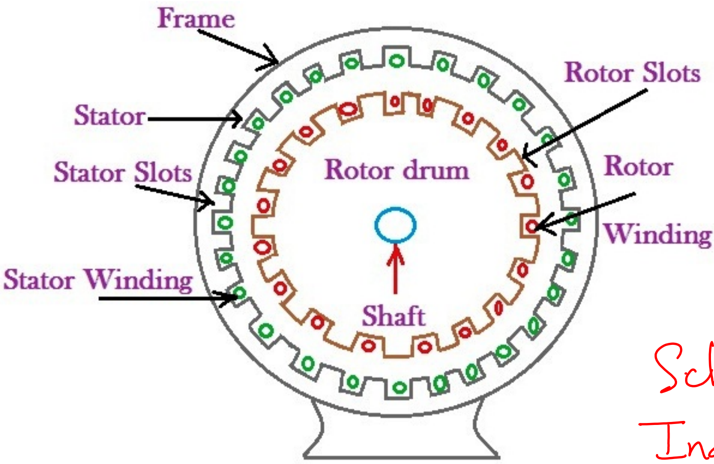
23.07.2021

Induction Motors
(Reference : Chapter 7)

- An ac machine without dc field current.
- There will be induced voltage in the rotor winding giving rise to rotor current & thereby rotor's magnetic field.
- Sometimes it also called a Rotating Transformer.
- Rarely used as a generator (though the machine remains the same physically), therefore, Induction Machine means induction motor.

Construction of Induction Motor :

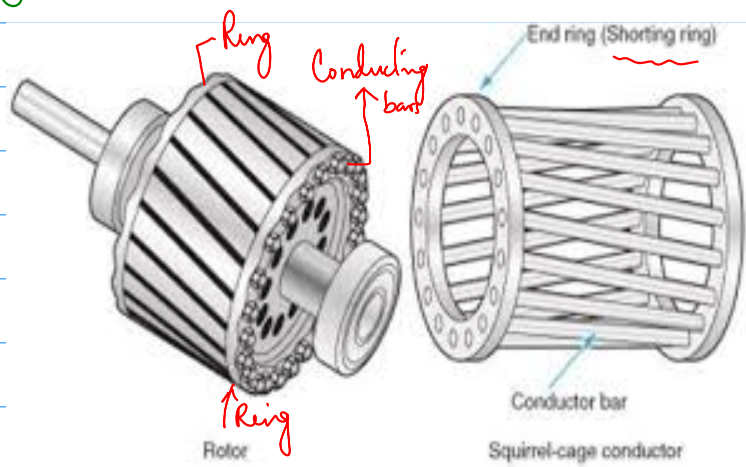
- Same physical stator as that of Sync. Machine (No change in the construction of stator winding)
- However, the rotor construction varies.

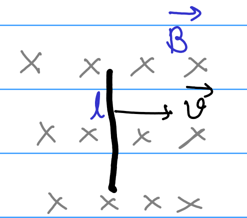


Schematic of the Induction Motor

Rotor Construction

1) Cage Rotor :



