Topic 2

Three phase Induction Motor

Basic principle

Construction

Operation

Three phase induction motor

- Three phase induction motors are widely used in industries for medium power applications
- Lifts, cranes, pumps, fans etc.
- Induction motors are
  – cost effective
  – Rugged
  – require less maintenance
- Almost 80% of AC motors used worldwide in industries are three-phase induction motors.

Introduction

- Like any other motor, a three-phase induction has
  - An outer static part called the stator
  - Inner rotating part called the rotor
  - Separated by a small air gap.
- The stator is wound with a **three-phase winding**
- **Three-phase voltage** is supplied to the stator windings.
- This creates a uniform electro-magnetic field in the stator
- The **magnetic field rotates in space** around the inner periphery of the stator.
- The uniform speed at which the stator magnetic field rotates is called the **synchronous speed**.

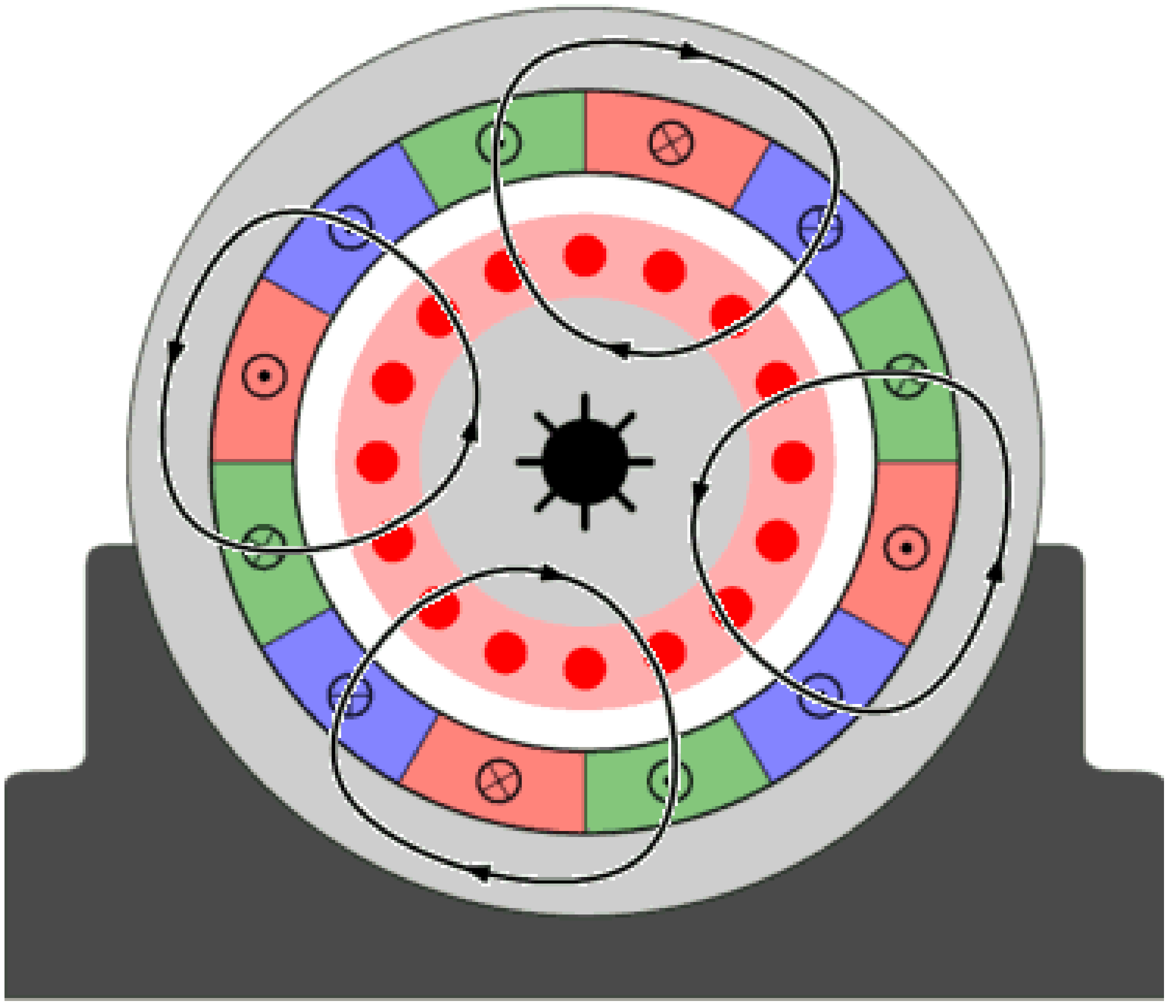
Introduction

- The rotor also has a multi-phase winding embedded in the slots provided on a cylindrical iron structure.
- These rotor windings are **short circuited among themselves** and no supply is given to the rotor.
- There is no electrical connection between the stator and the rotor.
- The rotating flux created by the stator when links with the rotor, induces an alternating EMF in the rotor.

Introduction

- Due to linking with this varying magnetic field, EMF is induced in the rotor conductors
- The rotor induced EMF causes current to flow in the rotor windings
- This current is due to **magnetic induction**, and hence the name induction motor.
- The current flowing in the rotor interacts with the magnetic flux created by the stator to produce a torque that makes the rotor to rotate.
- The rotor always rotates at a speed **lower than the synchronous speed** (speed of the stator rotating magnetic field), and hence induction motors are also called **asynchronous motors**.

