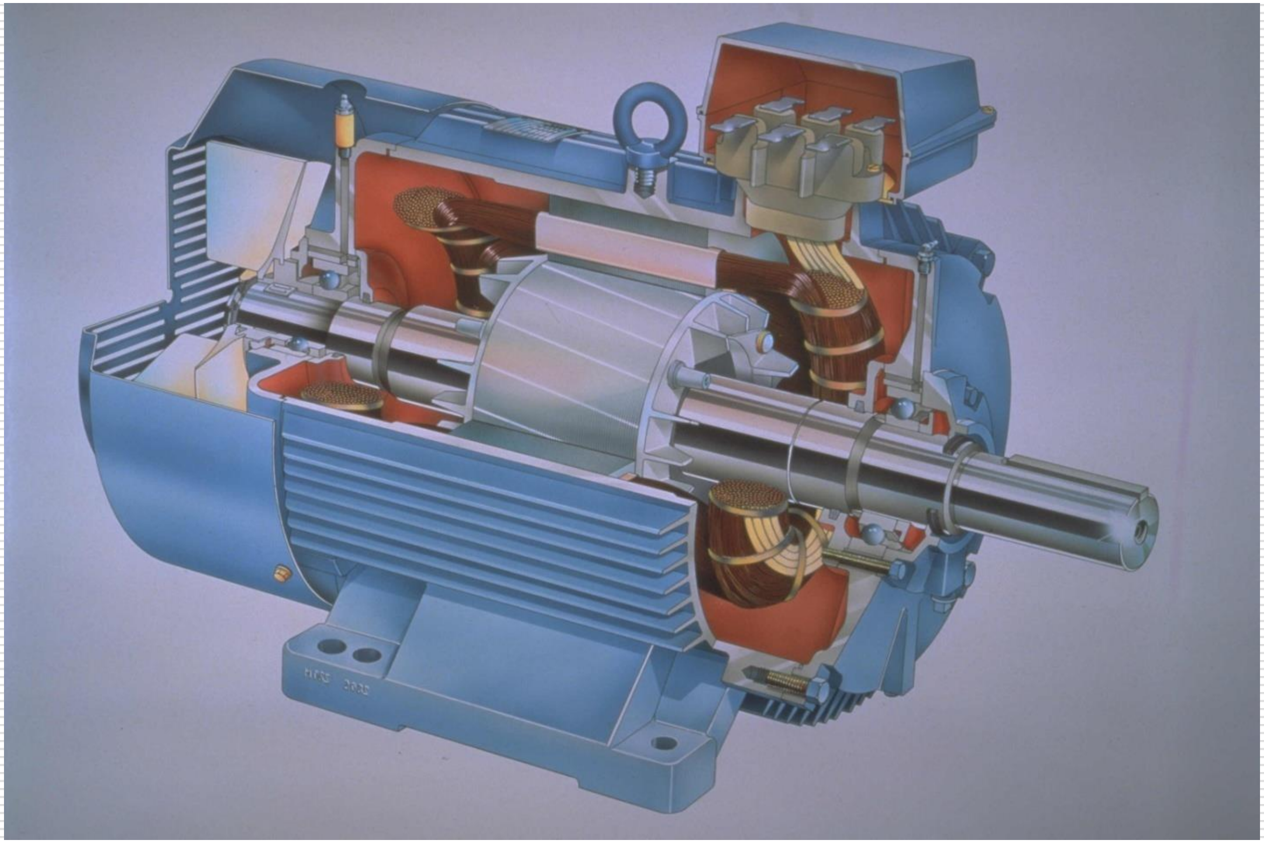
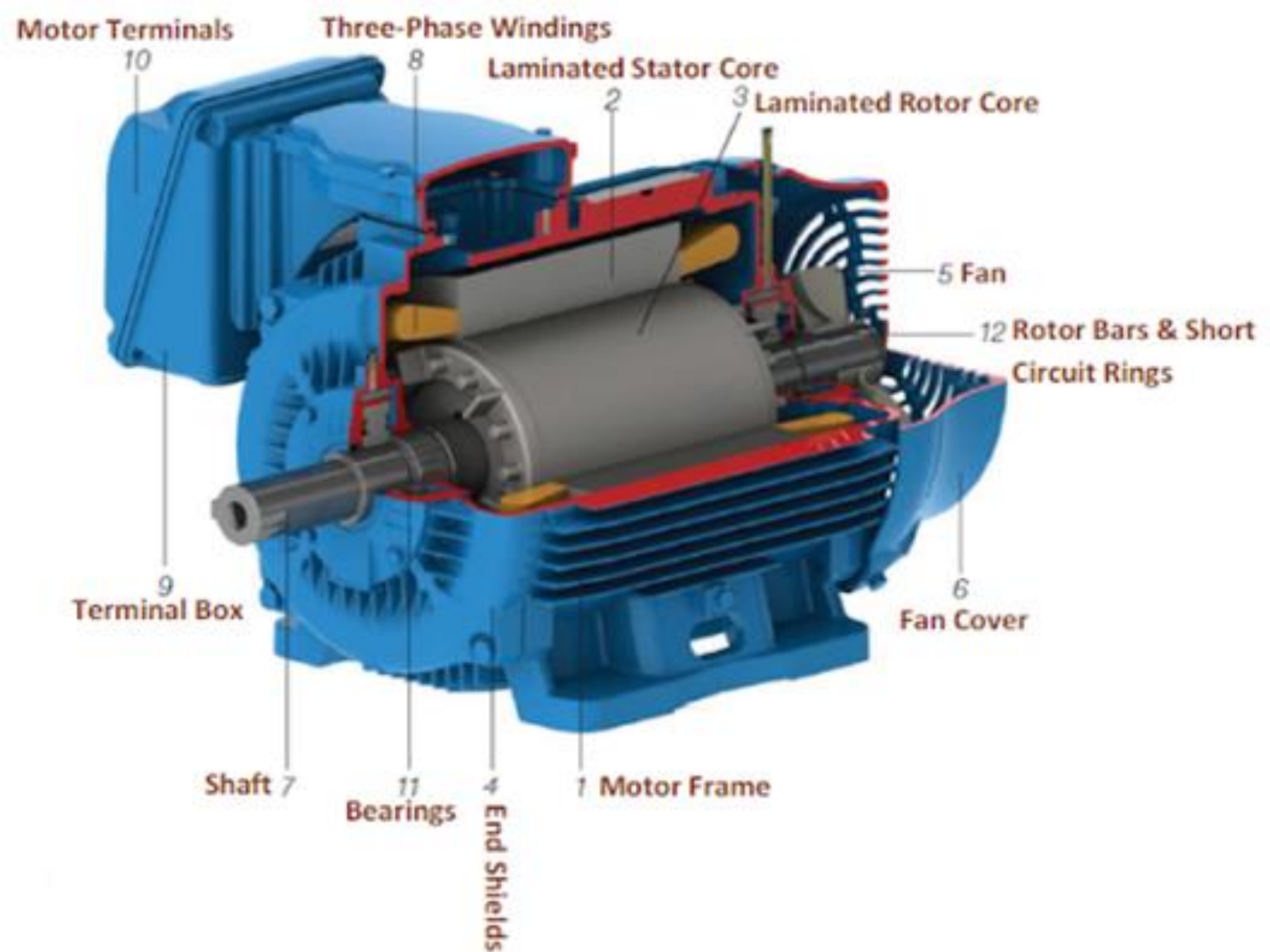
Induction Motors