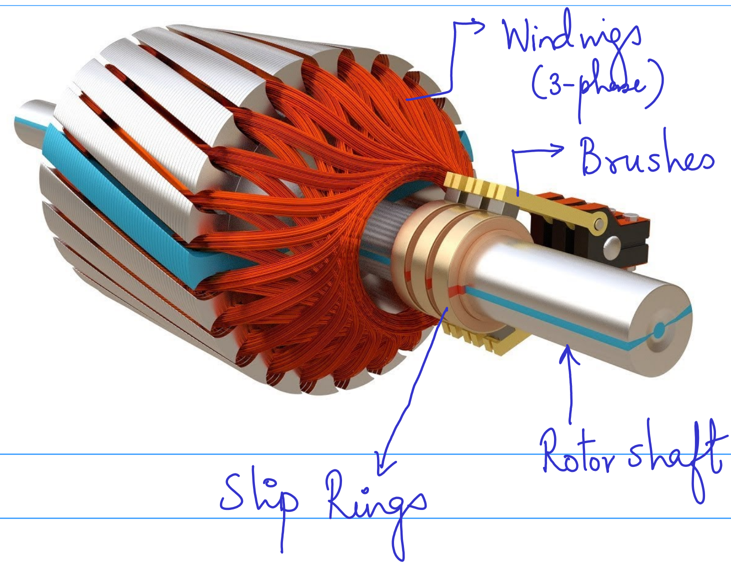


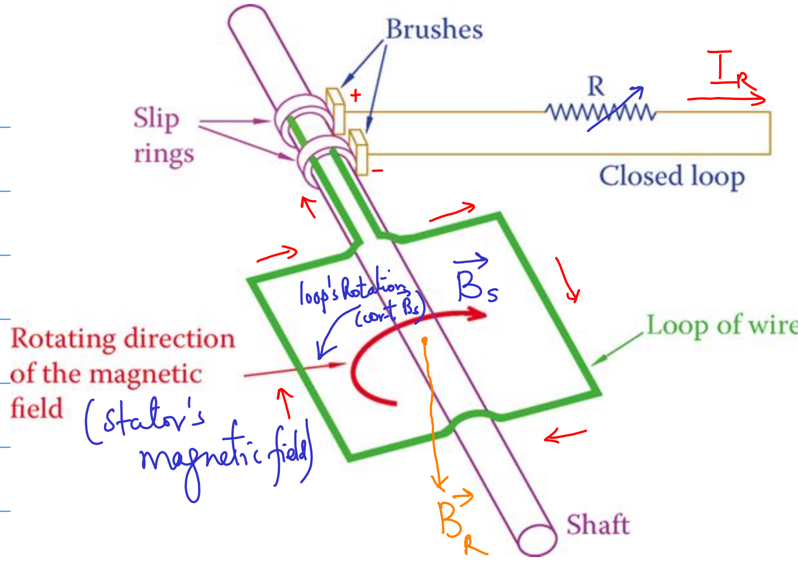
$$e_{ind} = (\vec{v} \times \vec{B}) \cdot \vec{l}$$

Series of conducting bars laid into the slots carved into the face of the rotor & electrically shorted at either end by SHORTING RINGS.

2) Wound Rotor :

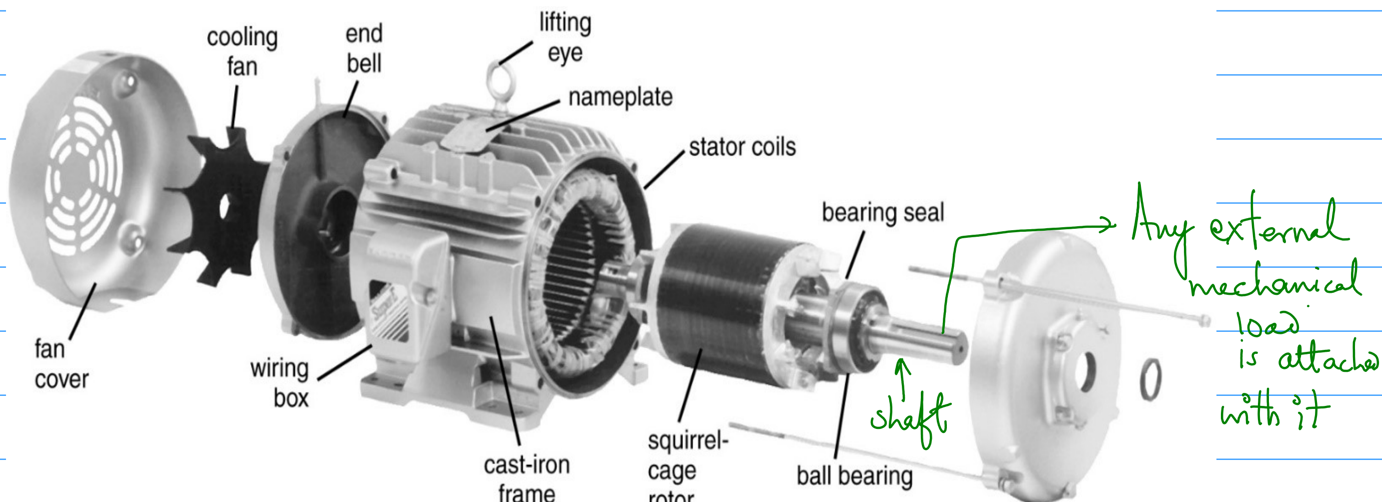
It has a set of 3-phase windings that are mirror images of the windings on the stator. (Usually they are Y-connected) & they are Tied to slip rings on the rotor shaft





Wound Rotor (Single loop)

- The wound rotor windings are SHORTED through the brushes riding on the slip rings.
- As compared to cage rotor, the wound rotors are :
  1) Costly
  2) Requires regular maintenance of brush-ring arrangement.
- The wound rotor is rarely used.



