Induction Machine

By: Er. Pranav Kumar

Salient features (Types of energy conversion)

→ In Induction motor :- Electrical energy to mechanical energy.
→ In Induction generator: Mechanical energy to electrical energy.

* Induction machine's have two modes:
  (i) Motoring mode :- $N < N_s$
  (ii) Generating mode :- $N > N_s$

* At $N = N_s$ Induction motor doesn't operate.
* Induction machine also called Asynchronous machine.
* In Induction machine the two windings are stator wdg & Rotor wdg.
* Induction machine is singly excited machine like Transformer.
* Both Induction machine and Transformer operate on same principle i.e mutual induction principle.
* Induction machine is a transformer with a rotating short circuit secondary.
* The phaser diagram and equivalent ckt of 3-ϕ induction motor are almost similar to those in transformer.
* In Induction motor, the magnetizing current is 30 to 50% of rated current.
* Induction machine is variable frequency machine (i.e slip frequency)
* This machine is electro-mechanical energy conversion machine
* In Induction machine magnetic circuit is discontinuous magnetic circuit or composite magnetic circuit. (Air gap is the magnetic path between stator & Rotor)
* Reluctance offered to the flux is high as compared with transformer due to air gap.

P.T.O

* Induction motor is just similar to D.C shunt motor and has DC shunt motor type characteristics (DC shunt motor is replaced by Induction motor)

* Speed control of Induction machine is very difficult

* Mech power output of I.M

$$P = \frac{2\pi NT}{60}$$

Note:- $P \propto N$

* Difference between Induction machine and Transformer.

Transformer	Induction Machine
(i) It is not energy conversion device	(i) It is a Energy conversion device (i-e electro mechanical energy conversion device
(ii) Primary and secondaries are always stationary.	(ii) Stator wdg is stationary but rotor winding is not stationary
(iii) Constant frequency device	(iii) Variable frequency device.
(iv) continious magnetic ckt	(iv) Discontinious magnetic ckt.
(v) It takes Less magnetizing current	(v) It takes more magnetizing current

* Difference b/w Synchronous generator and Induction generator.

(i) Rotor speed (N) is equal to synchronous speed (Ns)	(i) It can produce power only when $N > N_s$
(ii) Constant speed prime movers are required (eg: steam turbine, Hydel turbine and diesel engine.	(ii) Variable or fluctuating speed prime movers are required (eg: Wind turbine, Tidal turbine)
(iii) To regulate speed governer system will be used. power is generated at constant frequency f: 50Hz No need of power conversion	(iii) No governing system. Power is generated at different frequencies conversion is required to connect this supply to grid. AC → DC → AC.

* Production of rotating magnetic field by using 3-ϕ system.

→ To produce rotating magnetic field, there are two conditions to be satisfied in 3-ϕ system.

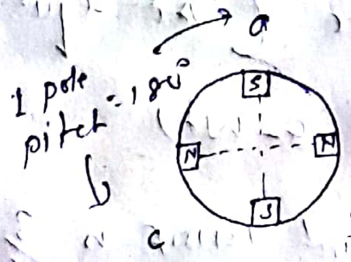
(1) The phase windings are displaced by 120° electrical w.r.t space θ (space angle.)

(11) Current allowed in the winding should be time displaced by 120° (electrical) w.r.t time angle ω.

* One pole-pitch = 180° electrical

$$\boxed{\theta_e = \frac{P}{2} \times \theta_m}$$

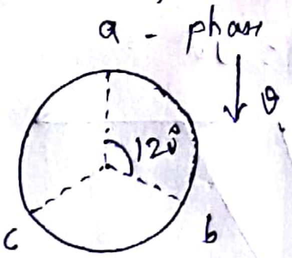
For example in 2-pole Machine



$\theta_e = \frac{2}{2}\theta_m$

$\Rightarrow \theta_e = \theta_m = 180°$ electrical

* Let each phase of 3-ϕ winding has 'N' turns and space angle θ.



Now

a-phase : $N_{ph}\cos\theta$

b-phase : $N_{ph}\cos(\theta-120°)$

c-phase : $N_{ph}\cos(\theta-240°)$

Similarly the current w.r.t time angle ω are.