Motor Terminals
10
Three-Phase Windings
8
Laminated Stator Core
2
3 Laminated Rotor Core
5 Fan
12 Rotor Bars & Short
Circuit Rings
6
Fan Cover
9
Terminal Box
Shaft 7
11
Bearings
4
End Shields
1 Motor Frame

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

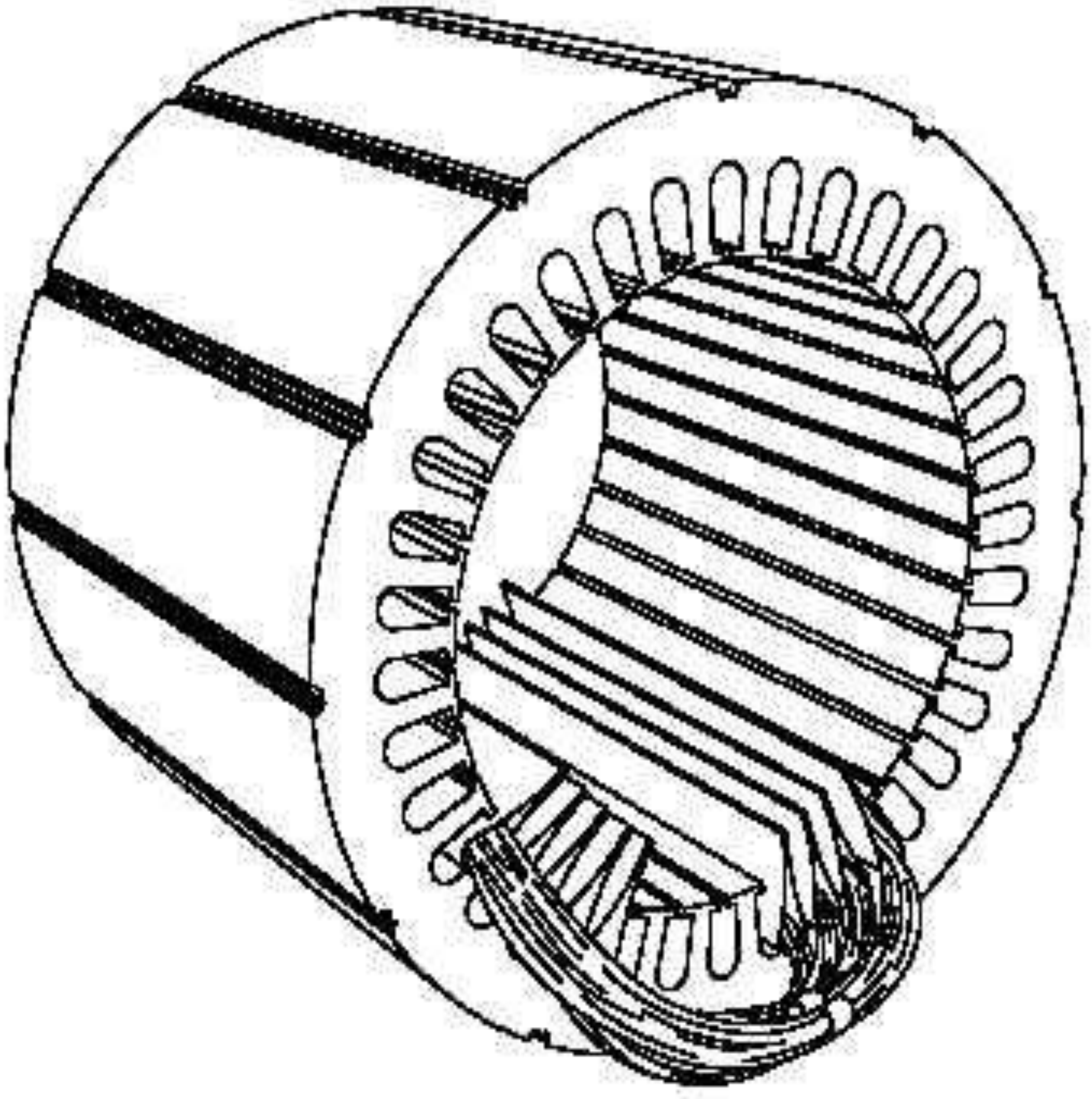
An induction motor has two main parts

- Stator
- Rotor

Stator

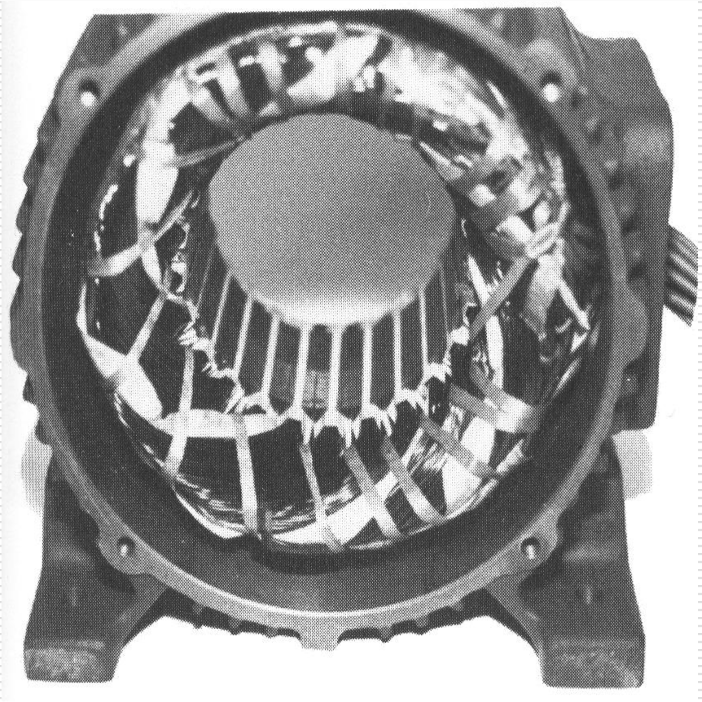
- Outer Frame
- Stator Core
- Stator Winding

