Lecture-32

On

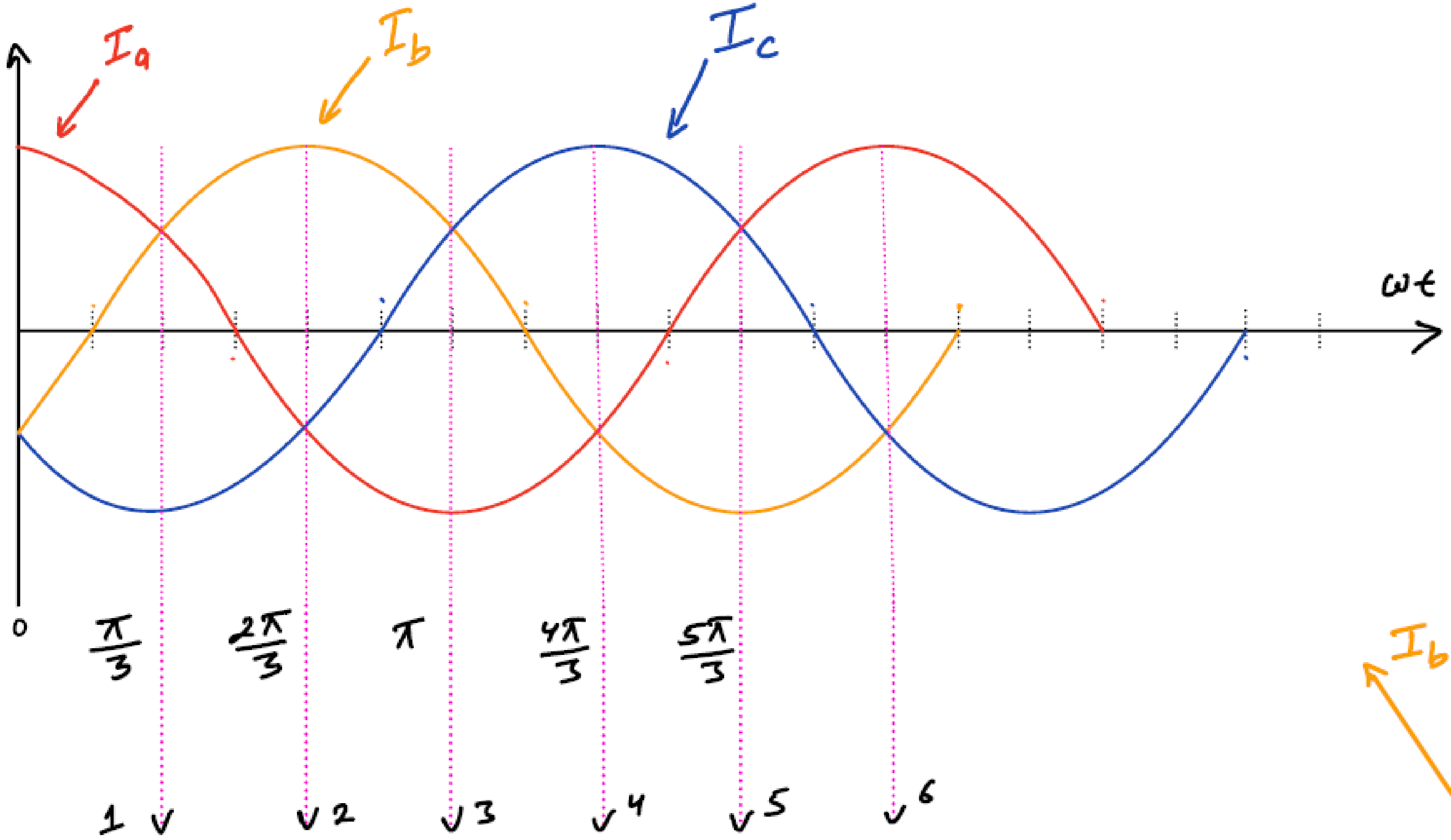
INTRODUCTION TO ELECTRICAL ENGINEERING (ESO203)

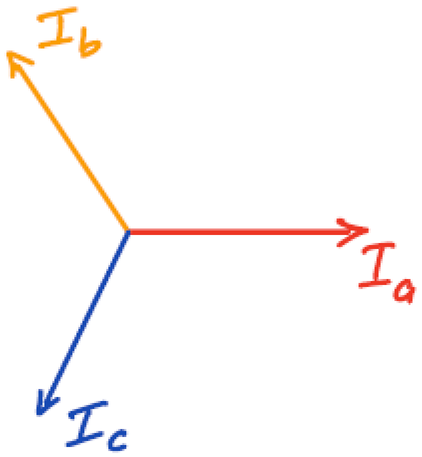
- Induction Machine.