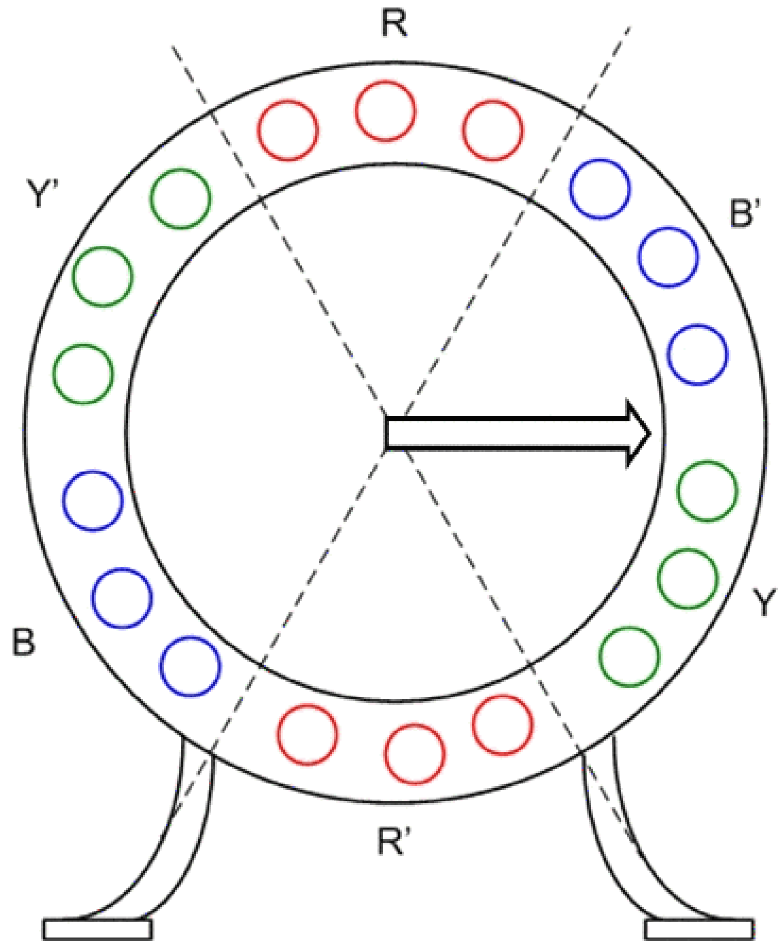
Generation of Rotating Magnetic Field (RMF) in Stator



Generation of Rotating Magnetic Field (RMF) in Stator

- To create such a rotating magnetic field (RMF), three windings, physically separated from each other, are placed in the stator of a three-phase induction motor.
- When this three-phase winding is supplied from a three-phase voltage source, an electromagnet is formed in the stator.
- The magnetic field thus produced will be found to rotate in space around the stator inner periphery.
- Under action of this RMF, the rotor placed in the space inside the stator will be rotating.
- Thus motor action is achieved by converting the input electrical energy supplied to the stator into mechanical rotation of the rotor

RMF



Speed of RMF – Synchronous speed

Speed of the rotating magnetic field in stator (Synchronous speed)

$$\boxed{N_S = \frac{120\,f}{P}\,RPM}$$

Supply frequency	Number of poles	Speed N_S (RPM)
50 Hz	2	3000
50 Hz	4	1500
50 Hz	6	1000
50 Hz	8	750

Speed of rotor

- The rotor always rotate at an average speed (Nr) that is lower than the synchronous speed (Ns)
- This relative difference in speed is called **'slip'**

$$s = \frac{N_S - N_r}{N_S}$$ (Fraction)

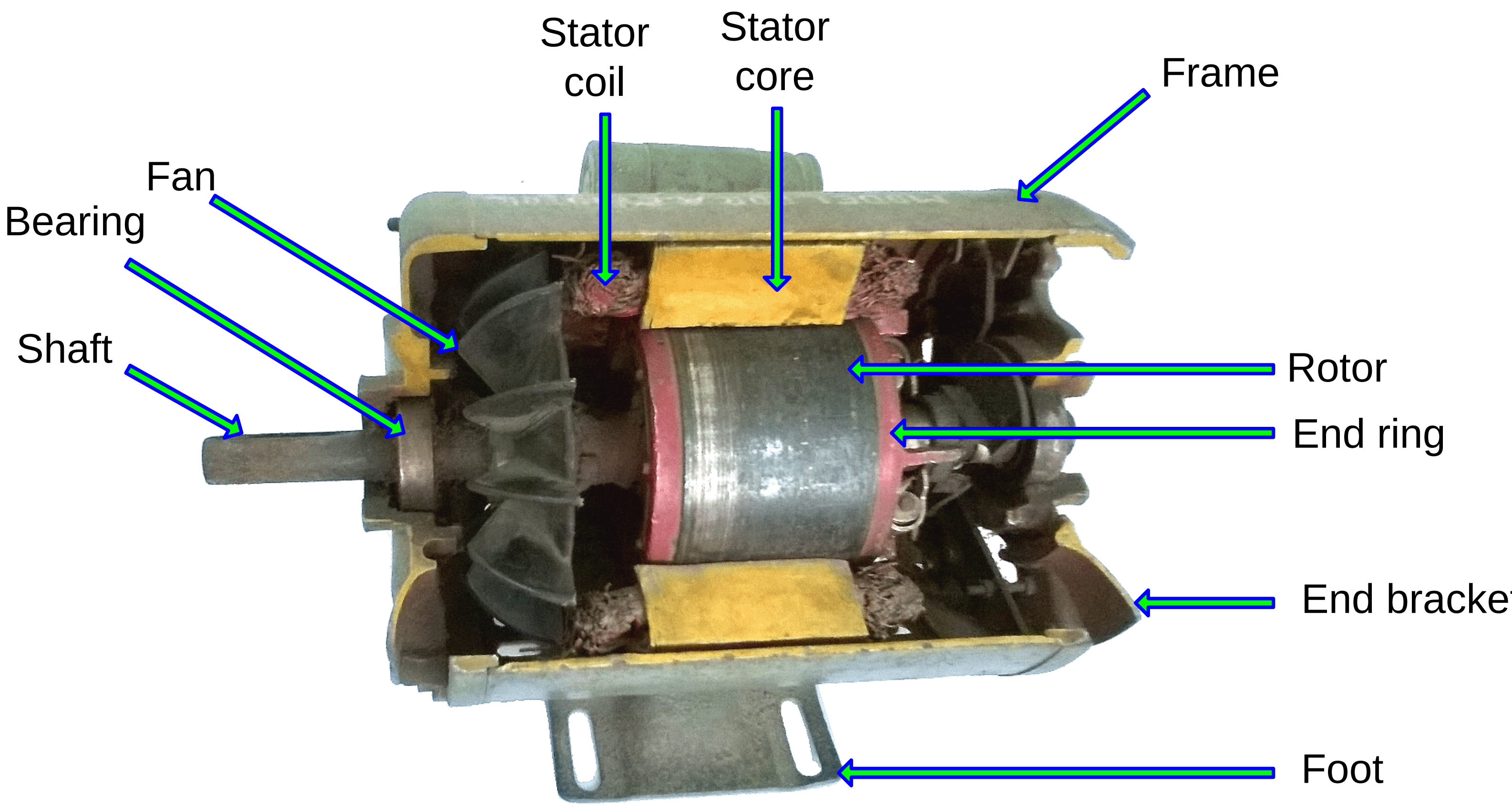
$$s = \left(\frac{N_S - N_r}{N_S} \right) \times 100\%$$