Outter Frame



Stator Core & Stator Winding

- **consisting of a iron or steel frame that supports a hollow, cylindrical core**
- **core, constructed from stacked laminations, having a number of evenly spaced slots, providing the space for the stator winding**



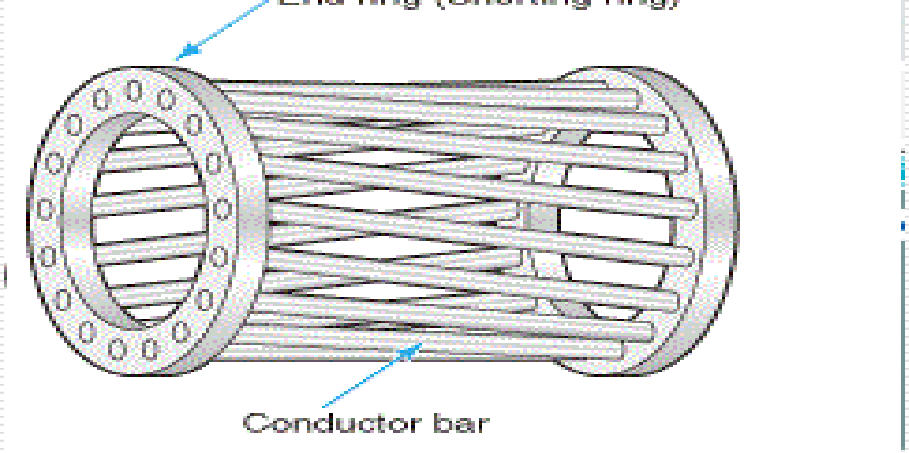
Stator of IM

Rotor of Induction Motor

Two types of rotor are employed in 3 phase Induction Motor

1. Squirrel cage rotor
2. Slip ring or Phase wound rotor

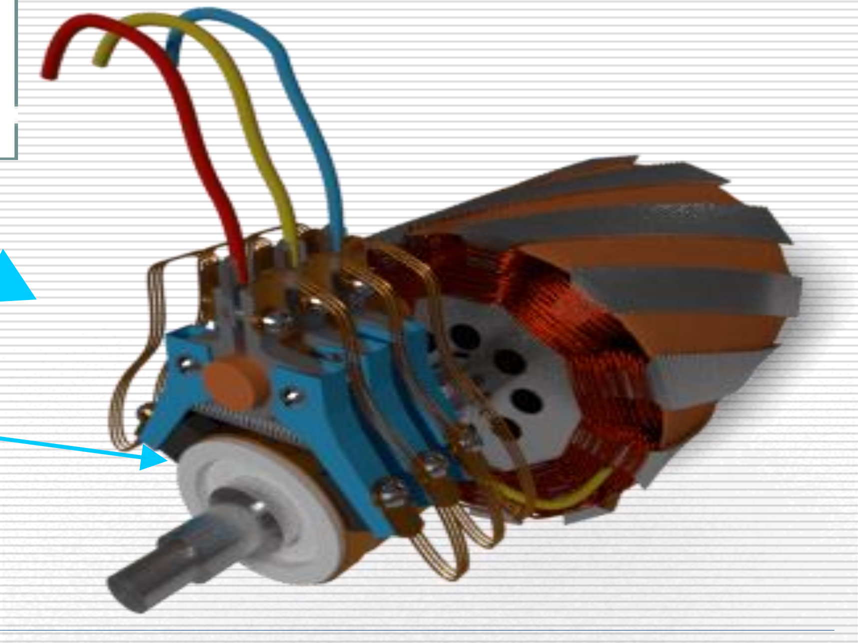
Construction



(b) Squirrel-cage conductor

Squirrel cage rotor

Wound rotor



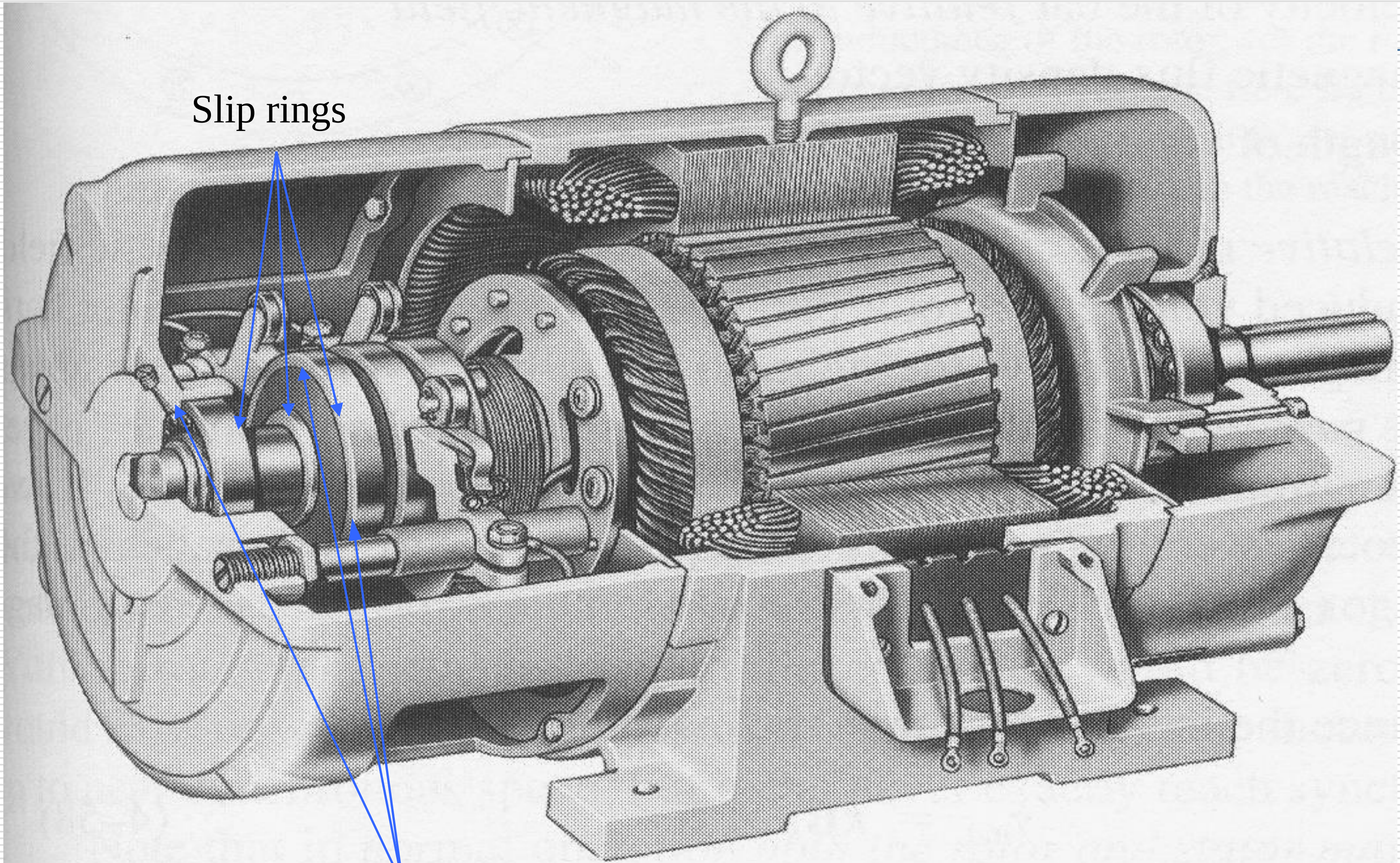
Notice the
slip rings

Construction

- **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.**