Induction Motors

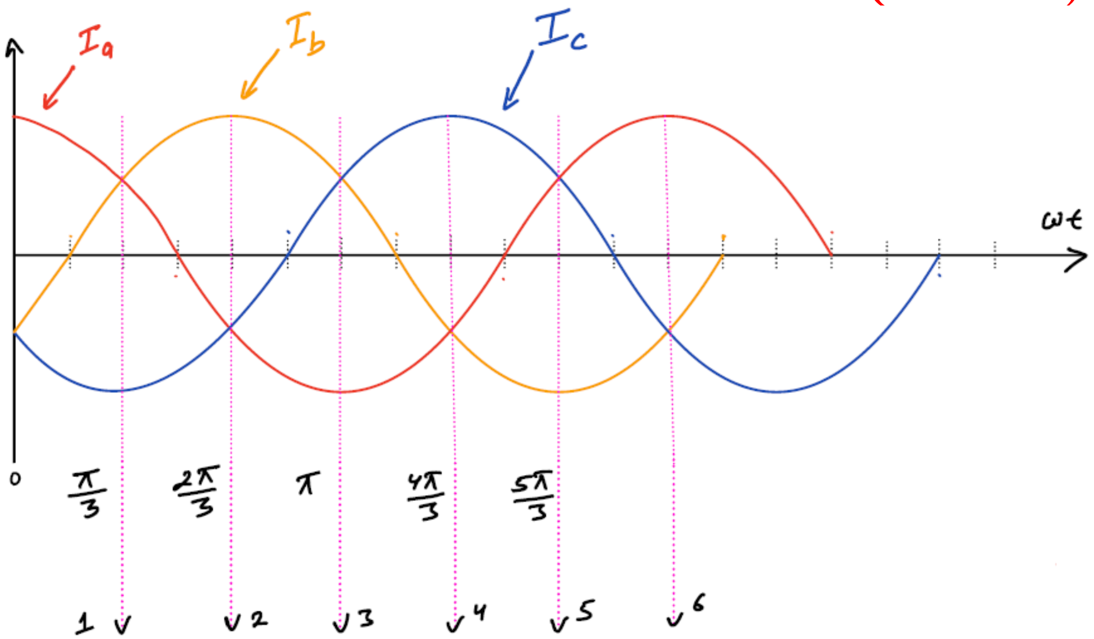
- In an induction motor, alternating current is supplied to the stator directly and to the rotor by induction or transformer action from the stator.
- The stator is similar to the synchronous machines, but the rotor is different.
- There is no DC field required to run the machine.
- Construction and use of induction machines are easier and more economic compared to DC and synchronous machines.
- Induction motors are the most widely used type of motor used in industries and home appliances.

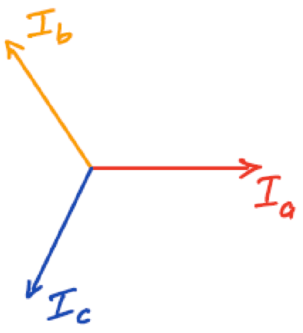
Induction Motors (cont…)





Induction Motors (cont…)





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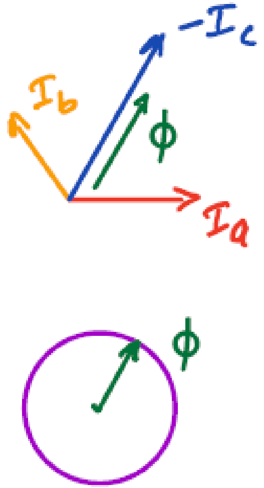

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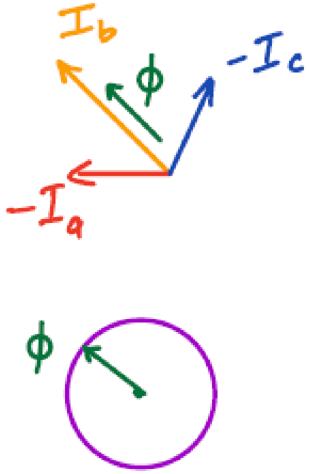

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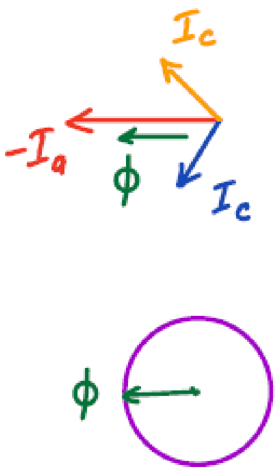