$I_a = I_m\cos\omega t$

$I_b = I_m\cos(\omega t-120°)$

$I_c = I_m\cos(\omega t-240°)$

* The MMF produced in machine due to a-phase ~~F_a~~ is $F_a = N_{ph} \cos\theta \cdot I_m \cos\omega t$ ($\because$ MMF = NI)

$\therefore F_a = F_m \cos\theta \cdot \cos\omega t$ —(I) (let $N_{ph} I_m = F_m$)

Similarly $F_b = N_{ph} \cos(\theta - 120^\circ) \cdot I_m \cos(\omega t - 120^\circ)$

$\vec{F_b} = F_m \cos(\theta - 120^\circ) \cos(\omega t - 120^\circ)$ —(II)

$F_c = N_{ph} \cos(\theta - 240^\circ) \cos(\omega t - 240^\circ)$

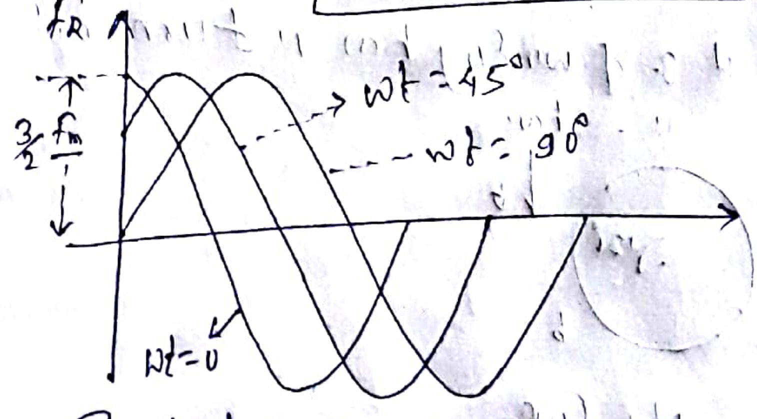
$F_c = F_m \cos(\theta - 240^\circ) \cos(\omega t - 240^\circ)$ —(III)

The resultant MMF produced in the machine is $F_r = F_a + F_b + F_c$ (Add equ^n (I), (II) & (III))

$F_r = \frac{3}{2} F_m \cos(\theta - \omega t)$

Amplitude of resultant MMF is $\frac{3}{2} F_m$

Where $\boxed{F_m = N_{ph} I_m}$



Resultant MMF waves

Resultant MMF $F_r = \frac{3}{2} F_m \cos(\theta - \omega t)$

At $\omega t = 0$ $F_r = \frac{3}{2} F_m \cos\theta$

At $\omega t = 45^\circ$ $F_r = \frac{3}{2} F_m \cos(\theta - 45^\circ)$

At $\omega t = 90^\circ$ $F_r = \frac{3}{2} F_m \cos(\theta - 90^\circ) = \frac{3}{2} F_m \sin\theta$

(Production of rotating magnetic field) By: Er. Pranav Kumar

* m- phase system.

m- phase wdg's are physically displaced by angle $\frac{2\pi}{m}$ rad electrical (i-e space angle θ)

m - phase currents must be time displaced by $\frac{2\pi}{m}$ rad electrical (i-e space angle ω)

$$\boxed{F_r = \frac{m}{2} F_m (\theta - \omega t)}$$ ***

Amplitude = $\frac{m}{2} F_m$ & F_r is function of $(\theta, \omega t)$

→ The speed of this mmf wave is synchronous speed

$$\boxed{N_s = \frac{120f}{P} \text{ r.p.m}}$$

* 2 - phase system:

2-phase windings are physically displaced by angle $\pi/2$ rad electrical (i-e space angle θ).