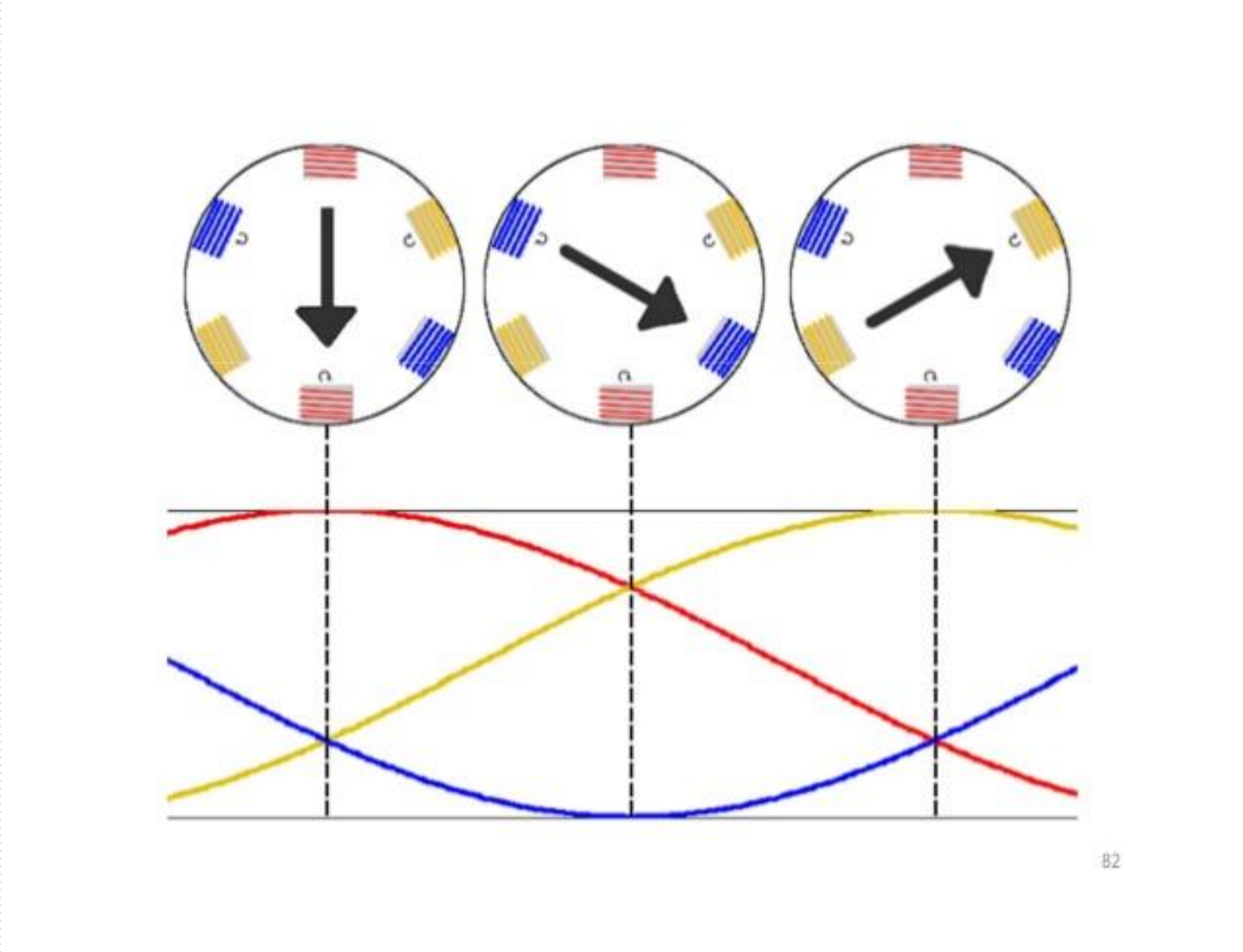
Construction



Cutaway in a typical wound-rotor IM.

Parts	Material	Function
Stator frame	Case iron	Supports the core,protects inner-parts.
Stator core	Silicon steel	Houses stator winding.
Stator Winding	Copper and insulated	Product rotating magnetic field.
Rotor core	Silicon steel	Houses rotor winding.
Rotor winding	Copper and insulated	To produce rotor current.
Air gap	–	To provide rotor and stator.
Air inlet-outlet	–	For air circulation.
Cooling fan	Aluminium	For air circulation.
Slip-rings	Phosphorus Bronze	Connects resistance to rotor circuit via-brushes.
Brushes	Carbon	To provide connection between resistance and slip-rings.
Shaft	M.S	Supports rotor.