Development of torque in Induction Motors :

- Since stator is having 3-ϕ windings, it produces a rotating magnetic field $\vec{B}_s$

Mech. Speed of rotation of $\vec{B}_s$ (rpm) $n_{sync.} = \frac{120 f_e}{P}$; P = no. of poles in stator's winding

f_e = electrical freq. (in Hz)

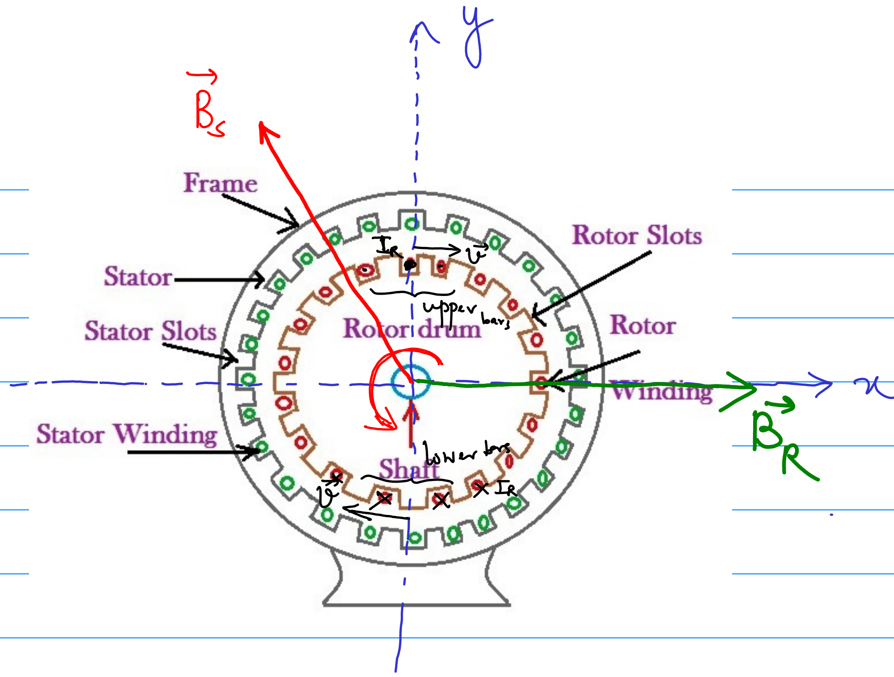
- This rotating magnetic field $\vec{B}_s$ passes over the rotors bars (in cage rotors) and it induces motional emf in the conducting bars.

$$e_{ind} = (\vec{v} \times \vec{B}_s) \cdot \vec{l}$$

where, $\vec{v}$ is relative velocity of the conducting bars w.r.t. the rotating $\vec{B}_s$.

- The relative $\vec{v}$ of the upper bars w.r.t $\vec{B}_s$ is to the rightward, hence, the direction of e_{ind} (or the current flow) is out the the page.

Whereas, in the lower bars it will be into the page



- Since the rotor assembly is inductive in nature, the induced rotor current 'I_R' lags behind the induced rotor voltages.

- This I_R will produce the magnetic field $\vec{B}_R$

- Therefore, there are two fields $\vec{B}_s$ & $\vec{B}_R$. They interact to produce Torque given as

$$\vec{\tau}_{ind} = k\left(\vec{B}_R \times \vec{B}_s\right)$$ in the counter-clockwise direction.

- In normal operation both the $\vec{B}_R$ & $\vec{B}_s$ rotates together at sync. speed n_{sync}. while the rotor itself turns at slightly slower speed.