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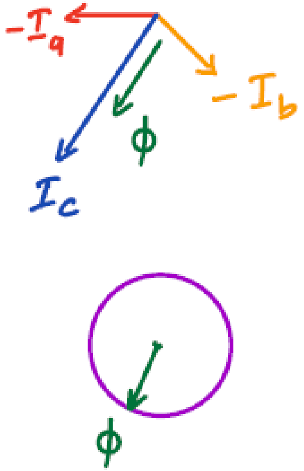
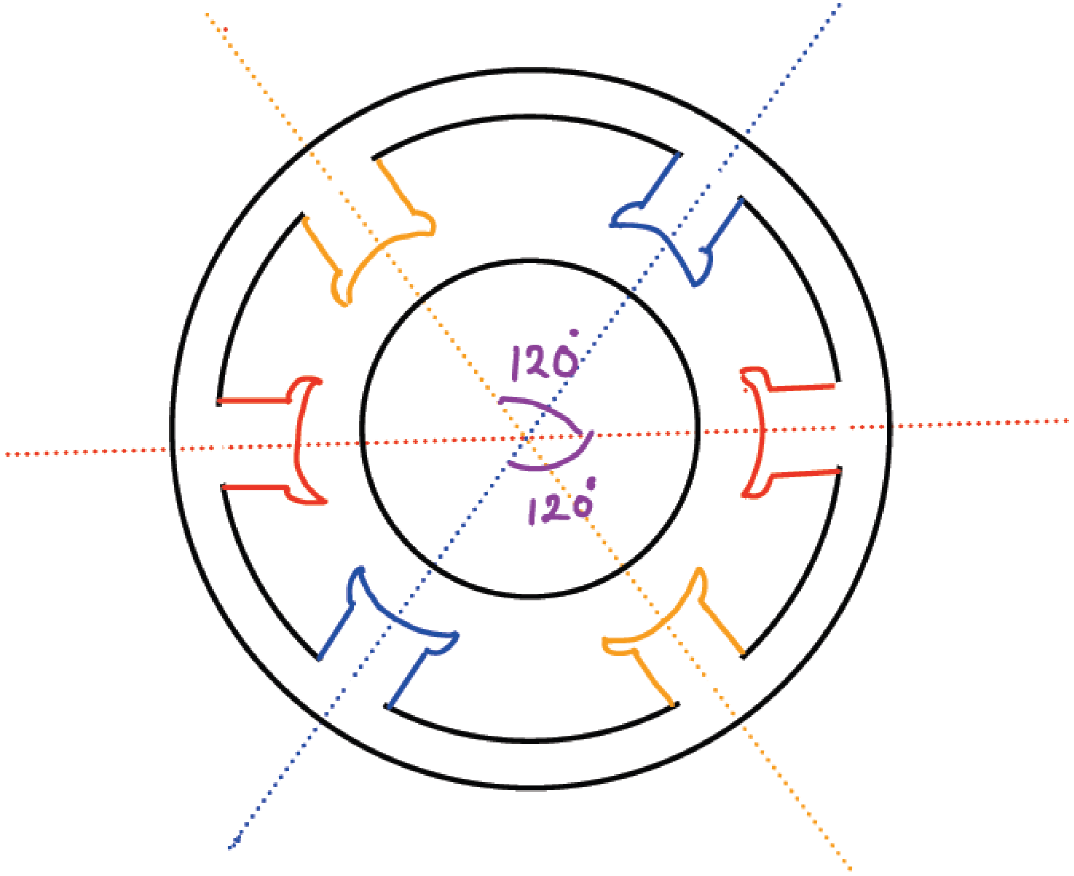
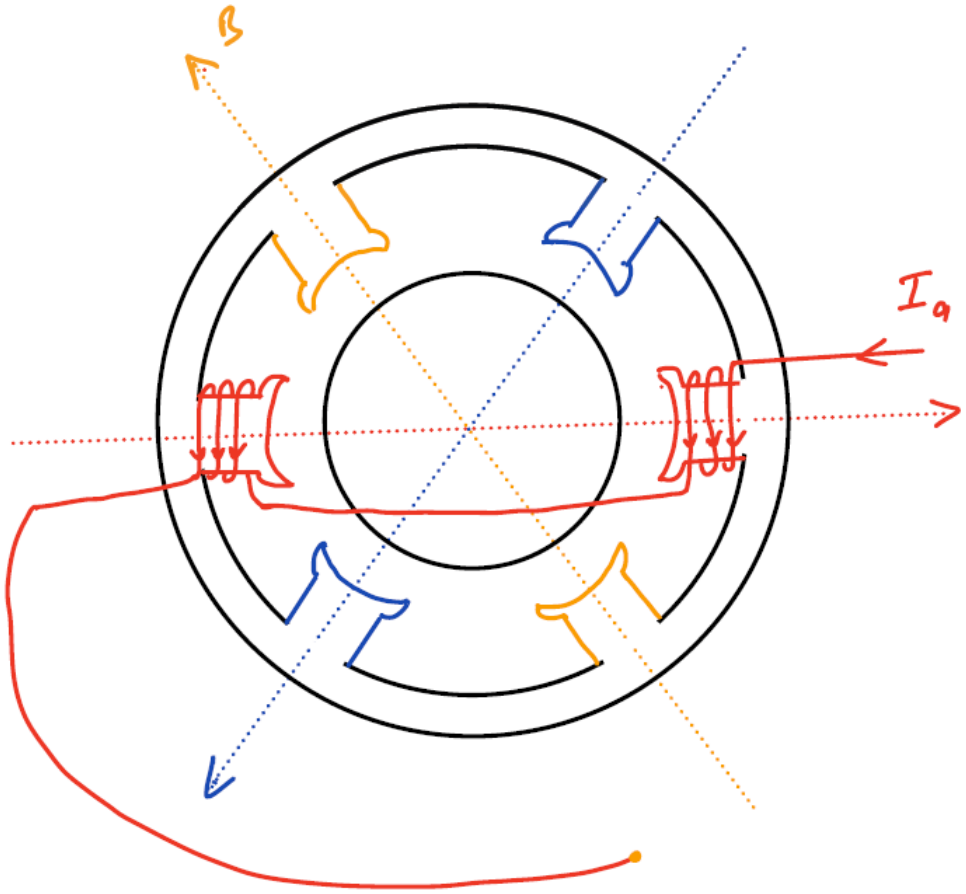
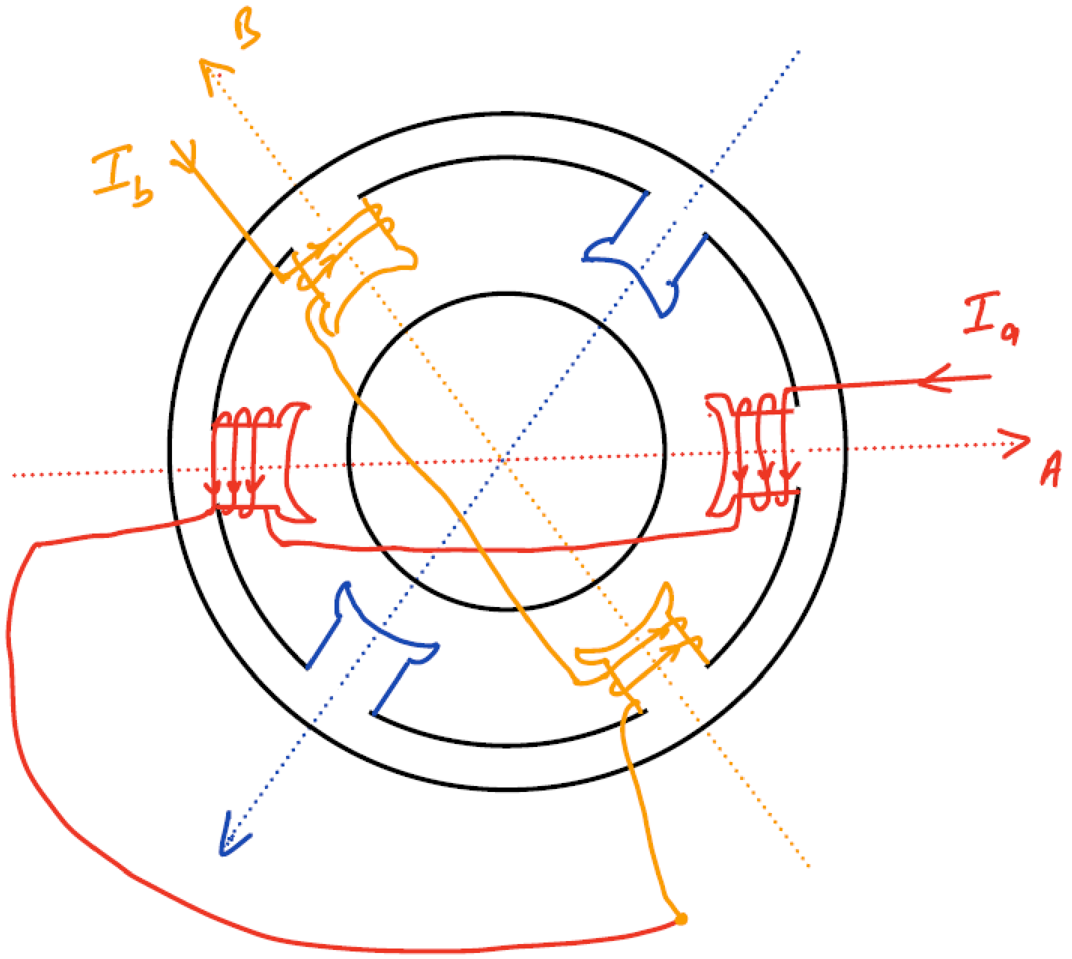