Working of 3 phase Induction Motor



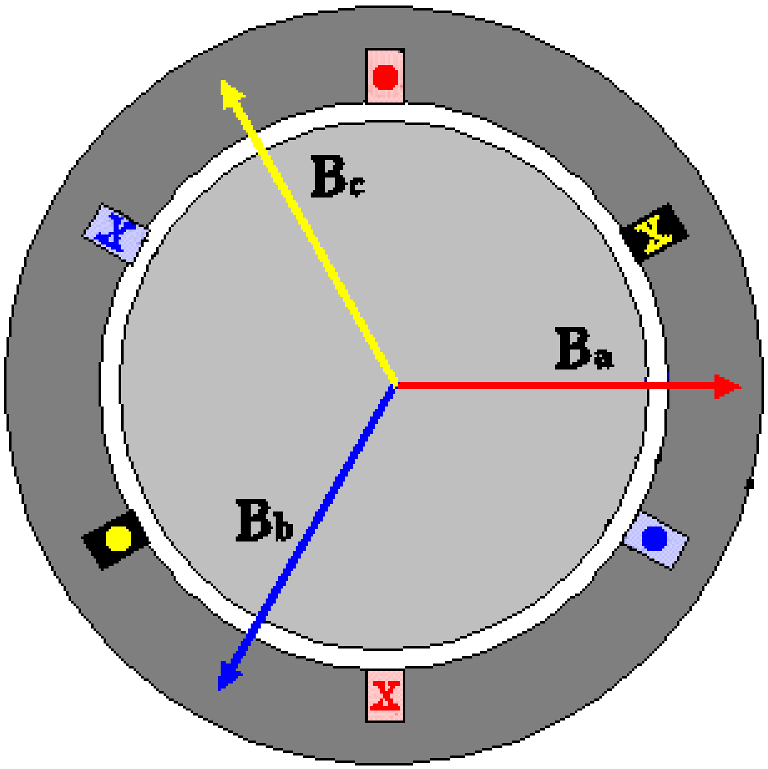
Rotating Magnetic Field

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

$$N_s = \frac{120\,f}{P}$$

Where f is the supply frequency and

P is the no. of poles and N_s is called the synchronous speed in *rpm* (revolutions per minute)