- Value of the slip 's' is thus a measure of the quantity by which the rotating disc 'slips' behind the rotating magnet.
- In most practical induction motors, the value of slip varies between 2 to 6 %.
- Rotor speed is thus given by: $N_r = (1 - s) N_S$

Construction
of
3-phase induction motors

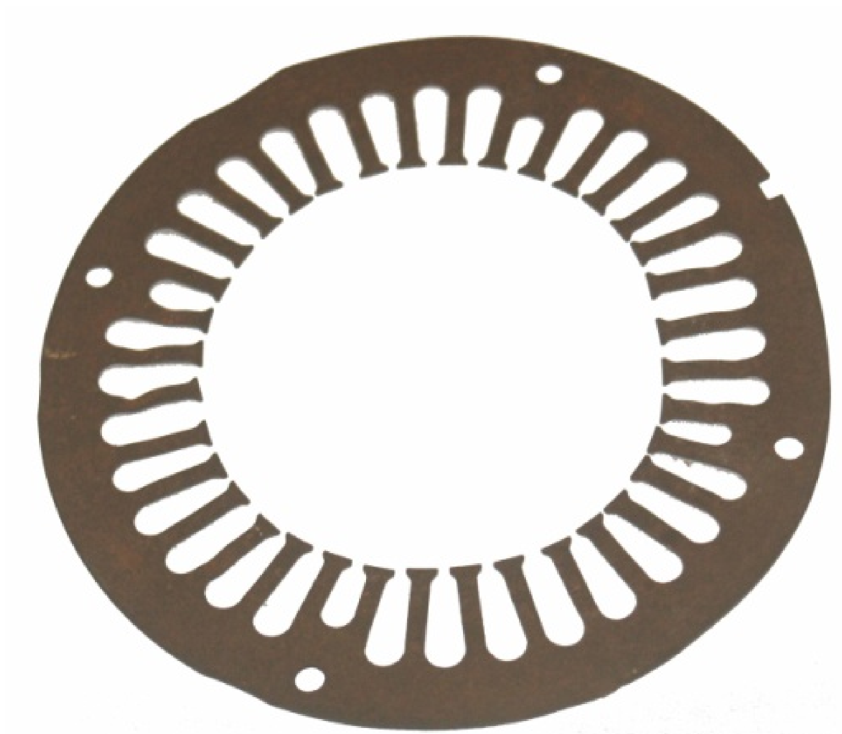
Constructional details of 3-phase induction motor

- A static part or stator that contains a three-phase winding
- A rotating part or rotor that will have conductors closed on themselves