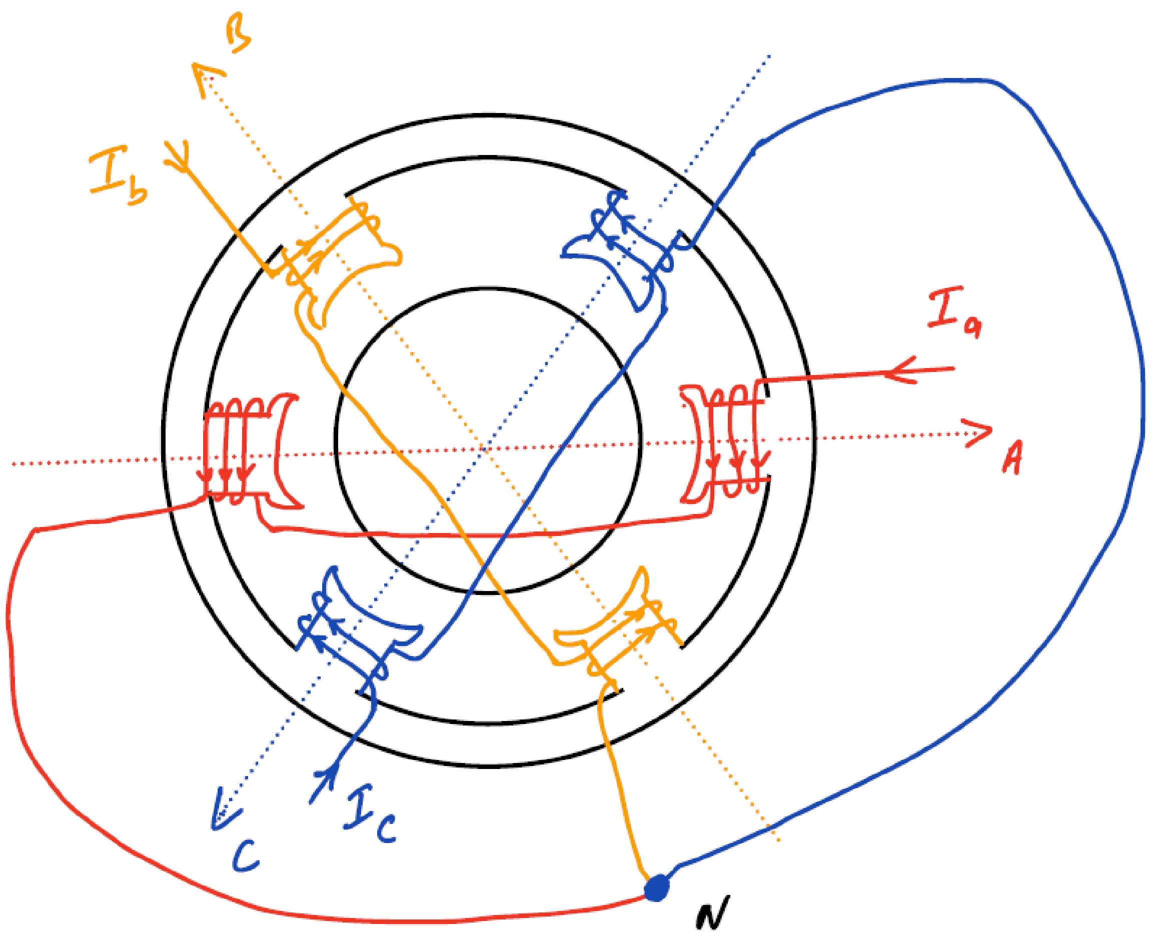
Induction Motors (cont…)



