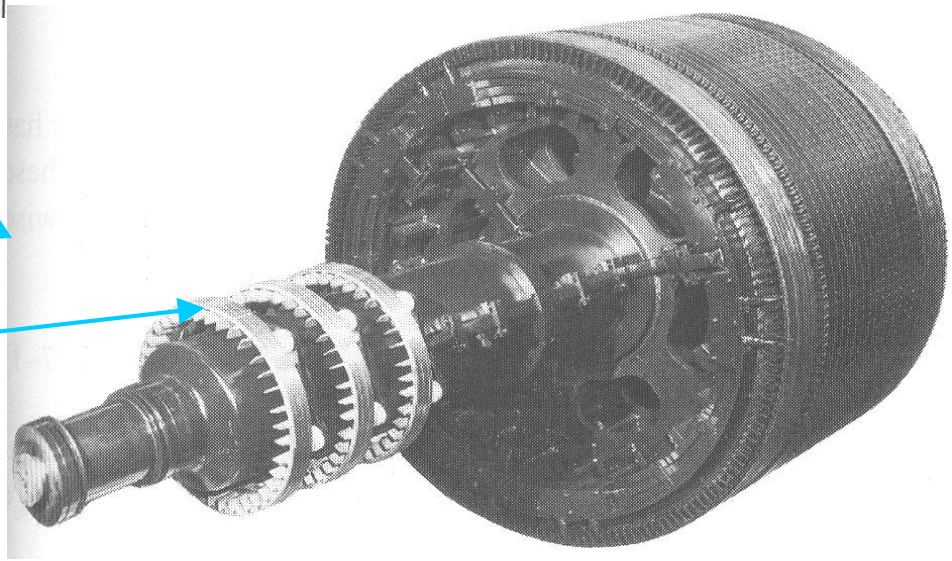
Construction



Squirrel cage rotor

Wound rotor

Notice the
slip rings



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).
  - 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.

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

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)

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

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

Slip and Slip Speed

The slip s of an induction motor is the difference between the synchronous speed and the rotor speed, expressed as percent (per unit) of synchronous speed

The per-unit slip is given by the equation

$$S = \frac{n_s - n_r}{n_s}$$

S = slip
n_s = synchronous speed [r/min]
n_r = rotor speed [r/min]

Voltage and Frequency Induced in the Rotor

The voltage and frequency induced in the rotor both depend on the slip. They are given by the following equation

$$f_2 = s\, f$$

$$E_2 = s\, E_{oc}\ (approx.)$$

f_2 = frequency of the voltage and current in the rotor [Hz]
f = frequency of the source connected to the stator [Hz]
s = slip
E_2 = voltage induced in the rotor at the slip s
E_{oc} = open-circuit voltae induced in the rotor when at rest [V]

Summary

- The basic types of three-phase induction motors are:

  squirrel cage induction motor

  wound rotor induction motor

- Wound-rotor motors have three slip rings on the rotor shaft to provide external connection to the rotor.
- synchronous speed of the induction motors are depends on number of stator poles per phase and frequency of the applied voltage.
- Maximum torque is developed when stator and rotor flux are in phase with each other.