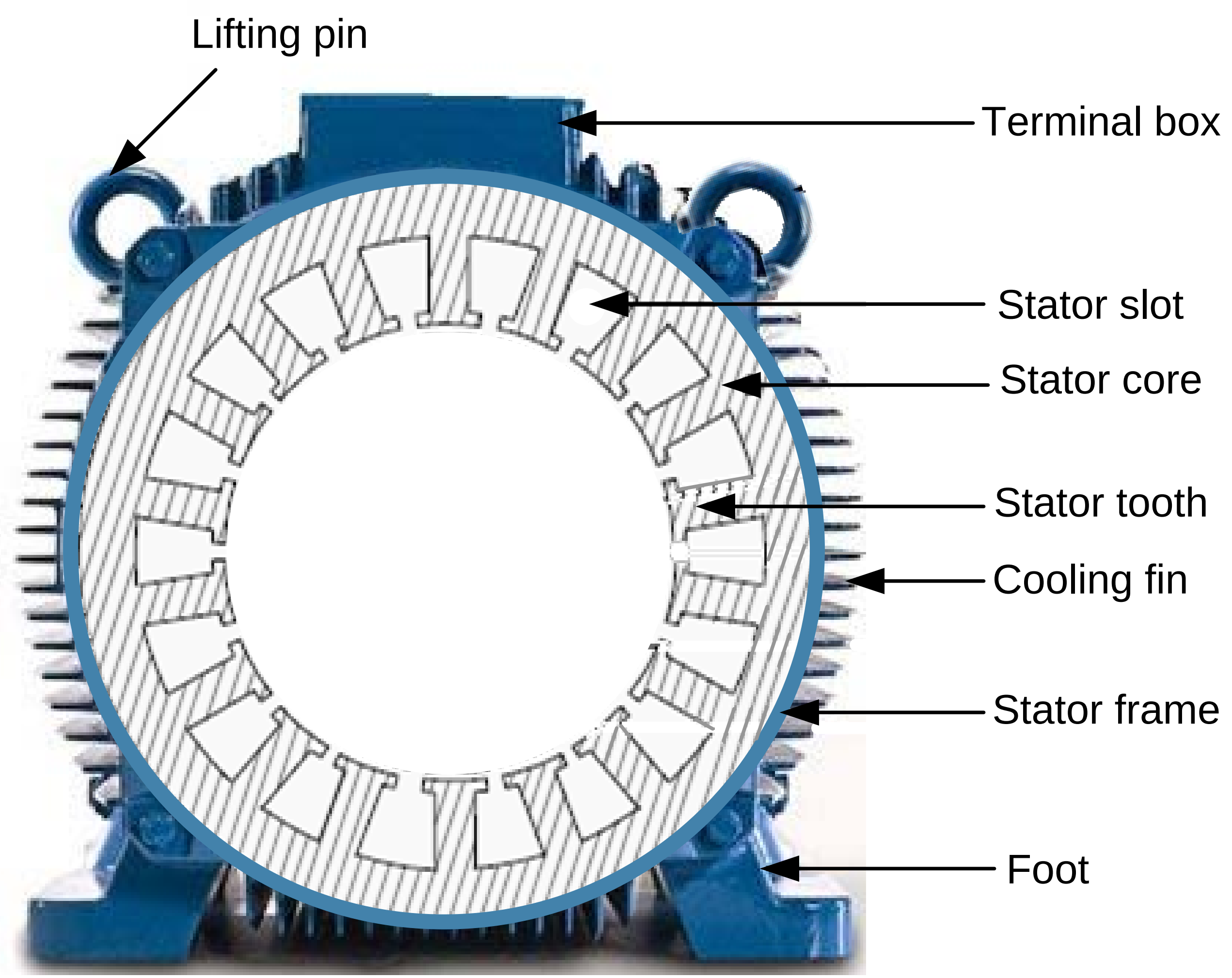


Stator

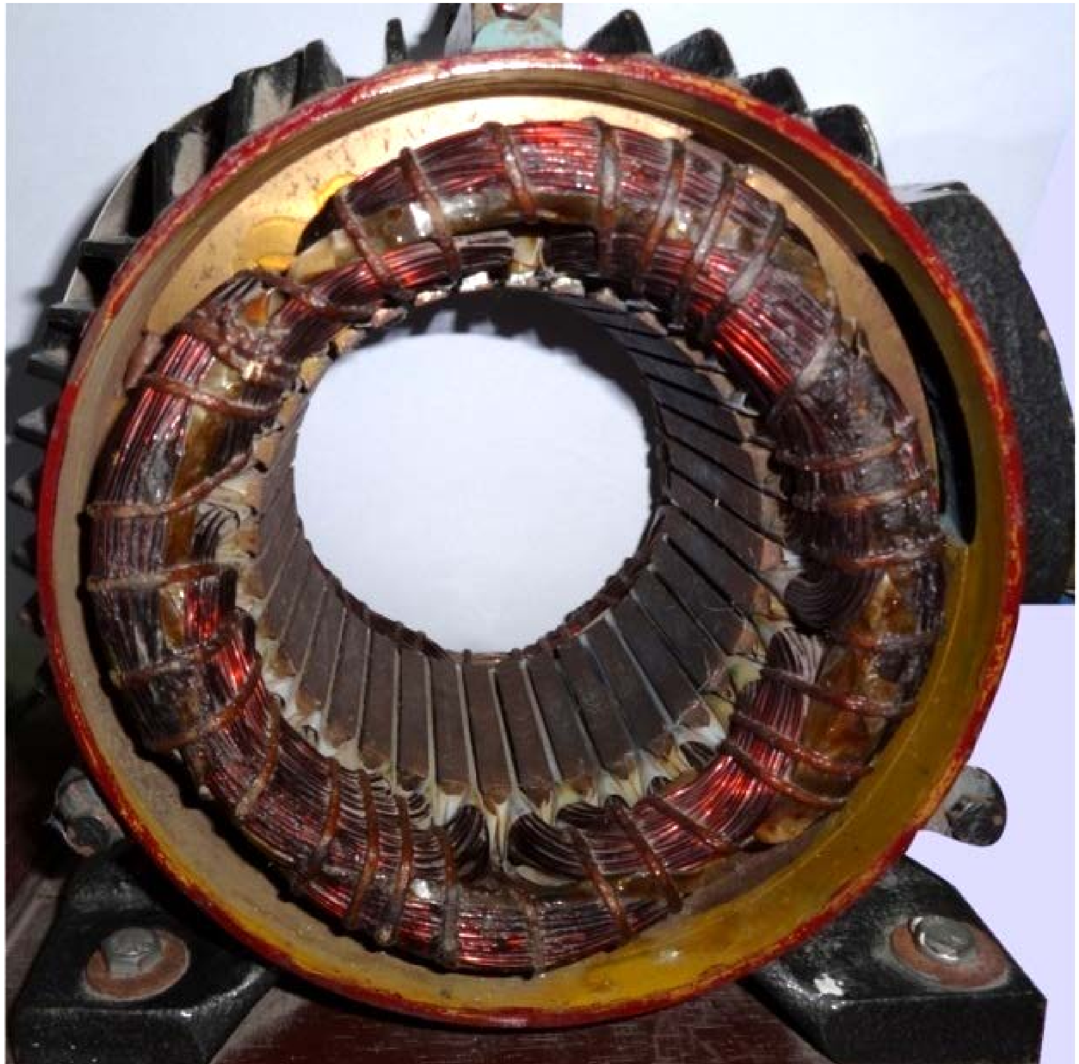
- Cast iron frame
- Cylindrical stator core
- Thin laminations (0.3 – 0.5 mm) of silicon steel
- Slots along inner periphery to put coils



Stator


Lifting pin
Terminal box
Stator slot
Stator core
Stator tooth
Cooling fin
Stator frame
Foot