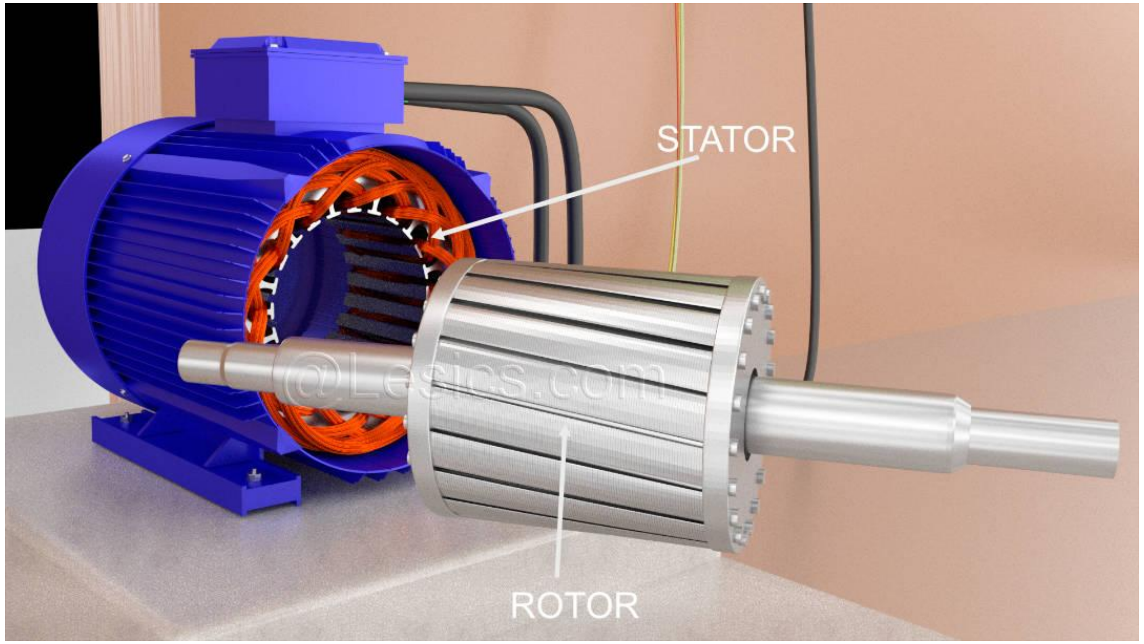


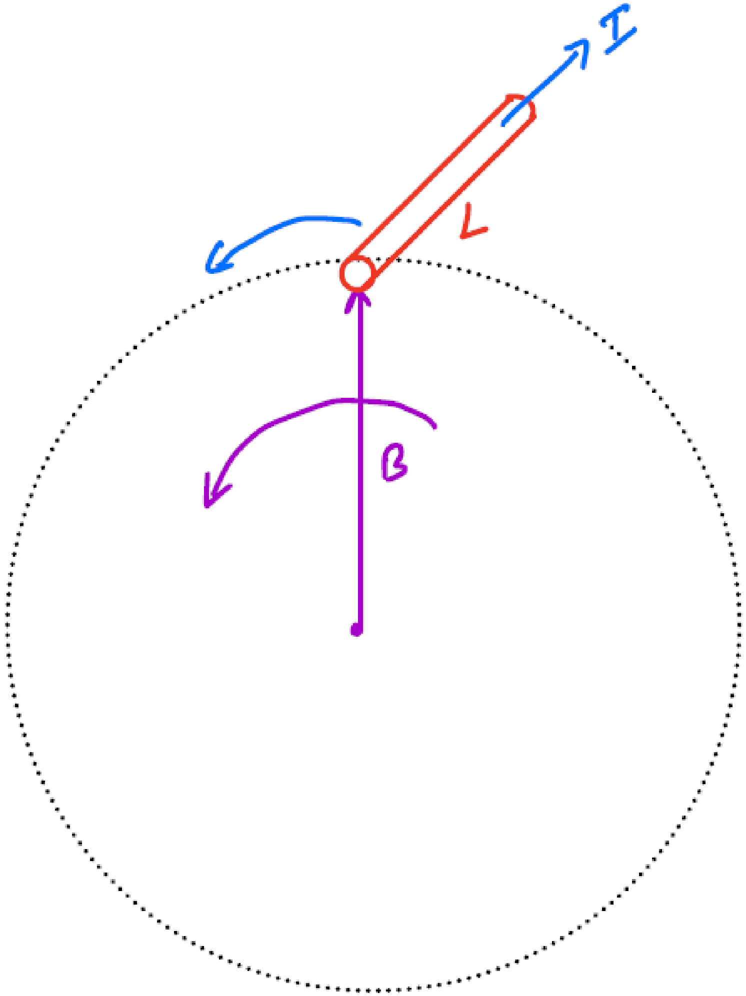
Induction Motors (cont…)





Induction Motors (cont…)





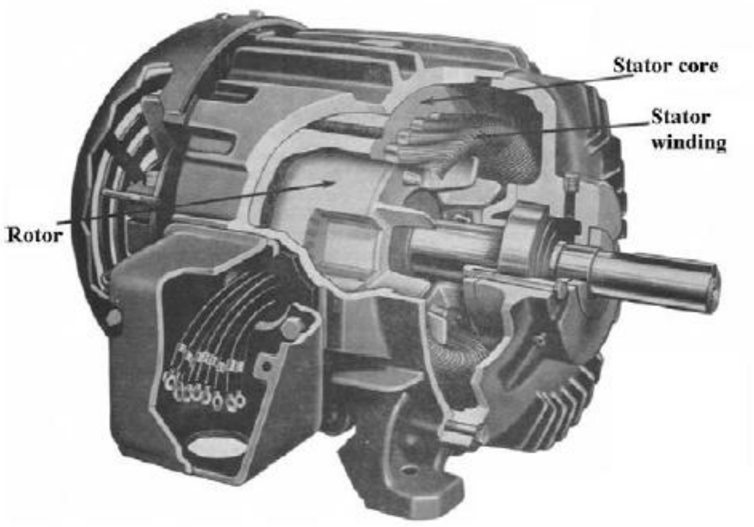
$F = BIL$

Induction Motors (Cont…)