26.07.2021

Induction Motors

Recap: Relative speed of Rotor w.r.t. rotating magnetic field produced by the stator.

- Since relative speed is so important, therefore, it is always logical to talk in terms of the relative speed.

- We know that the rotating magnetic field $\vec{B}_s$ is having sync. speed.

$$n_{sync} = \frac{120 f_e}{P}$$

- Let we have another speed n_m which is the mechanical speed of the shaft of the I.M.

- We define a relative speed called "SLIP SPEED" as,

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

n_{slip} = slip speed of the machine.

- We also define relative motion in terms of %

ie, 'SLIP'

$$\boxed{s = \left(\frac{n_{slip}}{n_{sync}} \cdot 100 \right) \%}$$

Alternatively,

$$S = \left(\frac{n_{sync} - n_m}{n_{sync}} \cdot 100 \right) \%$$

also,

$$s = \left(\frac{\omega_{sync} - \omega_m}{\omega_{sync}} \cdot 100 \right) \%$$

Remember : (i) When the rotor turns at sync. speed, ie, $n_m = n_{sync.}$; $s = 0$ (0%)

(ii) when the rotor is stationary ;
$n_m = 0$; $s = 1$ (100%)

(iii) when the rotor turns in between the two extremes

$$0 < n_m < n_{sync.} \quad ; \quad 0 < s < 1$$

If we know the value of slip for a given I.M., we can determine the speed of motor as

$$\boxed{\begin{aligned} n_m &= (1-s)\, n_{sync.} \\ \text{or,} \quad \omega_m &= (1-s)\, \omega_{sync.} \end{aligned}}$$

What will be the electrical frequency on the Rotor?

- Like transformer, the stator (primary) induces a voltage in the rotor (secondary), however, the the electrical frequency in the 'Rotor' is "NOT" necessarily the same as the stators.

ie, if we we feeding 50Hz freq. to the stator, then it is not necessarily the freq. of the rotor's voltage & current.

- Let consider the case where the rotor is Locked. ie,

$$n_m = 0 \quad ; \quad s = 1$$

$$f_r = f_e \qquad \left[f_e = \text{electrical freq. of the stator winding (say 50Hz)} \right]$$

- Let us consider the other extreme where

$$n_m = n_{sync.} \quad ; \quad s = 0$$

$$f_r = 0 \text{ Hz}$$

⇒ For any other speed in between, ie, $0 < n_m < n_{sync.}$ the rotor's electrical frequency $\propto$ to diff. of the n_{syn} & n_m

⇒ $\boxed{f_r = s f_e}$

$$f_r = s\, f_e$$

$$\boxed{f_r = \left(\frac{n_{sync} - n_m}{n_{sync}}\right) \cdot f_e}$$

We also know that $n_{sync} = \dfrac{120 f_e}{P}$

$$\boxed{f_r = (n_{sync} - n_m)\frac{P}{120}}$$

Solved Example :

Given : A 208-V, 10 hp, four-pole, 60 Hz, Y-connected induction motor has a full-load slip (s) of 5%.

(i) What is n_{sync} ?

$$n_{sync} = \frac{120 f_e}{P} = \frac{120 \times 60\,Hz}{4} = 1800 \text{ rpm}$$

$$\boxed{\begin{aligned} n_{sync} &= 1800 \text{ rpm} \\ n_m &= 1710 \text{ rpm} \end{aligned}}$$

(ii) What is n_m at rated Load ?

$$n_m = (1-s)\, n_{sync} = (1 - 0.05) \times 1800 \text{ rpm}$$
$$= 1710 \text{ rpm}$$

(iii) What is the rotor electrical frequency at rated load ?

$$f_r = s f_e = 0.05 \times 60\,Hz = 3\,Hz$$

(iv) What is the shaft torque at the rated load?

$$P_{Load} = \tau_{Load} \cdot \omega_m = P_{out}$$

$$\tau_{Load} = \frac{P_{out}}{\omega_m} = \frac{10hp\left(746W/hp\right)}{\left(1710\,rpm\right)\left(2\pi\,rad/r\right)\left(1min/60sec\right)}$$

$$\boxed{\tau_{Load} = 41.7\,N\cdot m}$$