Stator



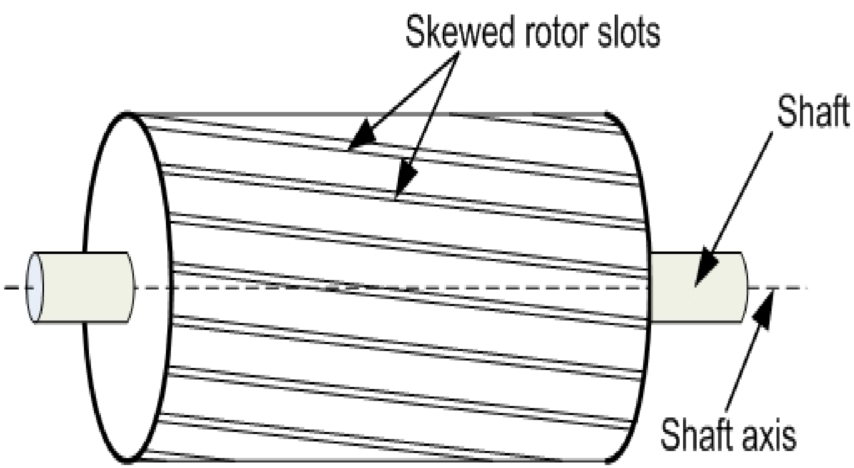
Rotor

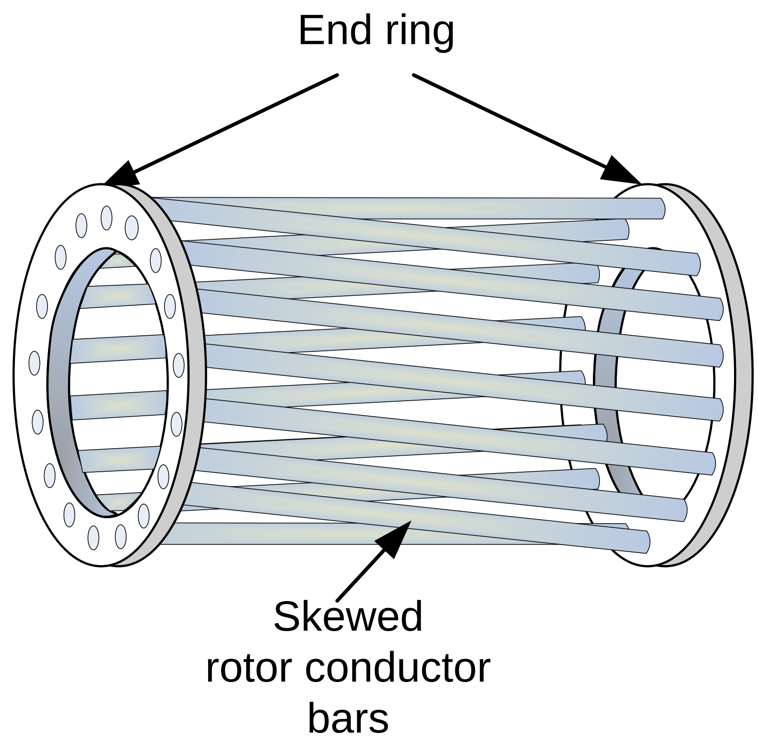
- **Squirrel cage type (SQIM) or cage type**
- **Slip ring type (SRIM) or wound rotor type**

- Rotor is of cylindrical shape
- Made of stacks of silicon-steel laminations
- Slots provided around its outer periphery for placing the rotor conductors

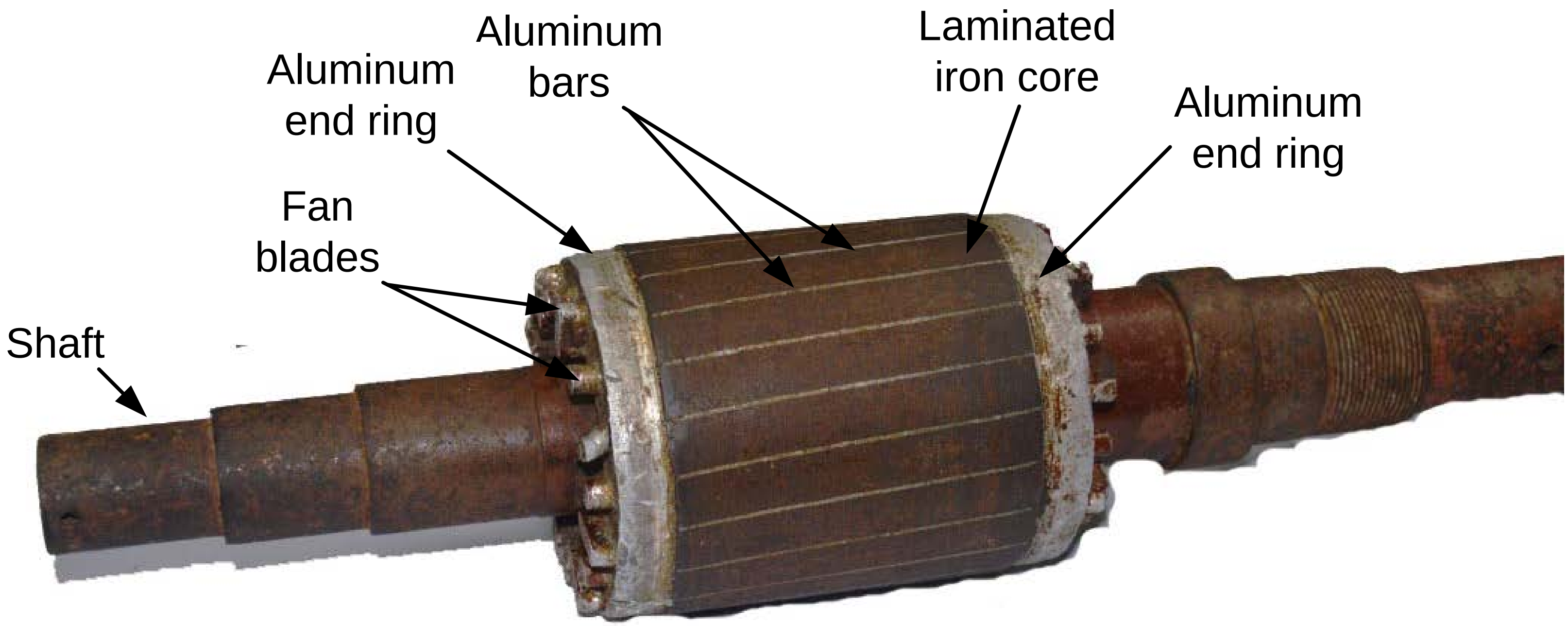
SQIM Rotor

- Iron cylindrical rotor with slots along their length around periphery
- Aluminum or copper rods (or bars)
- All these rotor bars or rods are shorted at two ends by circular end-rings