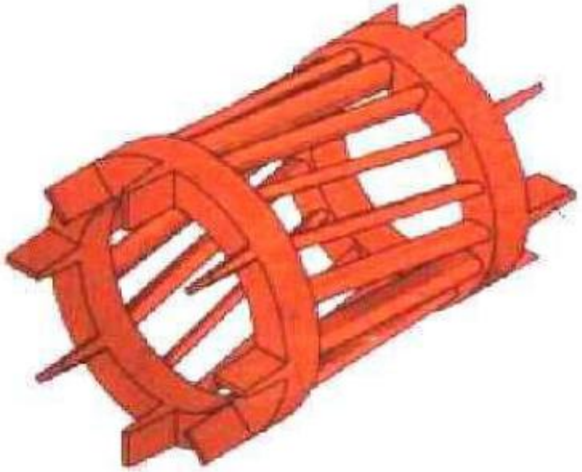
Induction Motor Construction:

- There are basically 2 types of rotor construction:
  - Squirrel Cage: No windings and no slip rings.
  - Wound rotor: It has 3 phase windings, usually Y-connected, and the winding ends are connected via slip rings.
- Wound rotor are known to be more expensive due to its maintenance cost to upkeep the slip rings, carbon brushes and also rotor windings.

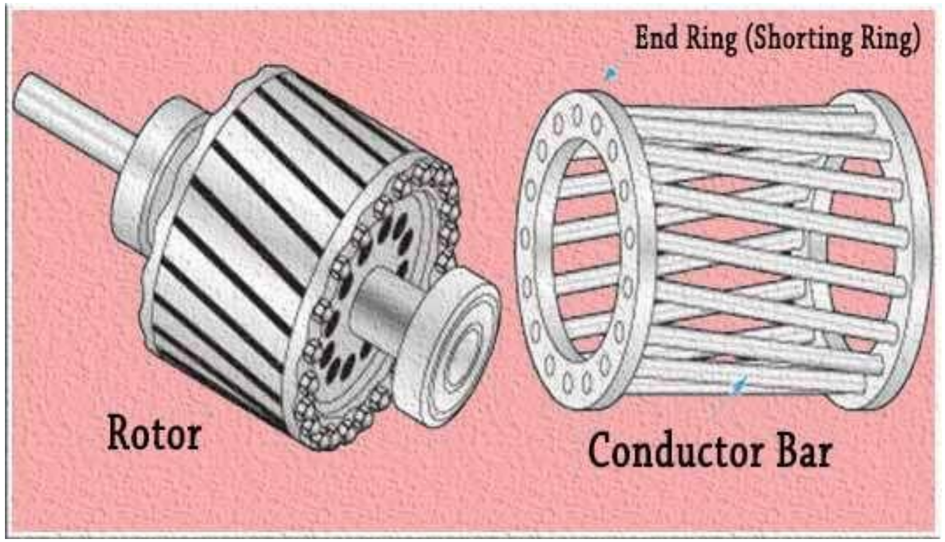
- Squirrel Cage Rotor:



Cutaway view of a 3-phase squirrel-cage induction motor

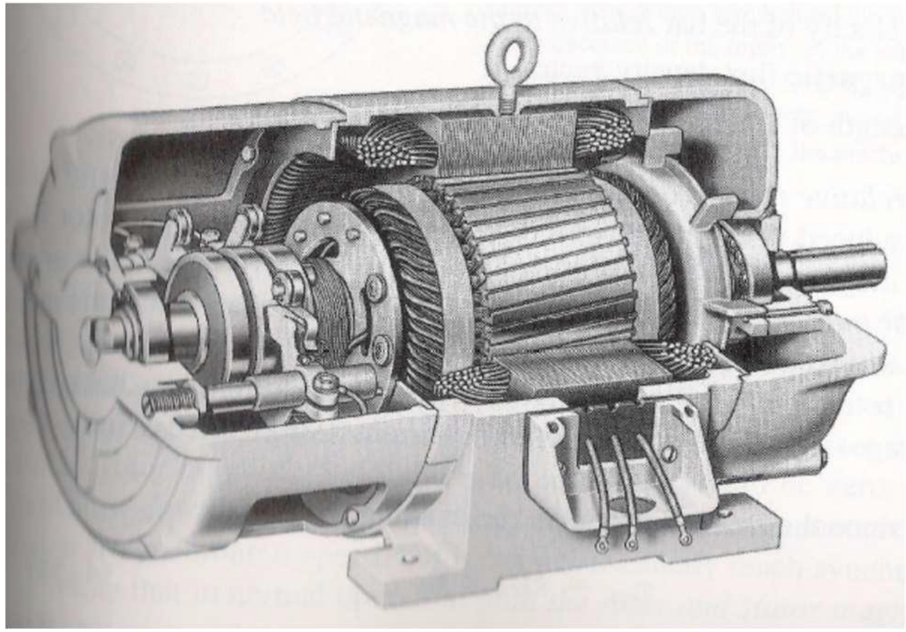


Cage made of conducting bars short-circuited at both ends



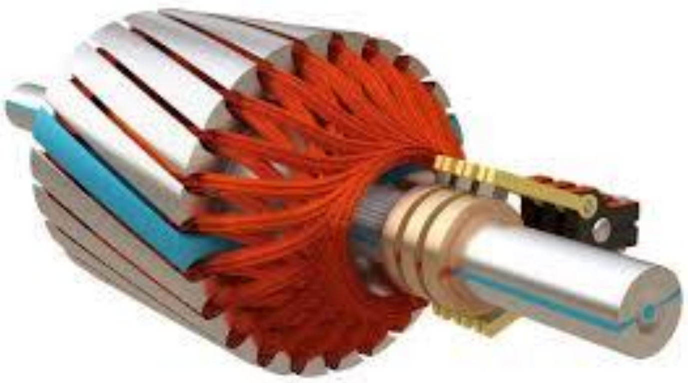
Induction Motors (Cont…)