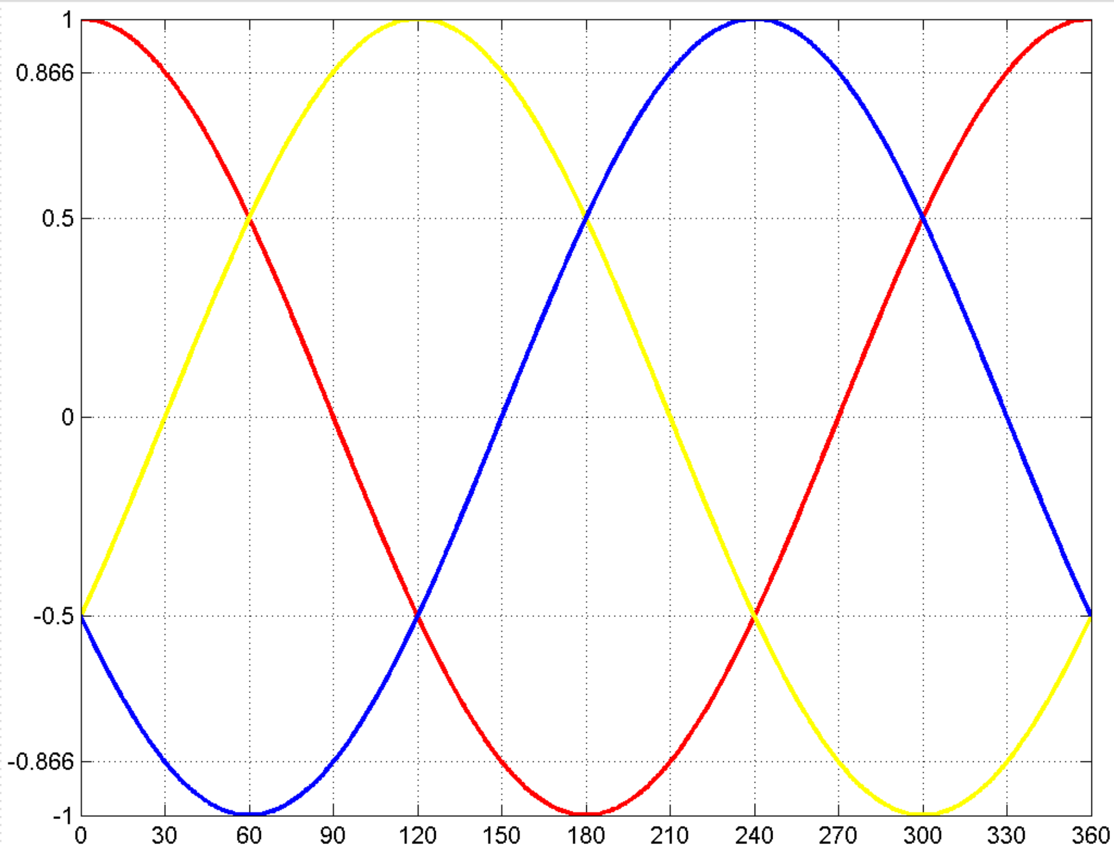


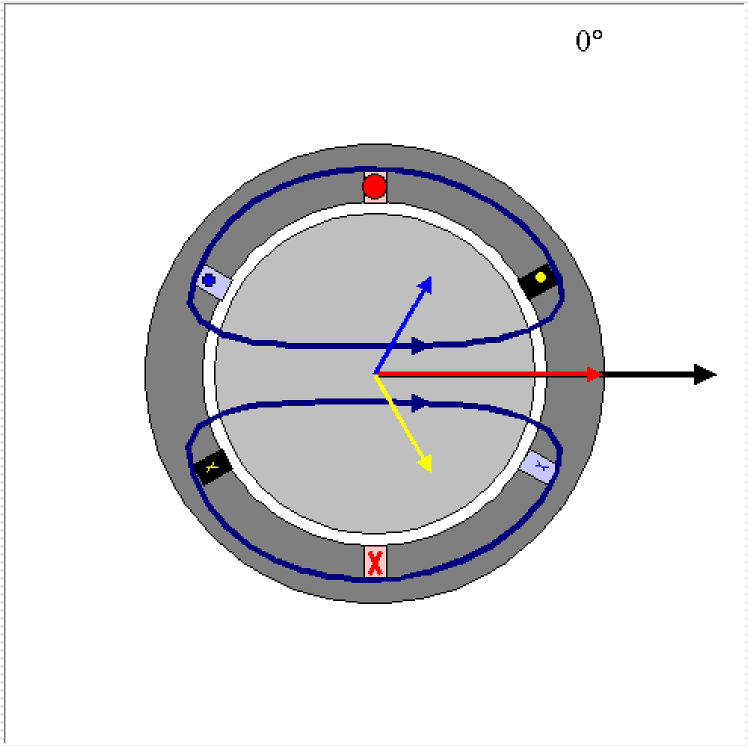
Synchronous speed

$$N_s = \frac{120\,f}{P}$$

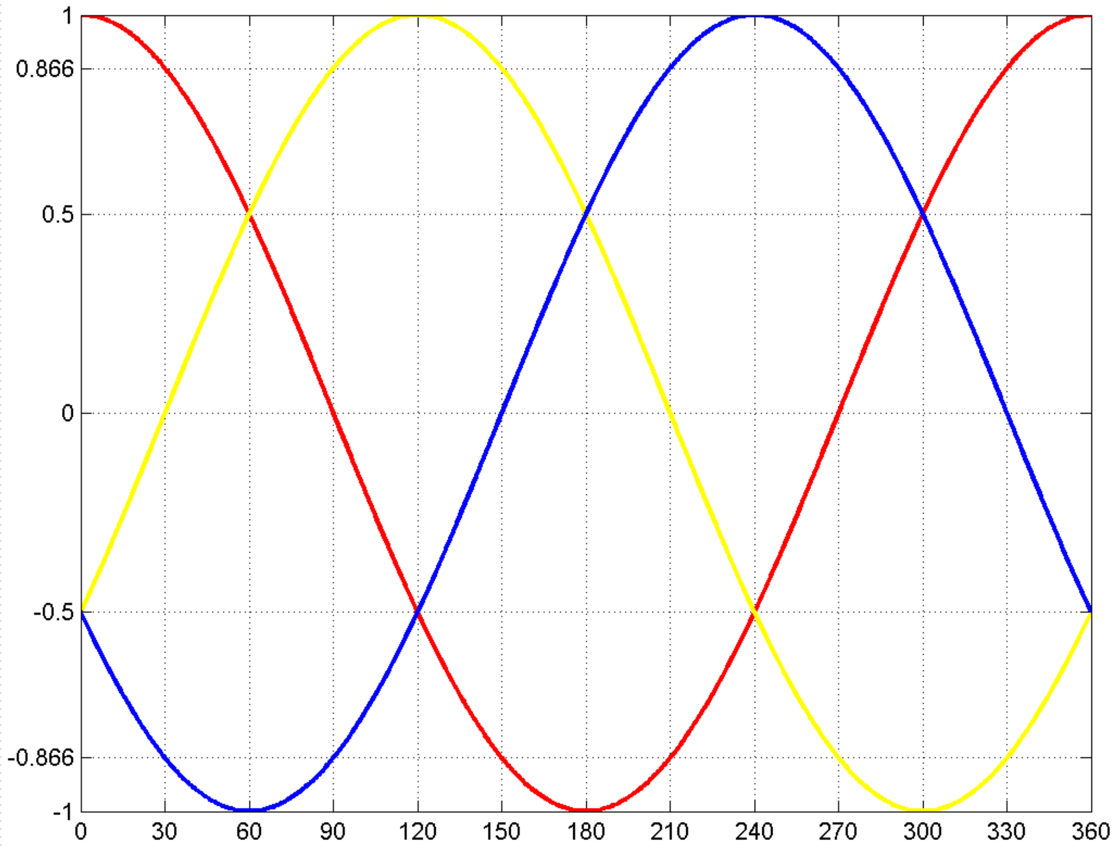
P	50 Hz
2	3000
4	1500
6	1000
8	750
10	600
12	500