2 - phase currents must be time displaced by $\pi/2$ rad electrical (i-e space angle ω)

$$F_a = F_m \cos\theta \cos\omega t$$

$$F_b = F_m \cos(\theta - 90^\circ) \cos(\omega t - 90^\circ)$$

$$= F_m \sin\theta \sin\omega t.$$

$$F_R = F_a + F_b = F_m(\cos\theta \cdot \cos\omega t + \sin\theta \cdot \sin\omega t)$$

$$\boxed{F_R = F_m \cos(\theta - \omega t)}$$ *

Amplitude = F_m ; F_R is depends on $(\theta, \omega t)$

Resultant MMF wave depends on both θ and ωt. It means resultant MMF wave not only varies w.r.t time but also with space angle θ. So it is called traveling MMF wave or Rotating MMF wave.

* Speed of rotating resultant MMF wave is 'ω' electrical (rad/sec)

But ω_e (elec rad/sec) $= \frac{P}{2} \omega_m$ (mech rad/sec)

$$2\pi f = \frac{P}{2} \times \left(\frac{2\pi N}{60} \right)$$

$$\Rightarrow \boxed{N = \frac{120 f}{P} \text{ r.p.m}}$$

This speed is called synchronous speed. Therefore the speed of resultant MMF wave is synchronous speed and flux produced by this MMF wave is also in rotating nature with synchronous speed.

$$\text{Since } \boxed{\text{Flux} = \frac{\text{mmf}}{\text{Reluctance}}}$$

* Whenever 3ϕ windings are physically displaced by $2\pi/3$ radians electrical and being feed from $3-\phi$ currents, MMF wave also time displaced by $2\pi/3$ radians electrical then the resultant MMF wave due to $3-\phi$ has a constant amplitude of $\frac{3}{2} F_m$ and is rotates at synchronous speed in air gap.
* The flux wave due to this MMF wave is also rotating at same synchronous speed in air gap which is called as rotating magnetic field. (RMF).
* Direction of rotation of magnetic field can be changed by changing the phase sequence.

* The speed of MMF wave is synchronous speed

$$\boxed{N_s = \frac{120f}{P} \quad r.p.m}$$

* Induction machines are generally called as poly phase Induction machines, since they can be design for any no. of phases (3ϕ, 5ϕ, 7ϕ ......) for producing rotating magnetic field.

* But available supply is three phase only, $3-\phi$ Induction machines are more popular.

By: Er. Pradan Kumar

* Construction details of Induction machine:

ⓐ Stator ⓑ Rotor.

(a) Stator :-

(1) Shape is hollow cylindrical (for rotating magnetic field)

(2) Magnetic Yoke is made with cast iron.

(3) Stator core is made up of silicon steel.
(to reduce hysteresis Loss)

(4) Stator core is Laminated core (to reduce eddy current loss)

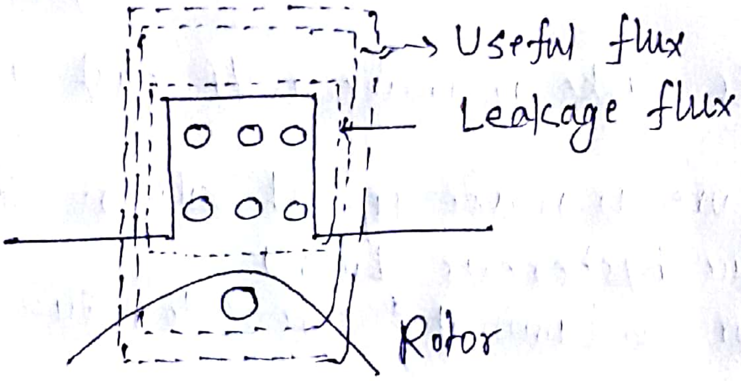
☞ In DC machine poles are projected inside and are visible. So, it is called Hetropolar construction.

☞ In Induction machine poles are distributed over entire surface of stator core and are not visible.
This construction is Homopolar construction machine.

Types of slots:

(1) Open type slots.
(2) Semi open type
(3) Completely closed type.