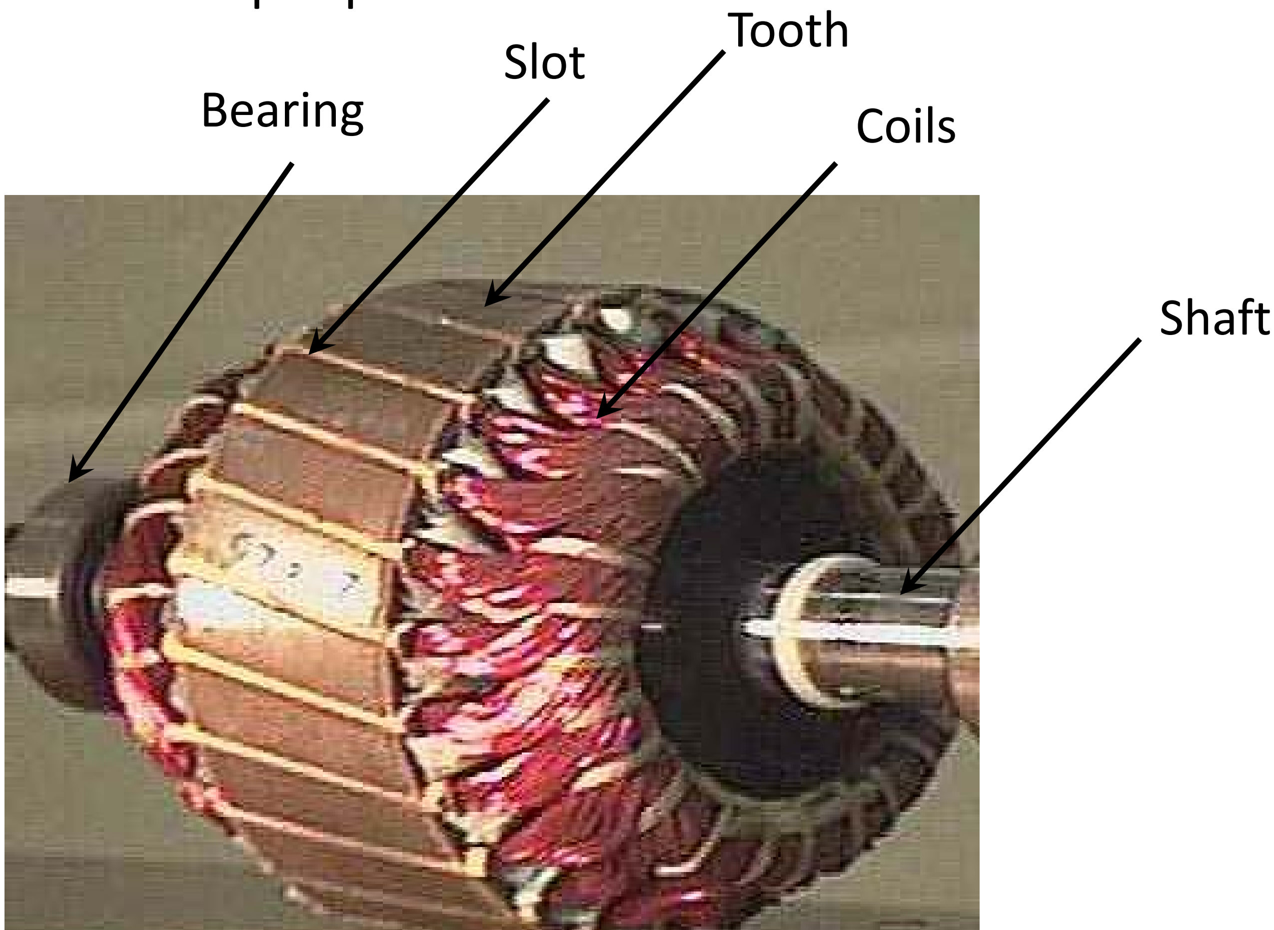


SQIM Rotor


Aluminum
bars
Laminated
iron core
Aluminum
end ring
Aluminum
end ring
Fan
blades
Shaft

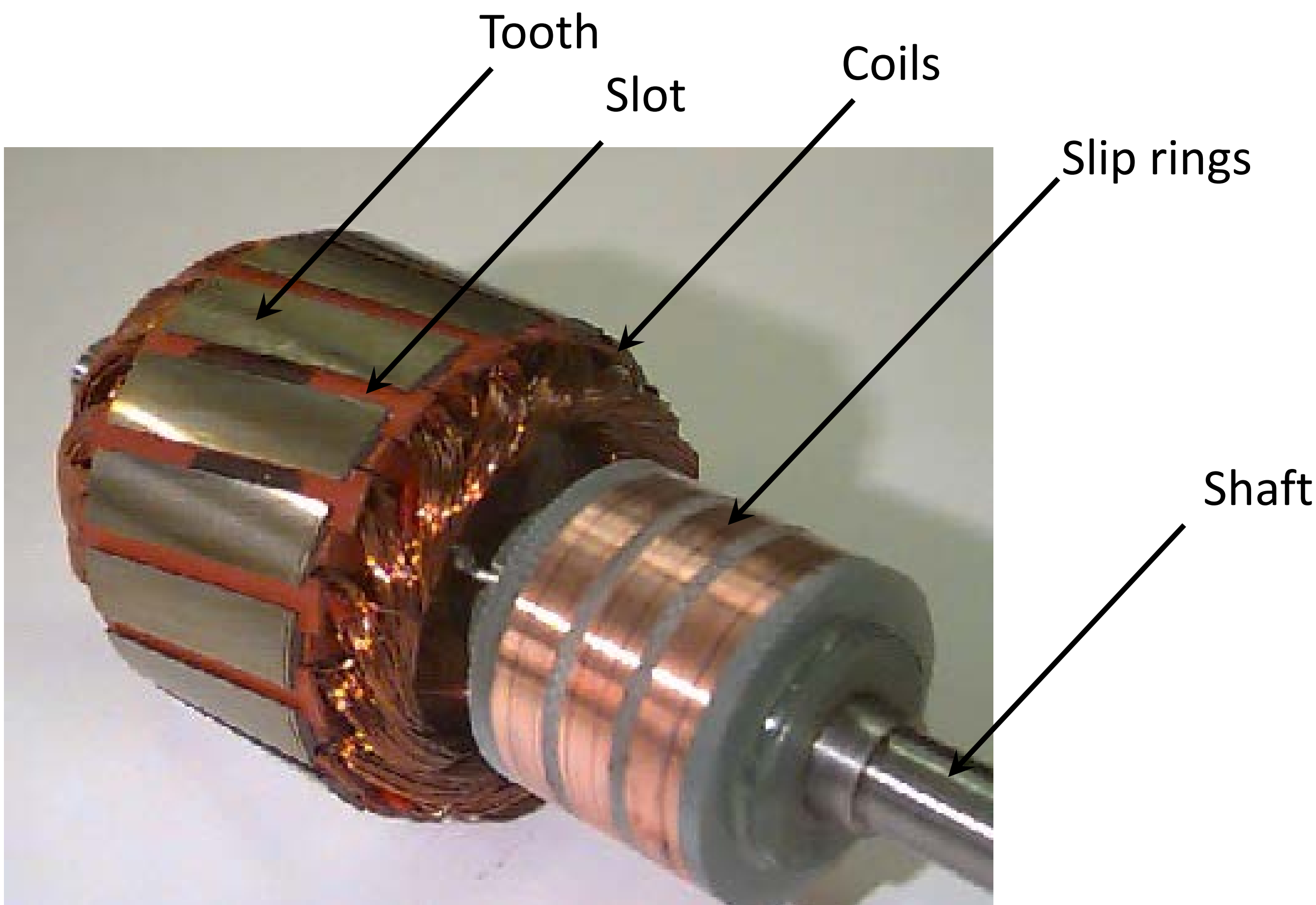
SRIM Rotor

- SRIMs use insulated copper coils as rotor winding.
- These coils are placed inside the open or semi-closed slots provided around the rotor peripheral surface.