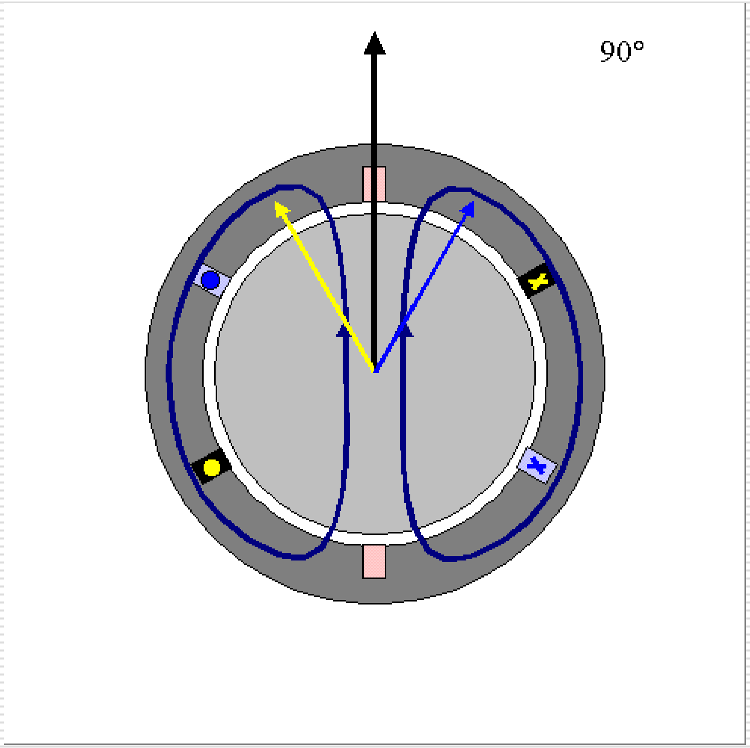
Rotating Magnetic Field



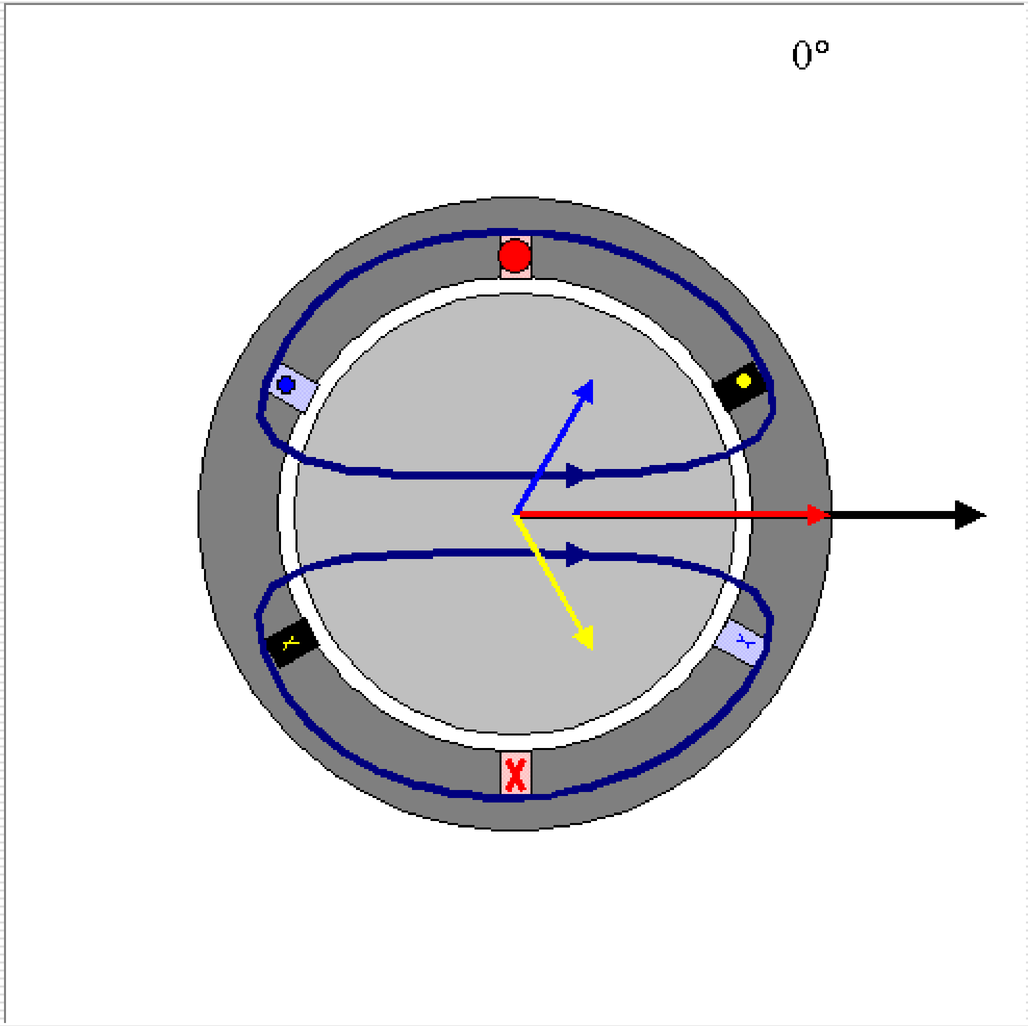


Rotating Magnetic Field





Rotating Magnetic Field



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, an 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

Slip

- 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*

$$\%S = \frac{Ns - N}{Ns} \times 100$$

Where S = slip

N_s = synchronous speed

N = mechanical shaft speed of the motor

Frequency of Rotor

- **Assume rotor is stationary**
  - Relative speed between the rotor winding and rotating magnetic field is N_s $\quad f = \frac{PN_s}{120}$
- **When the rotor speeds up**
  - Relative speed is $(N_s - N)$
- **Rotor Frequency** $\quad f_r = \frac{P(N_s - N)}{120}$

$$Slip\ s = \frac{N_s - N}{N_s} \Rightarrow N_s - N = sN_s = s \times \frac{120f}{P}$$

$$\therefore f_r = \frac{P(N_s - N)}{120} = \frac{P}{120} \times s \times \frac{120f}{P} = sf$$