(1) Open type slot:-



Advantages :-

(i) Windings can be placed into the slots very easily. The winding which is formed before placed into the slots is called former winding

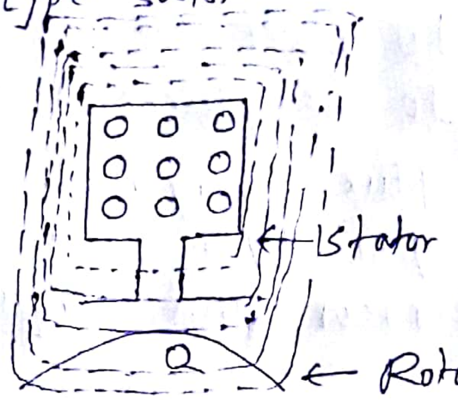
(ii) Leakage reactance is less in open type slots. Therefore more amount of power will be transferred from stator to rotor and torque production is high.

Disadvantages :

(i) The average air-gap length between stator and rotor is high. Therefore machine draws more exciting current.

(ii) Air gap length is irregular, then non uniform flux distribution. Therefore harmonics are high and operation of motor is vibrating and noisy.

② Semi open type slots:-



Advantages :-

(i) The airerage air gap length between stator and rotor is Less, therefore machine draws Less exciting current.

(ii) Flux distribution is uniform and then harmonics are Less.

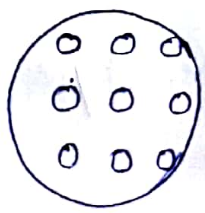
(iii) The operation of motor is smooth.

Disadvantages:-

(i) Inserting winding into the slots is difficult.

(ii) More Leakage flux, reactance of Leakage flux is high. Therefore Less amount of power will be transferred from stator to rotor and torque production is Less.

(3) Closed type slots:-



Advantages

(i) The average air gap length between stator and rotor is very Less, therefore machine draws very Less exciting current.

(ii) Flux distribution is uniform, harmonics are almost abesent.

(iii) The operation of motor is very smooth.

Disadvantages

(i) Very difficult to place winding in slots. Turn by turn winding has to be placed in winding.

(ii) The Leakage flux is very high as comapre to ~~semiopen~~ Semi-open type slots. Power transfer from stator to rotor and torque production will be Less.

Conclusions:-

☞ Exciting current:

I_N (open) > I_N (semi open) > I_N (closed)

☞ No. load power factor:

$\cos\phi_0$ (open) < $\cos\phi_0$ (semi) < $\cos\phi_0$ (closed type)

☞ Leakage reactance

X_l (open) < X_l (semi-open) < X_l (closed)

☞ Torque production:

T (open) > T (semi open) > T (closed)

☞ Harmonic torque.

Open > Semi-open > closed.

* In general semi-open type slots are preferred in Induction machine.

Open types slots are preferred in D.C machines and synchronous machine.