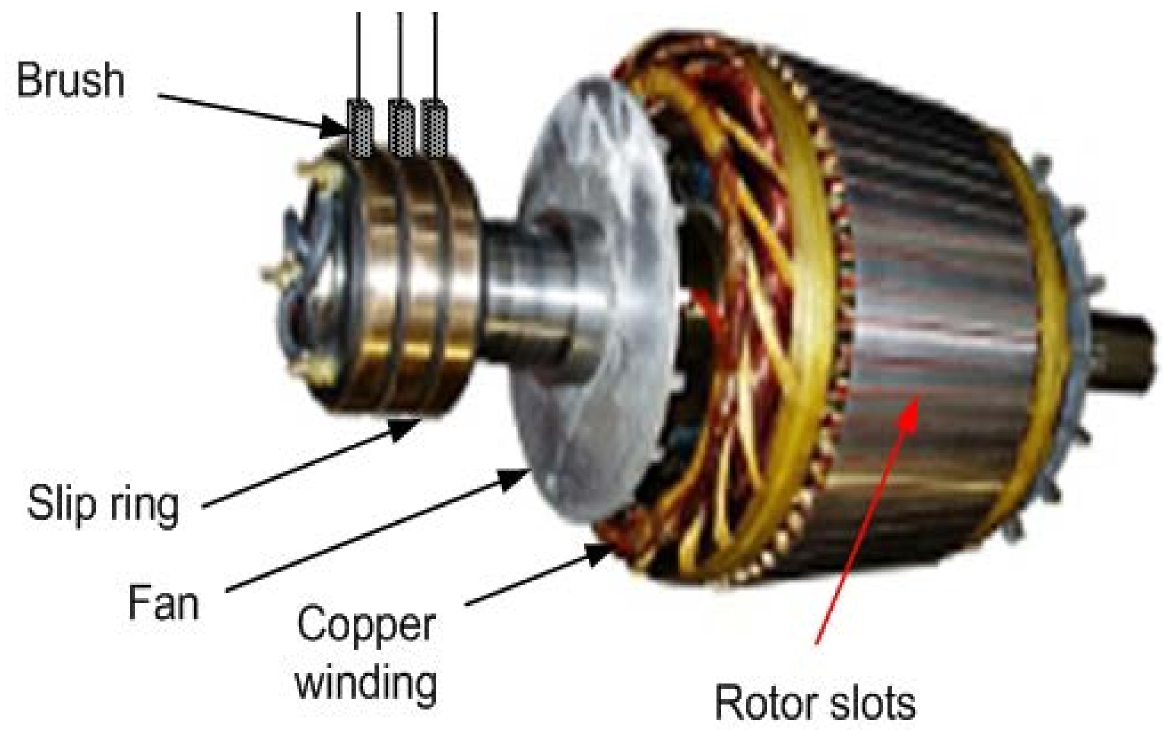
SRIM Rotor

- The three rotor winding phases are connected in star at one end.
- The other three free ends are connected to three brass slip rings mounted on the shaft.



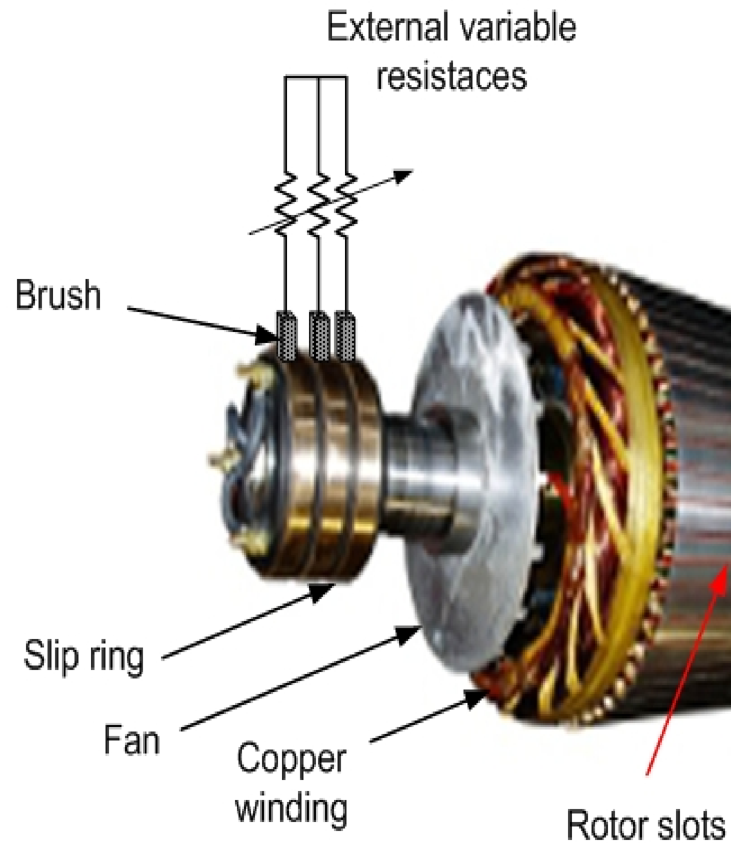
SRIM Rotor

- As the motor along with the winding rotates, the slip rings also rotate at the same speed as the shaft.
- Three graphite brushes fixed to the frame of the motor are pressed over the three slip rings by spring pressure.



SRIM Rotor

- The three brushes are further externally connected to a 3-phase star connected rheostat for the purpose of starting and speed control.
- At the time of starting, maximum resistance is inserted in the rotor circuit to avail maximum starting torque.
- These resistances are gradually cut out as the motor picks up speed.
- For normal running condition, the external resistances are completely cut off and the three slip rings are directly short circuited with each other.