$$also\ called\ slip\ frequency\ f_r = sf$$

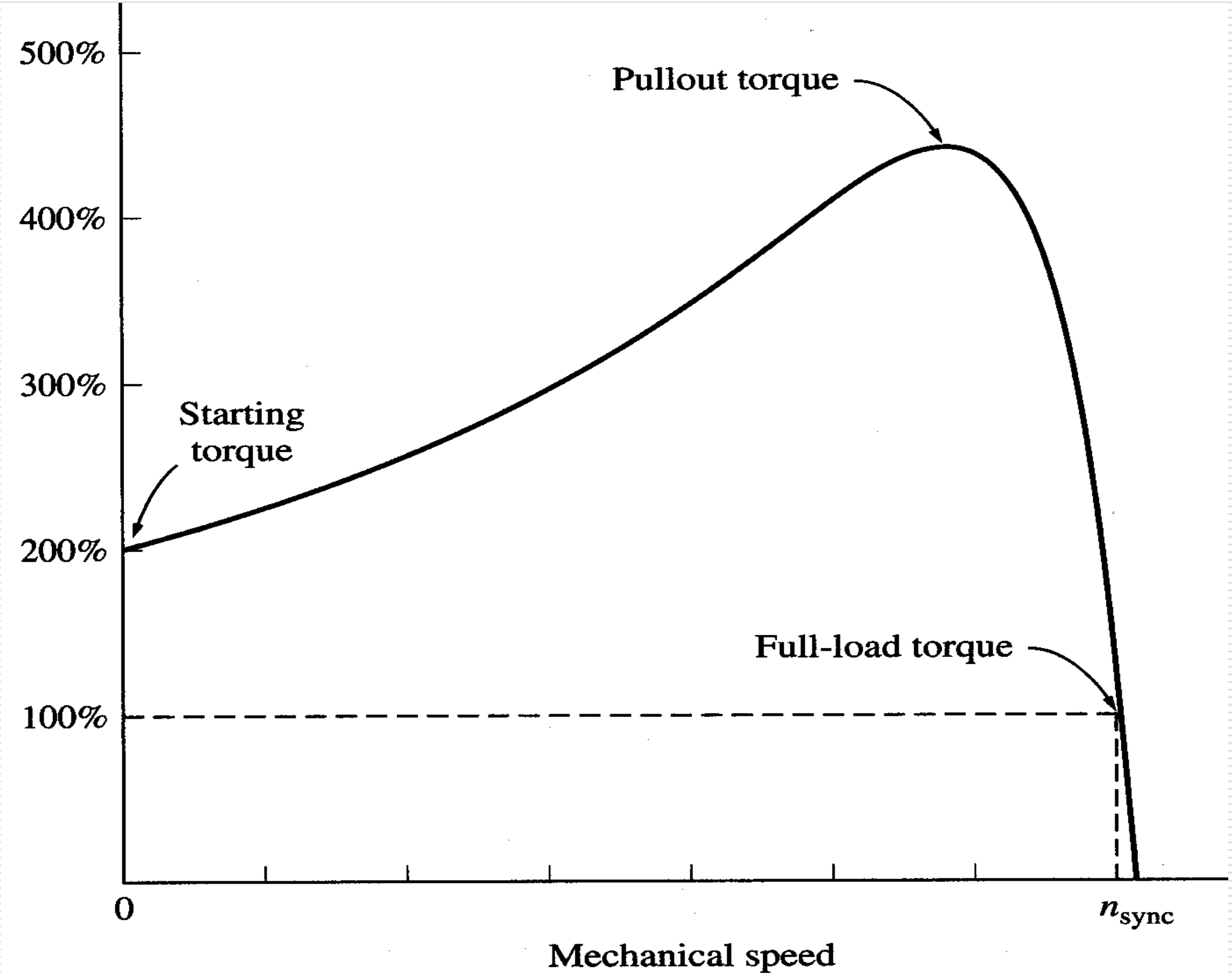
Induction Motors and Transformers

- 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

Power losses in Induction machines

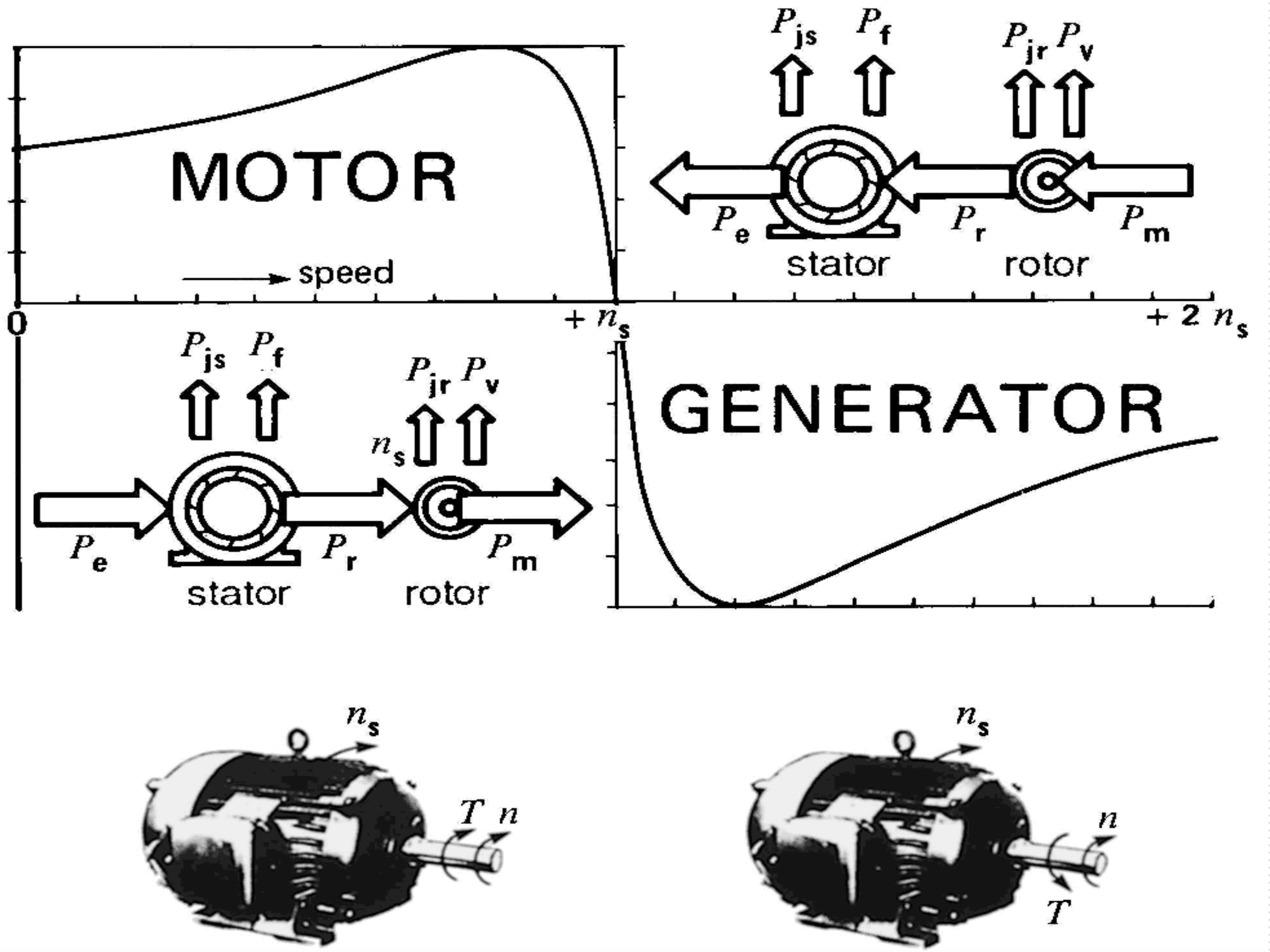
- Copper losses
  - Copper loss in the stator (P_{SCL}) = $I_1^2R_1$
  - Copper loss in the rotor (P_{RCL}) = $I_2^2R_2$
- Core loss (P_{core})
- Mechanical power loss due to friction and windage

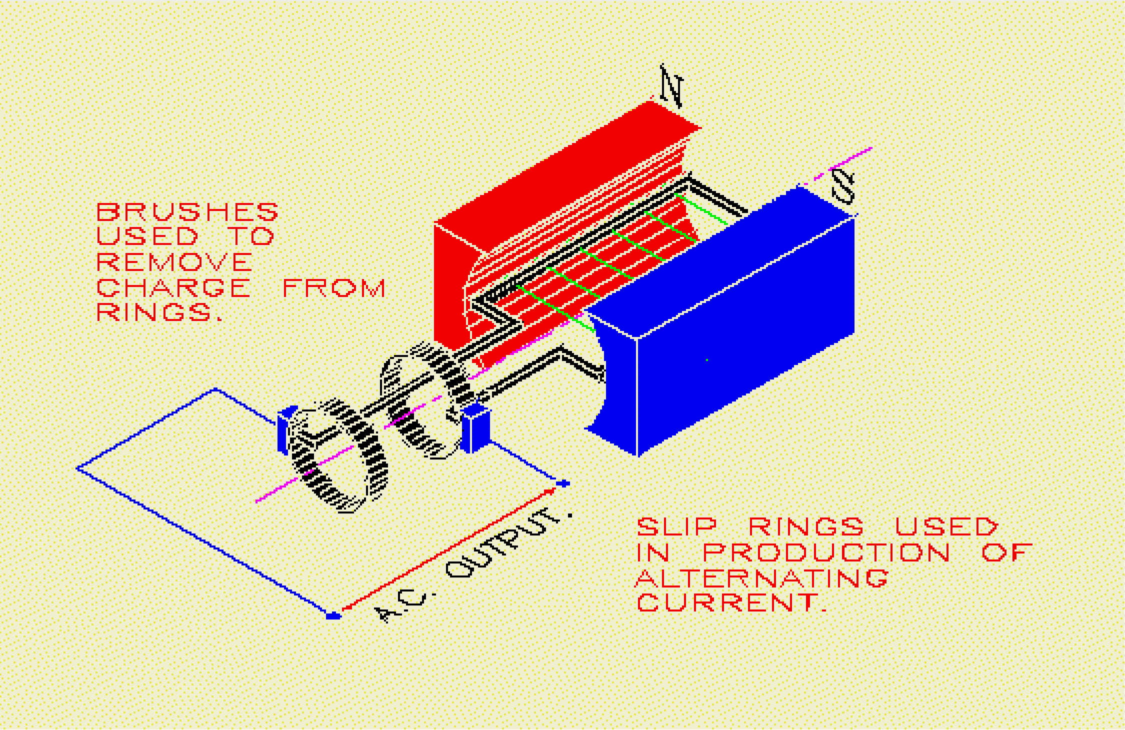
Torque-speed characteristics



Typical torque-speed characteristics of induction motor

Complete Speed-torque c/c




N
S
BRUSHES USED TO REMOVE CHARGE FROM RINGS.
A.C. OUTPUT.
SLIP RINGS USED IN PRODUCTION OF ALTERNATING CURRENT.

EMF Equation

E = 4.44 Kp Kd f N ϕm

$$T = \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2} \times \frac{3}{2\pi n_s}$$