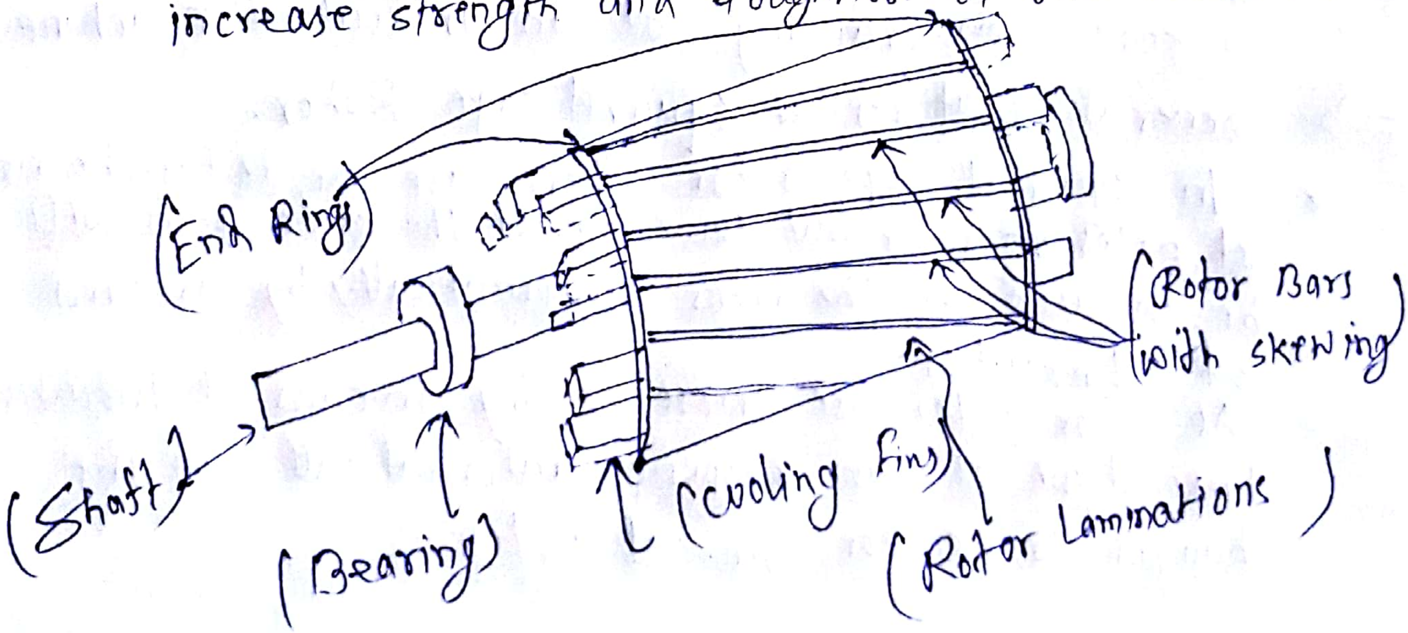
(b) <u>ROTOR</u> :-

(1) Squirrel cage Rotor
(The corresponding machine is squirrel cage Induction Machine)

(2) Wound Rotor.
(The corresponding machine is slip ring or wound rotor)
Induction machine

(1.) Squirrel cage Rotor:.

* Rotor core is made up of silicon steel.
* Rotor bars are either made up of by copper or aluminium.
* Rotor slots are semiclosed slot. types.
* The rotor frequency range is 2-3 Hz. Therefore eddy current or losses are very less.
* At the Losses ~~are~~ is less, the rotor can made with thick laminations.
* Two short ckt rings are required to short circuit all the rotor bars.
* Short ckt rings (end ringe) are also gives good mechanical balance to the rotor bars.
* End rings are made by forging process in order to increase strength and toughness of the material.



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Advantage of skewing:

(i) The flux distribution is uniform.

(ii) The average flux at any point is same beacuse of skewing bars and harmonic torque is Less.
(beacuse of uniform flux)

(iii) The operation of machine is silent and smooth.

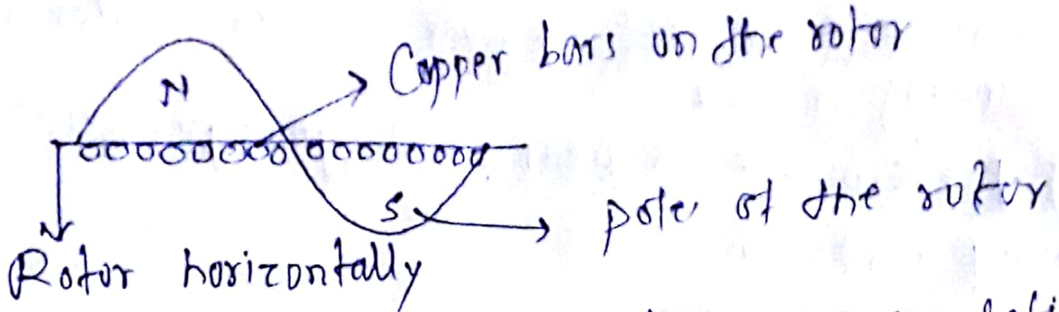
COGGING:- When the no of rotor slots is equal to the number of stator slots, the speed of all the harmonics by the stator slotting concide with the speed of corresponding rotor harmonics. Thus the harmonics of every order would try to exert synchronous torques at their synchronous speeds and the machine would refuse to start. This is known as Cogging. or magnetic locking. Therefore the no of stator slots should never be equal to the rotor slots. Cogging can easily overcome by making no. of rotor slots prime to no. of stator slots.