Frequency of Rotor Induced EMF (or current)

Rotor induced EMF $E_2 = 4.44 f_r K w_r T_r \phi$

$$\boxed{f_r = s f_s}$$

- At standstill (starting), slip = $s = \dfrac{N_s - N_r}{N_s} = \dfrac{N_s - 0}{N_s} = \dfrac{N_s}{N_s} = 1$
- Thus, $f_r = f_s$ at standstill

- But when the rotor starts to rotate, s is lower than 1

- Thus, frequency of the rotor induced EMF at running condition is only a fraction of the rotor induced EMF frequency at standstill condition.

Find the frequency of rotor induced EMF of an induction motor that runs at 1440 rpm with 50 Hz supply at the stator.

To find out the rotor frequency, we need to know the slip, for which we need to know the synchronous speed N_S.

The motor runs at a steady speed of 1440 rpm.

Since the rotor speed is always lower than the synchronous speed, the nearest synchronous speed value just higher than the given rotor speed of 1440 rpm is N_S = 1500 rpm corresponding to 4 poles & 50 Hz.

Thus, slip $$s = \frac{(N_S - N_r)}{N_S} = \frac{1500 - 1440}{1500} = 0.04$$

$\therefore$ Frequency of rotor induced EMF $f_r = sf_s = 0.04 \times 50 = 2\ Hz$

A 3-phase 6 pole 50 Hz induction motor has a slip of 1 % at no load and 3 % at full load. Calculate i)Synchronous speed (ii) no load speed (iii) full load speed iv) frequency of rotor current at no-load (v) frequency rotor current at full load.

(i) Synchronous speed $N_S = \dfrac{120 f}{P} = \dfrac{120 \times 50}{6} = 1000\ rpm$

(ii) No load slip S_1 = 1%

$\therefore$ No-load speed $N_{r1} = (1-S_1)\ N_S = (1-\ 0.01) \times 1000 = 990$ rpm

(iii) Full-load slip S_2 = 3%

$\therefore$ Full-load speed $N_{r2} = (1-S_2)\ N_S = (1-\ 0.03) \times 1000 = 970$ rpm

(iv) Frequency of rotor current at no-load = $S_1 \times f_s = 0.01 \times 50 = 0.5$ Hz

(v) Frequency of rotor current at full-load = $S_2 \times f_s = 0.03 \times 50 = 1.5$ Hz

Speed Vs. Torque graph
of
3-phase Induction Motor

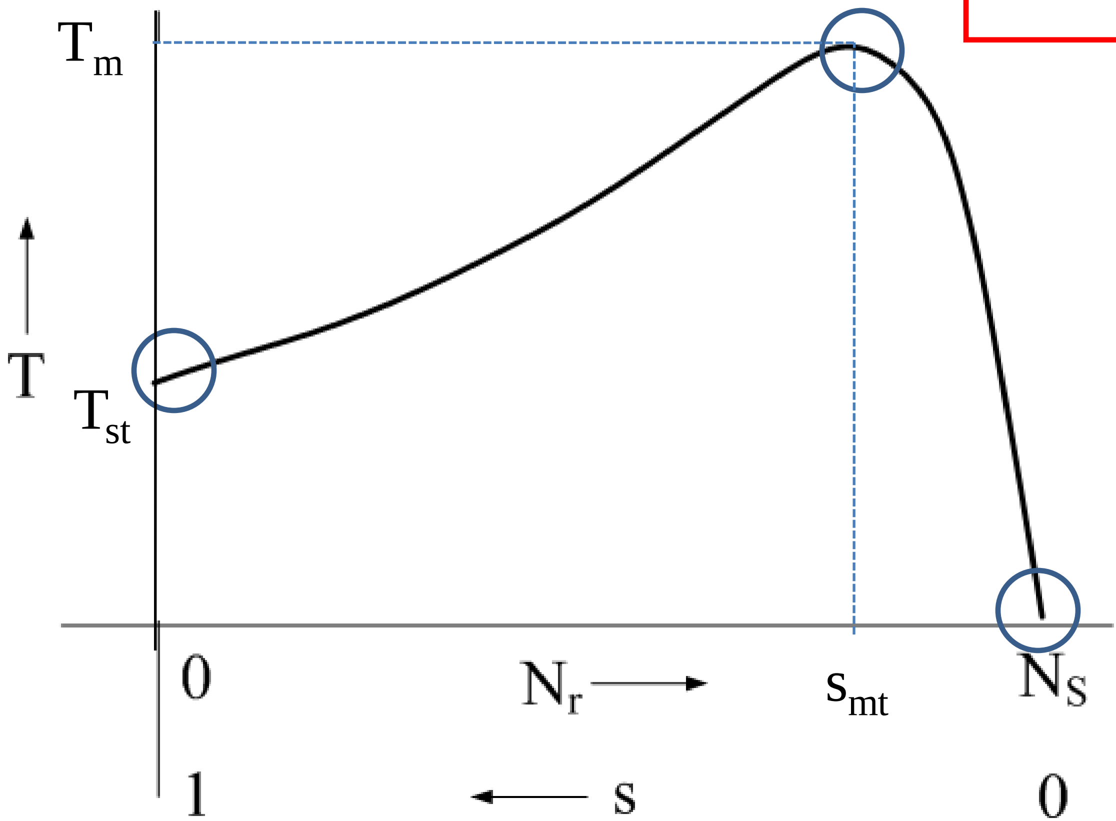
Torque vs. speed (or slip)

$$T = \frac{3}{\omega_S} \times \frac{V_1^{\,2}}{\left(r_1 + \frac{r_2'}{s}\right)^2 + \left(x_1 + x_2'\right)^2} \times \frac{r_2'}{s}$$

$$\omega_S = \frac{2\pi N_S}{60}$$

$$T_{st} = \frac{3}{\omega_s} \times \frac{V_1^{\,2} r_2'}{\left(r_1 + r_2'\right)^2 + \left(x_1 + x_2'\right)^2}$$

$$T_m = \frac{3V_1^{\,2}}{2\omega_s} \times \frac{1}{r_1 + \sqrt{r_1^{\,2} + \left(x_1 + x_2'\right)^2}}$$



T_{st} = Starting torque (torque at zero speed)

T_m = Maximum torque (peak torque) (breakdown torque) (pull-out torque)

S_{mt} = Slip for maximum torque

$$s_{mt} = \frac{r_2}{x_2}$$