❑ Wound Rotor:

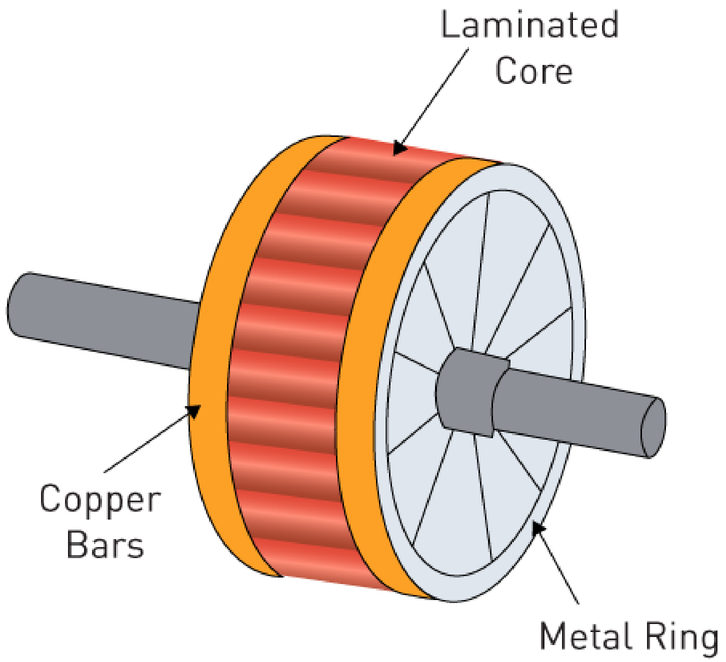


Cutaway view of a wound rotor induction motor.

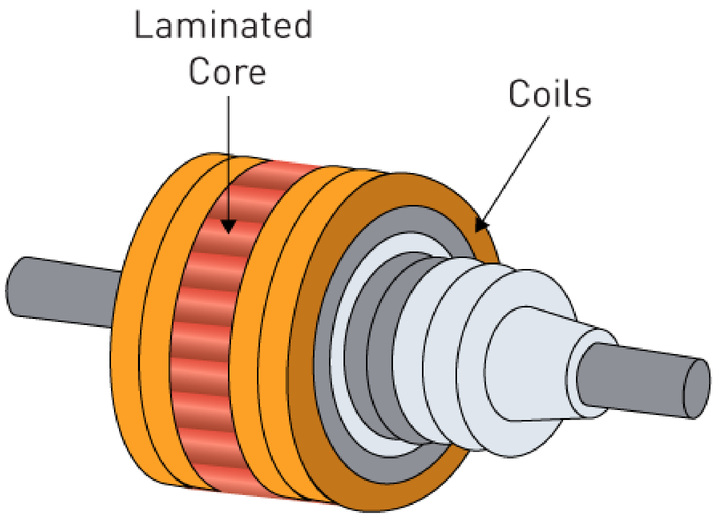
Wound rotor with slip-rings



Induction Motors (Cont…)



Squirrel Cage Rotor



Wound Rotor (Slip Ring)

❑ Basic Principle:

- When current flows in the stator, it will produce a magnetic field in stator such that $\boldsymbol{B}_S$ (stator magnetic field) will rotate at a speed:

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

Where f_e is the system frequency in hertz and P is the number of poles in the machine.

- This rotating magnetic field $\boldsymbol{B}_S$ passes over the rotor bars and induces a voltage in them. The voltage induced in the rotor is given by:

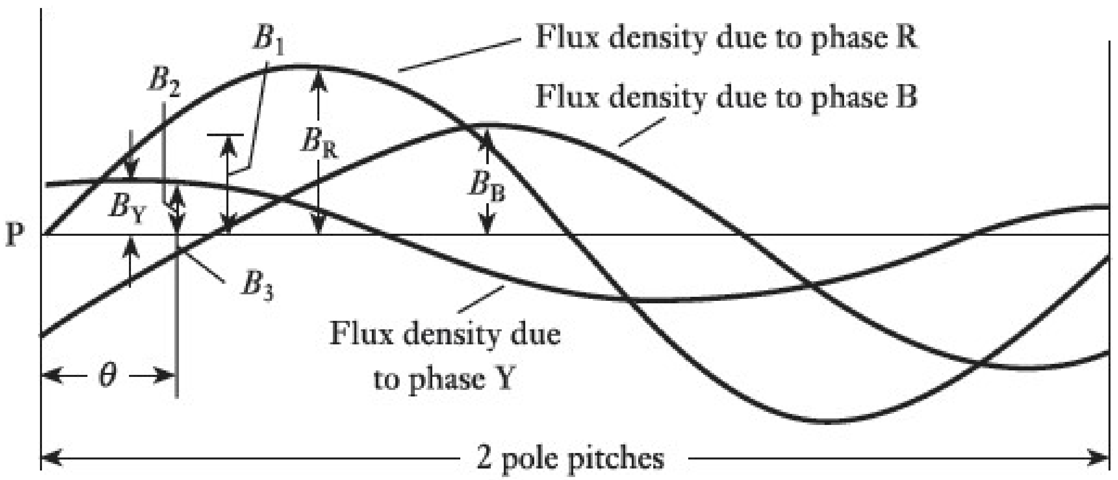
$$e_{ind} = (\boldsymbol{v} \times \boldsymbol{B})l$$

- Hence there will be rotor current flow which would be lagging due to the fact that the rotor has an inductive element. And this rotor current will produce a magnetic field at the rotor, $\boldsymbol{B}_R$. Hence the interaction between both magnetic field would give torque:

$$\boldsymbol{T}_{ind} = k\boldsymbol{B}_R \times \boldsymbol{B}_S$$

The torque induced would generate acceleration to the rotor, hence the rotor will spin.