CRAWLING:- The tendency of particularly squirrel-cage rotor to run at speed as low as one-seventh of their synchronous speed. This phenomenon is known as crawling of an induction machine.

⇒ General features of squirrel cage Rotor.

* In squirrel-cage rotor, there are no definite no. of poles on rotor but same no. of the stator poles will be induced in the rotor automatically by means of Induction.

⇒ As rotor poles are induced by means of induction, this type of can respond automatically to the changes in stator no. of poles.



* In squirrel cage rotor there are no definite no. of phases, but one can treat squirrel-cage rotor with no. of phases are equal to the no of copper bars under one poles.
* The rotor shown in above figure has 8-phases.
* Operation of induction machine is not possible with unequal no of stator and rotor poles.
* Operation of I.M. is possible with unequal no of stator and rotor phases.
* As squirrel-cage rotor has smooth outer surface the air gap length b/w stator and rotor is very Less. Then machine will take Less exciting current and operates at high no. load power factor and full load power factor.
* As squirrel cage rotor has low leakage flux and leakage reactance, the amount of power transfer from stator to rotor is high. Therefor its torque production capability under running condition is good.

⟹ Drawbacks of squirrel cage rotor:-

* As this type of rotor has low resistance, starting torque produced by machine is poor.
* The squirrel cage rotor has low rotor impedance and it will draw high starting ~~for~~ current. This is why some external starting methods are requred to start this type of Induction motor.

* As rotor resistance is low, power power factor at the time of starting is low.
* Starting performance is poor, but good performance in running condition.

(2.) WOUND ROTOR :-

Condition to be satisfied for placing rotor winding.

→ The rotor wdg must be distributed as well as short pitched just like stator winding.

→ Rotor winding must be provided with same no of poles as that of stator.

→ This type of rotor can't respond automatically the changes in stator no. of poles, i.e why rotor poles must be changed physically along with stator poles.

→ The rotor can be provided with any no of phases except single phase even though stator is provided with three phase.

→ The three-phase rotor wdg are always connected in star irrespective of whether its stator windings are connected in delta or star.

→ Slip rings are made up of phosphor bronze and the insulation between slip rings and shaft is mica.

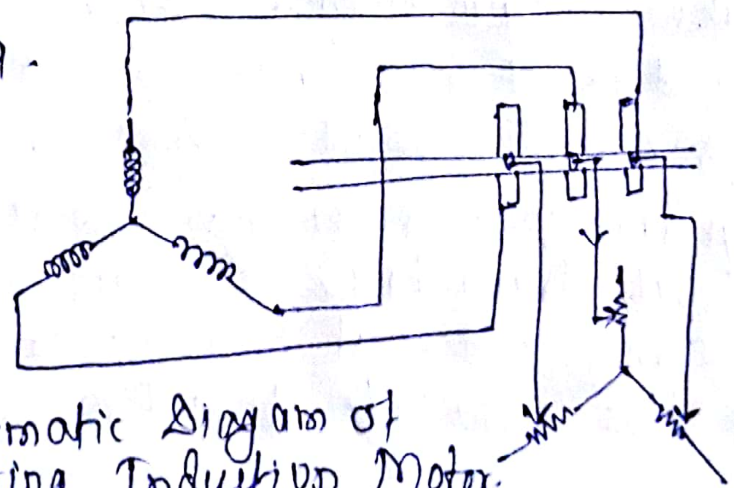


fig:- Schematic Diagram of Slip ring Induction Motor.

Functions of external Resistance in slip ring I.M.

→ It increases starting torque produced by Induction motor.

→ It is also increases the rotor power factor at the time of starting.

→ It limits the starting current drawn by Induction motor. Therefore no external starting methods are required to start this Induction motor.

→ If external resistance is varied on running condition then the speed of the Induction motor will be controlled. This method of speed controlling is called resistance speed controlling.

☞ In running condition leakage flux is high and hence leakage reactance of rotor is high. Therefore power transferred from stator to rotor is less and the machine has less running torque.

☞ Slip ring Induction motor has good starting performance but inferior running performance (high excitation current, low no-load and full load power factor., low torque under running condition) when compared to squirrel cage Induction machine.