Induction Motors (Cont…)



$$B_1 = B_R \sin\theta = B_m \sin\omega t \sin\theta$$

$$B_2 = B_m \sin\left(\omega t - \frac{2\pi}{3}\right)\sin\left(\theta - \frac{2\pi}{3}\right)$$

$$B_3 = B_m \sin\left(\omega t - \frac{4\pi}{3}\right)\sin\left(\theta - \frac{4\pi}{3}\right)$$

$$B_R = B_m \sin\omega t$$

$$B_Y = B_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$B_B = B_m \sin\left(\omega t - \frac{4\pi}{3}\right)$$

$$B_1 + B_2 + B_3$$

$$= B_m\left\{\sin\omega t \sin\theta + \sin\left(\omega t - \frac{2\pi}{3}\right)\sin\left(\theta - \frac{2\pi}{3}\right) + \sin\left(\omega t - \frac{4\pi}{3}\right)\sin\left(\theta - \frac{4\pi}{3}\right)\right\}$$

$$= 1.5B_m(\sin\omega t \sin\theta + \cos\omega t \cos\theta)$$

$$= 1.5B_m \cos(\omega t - \theta\ )$$

and is constant at $1.5B_m$ when $\theta = \omega t = 2\pi f t$

❑ Basic Principle:

- However, there is a finite upper limit to the motor's speed.

If the induction motor's rotor were turning at the synchronous speed → The rotor bars would be stationary relative to the magnetic field → No induced voltage → No rotor current → No rotor magnetic field → Induced Torque = 0 → Rotor will slow down due to friction

- Conclusion: An induction motor can thus speed up to near synchronous speed but it can never reach synchronous speed.

❑ Concept of Rotor Slip:

- The induced voltage at the rotor bar is dependent upon the relative speed between the stator magnetic field and the rotor. This speed is termed as slip speed:

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

where n_{slip} = slip speed of the machine

n_{sync} = speed of the magnetic field.

n_m = mechanical shaft speed of the motor.

- Slip is defined as, $s = \frac{n_{sync} - n_m}{n_{sync}} = \frac{\omega_{sync} - \omega_m}{\omega_{sync}}$

- The rotor speed (in r/min) and angular velocity can be therefore expressed as:

$$n_m = (1 - s)n_{sync} \quad or \quad \omega_m = (1 - s)\omega_{sync}$$

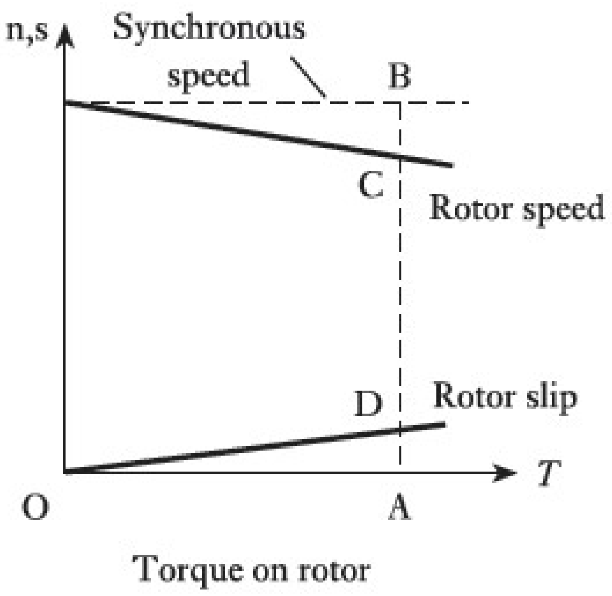
❑ Concept of Rotor Slip:

- The higher the speed of the rotor, the lower is the speed of the rotating field relative to the rotor winding and the smaller is the e.m.f. generated in the latter.
- Should the speed of the rotor attain the synchronous value, the rotor conductors would be stationary in relation to the rotating flux.
- There would therefore be no e.m.f. and no current in the rotor conductors and consequently, no torque on the rotor. Hence the latter could not continue rotating at synchronous speed. As the rotor speed falls more and more below the synchronous speed, the values of the rotor e.m.f. and current and therefore of the torque continue to increase until the latter is equal to that required by the rotor losses and by any load there may be on the motor.

❑ Concept of Rotor Slip:

- The speed of the rotor relative to that of the rotating flux is termed the Slip. For torques varying between zero and the full-load value, the slip is practically proportional to the torque.

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



❑ Electrical Frequency on the Rotor:

- An induction motor is similar to a rotating transformer where the primary is similar to the stator and the secondary would be a rotor. But unlike a transformer, the secondary frequency is not the same as in the primary.

- The electrical frequency f_r in the rotor can be defined as:

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

❑ Example:

A 208 V, 10hp, 4-pole, 60 Hz, Y-connected induction motor has a full-load slip of 5 percent.

(a) What is the synchronous speed of this motor?

(b) What is the rotor speed of this motor at the rated load?

(c) What is the rotor frequency of this motor at the rated load?

- **Solution:**

(a) Synchronous speed of the motor is:

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

(b) Rotor speed of the motor is given by:

$$n_m = (1 - s) n_{sync}$$

(c) Rotor frequency is given by:

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


THANKS
FOR YOUR
ATTENTION