ENTRI

INTRODUCTION

It is an a.c. motor, used for industrial drives since it is cheap, robust, efficient and reliable. It has good speed regulation and high starting torque.

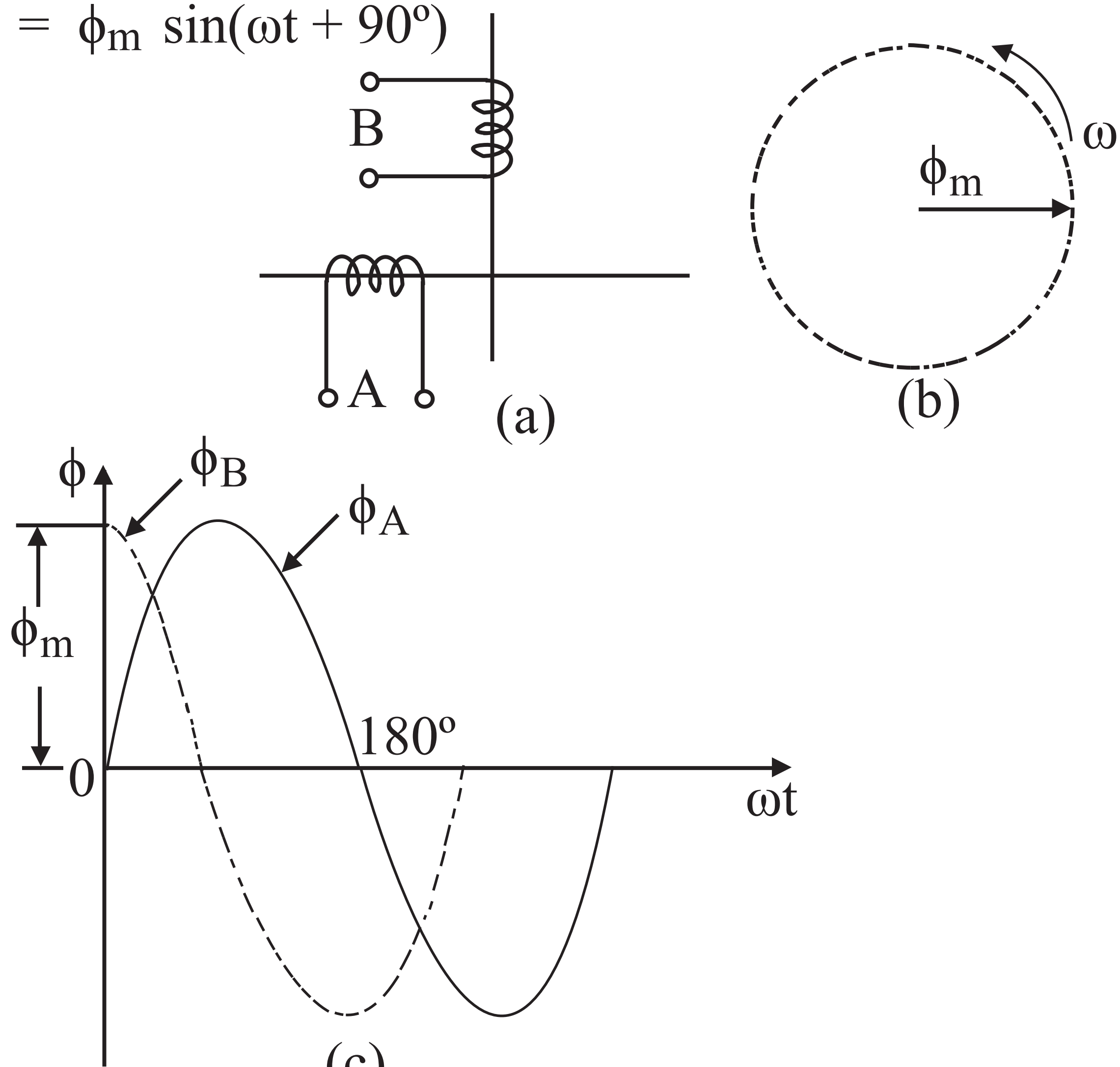
* Power is supplied to the rotor by means of electromagnetic induction, rather than by slip rings and commutators as in slip-ring AC motors.

Single Phase Induction Motor

Production of Rotating Field

$\phi_A = \phi_m \sin\omega t$

$\phi_B = \phi_m \sin(\omega t + 90^o)$



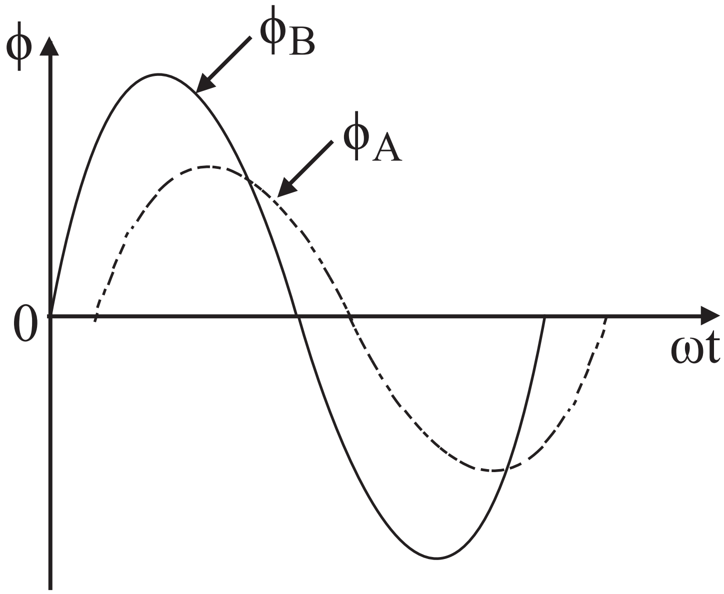


Figure : Displaced 90º in space

* A single phase IM is inherently not self-starting.

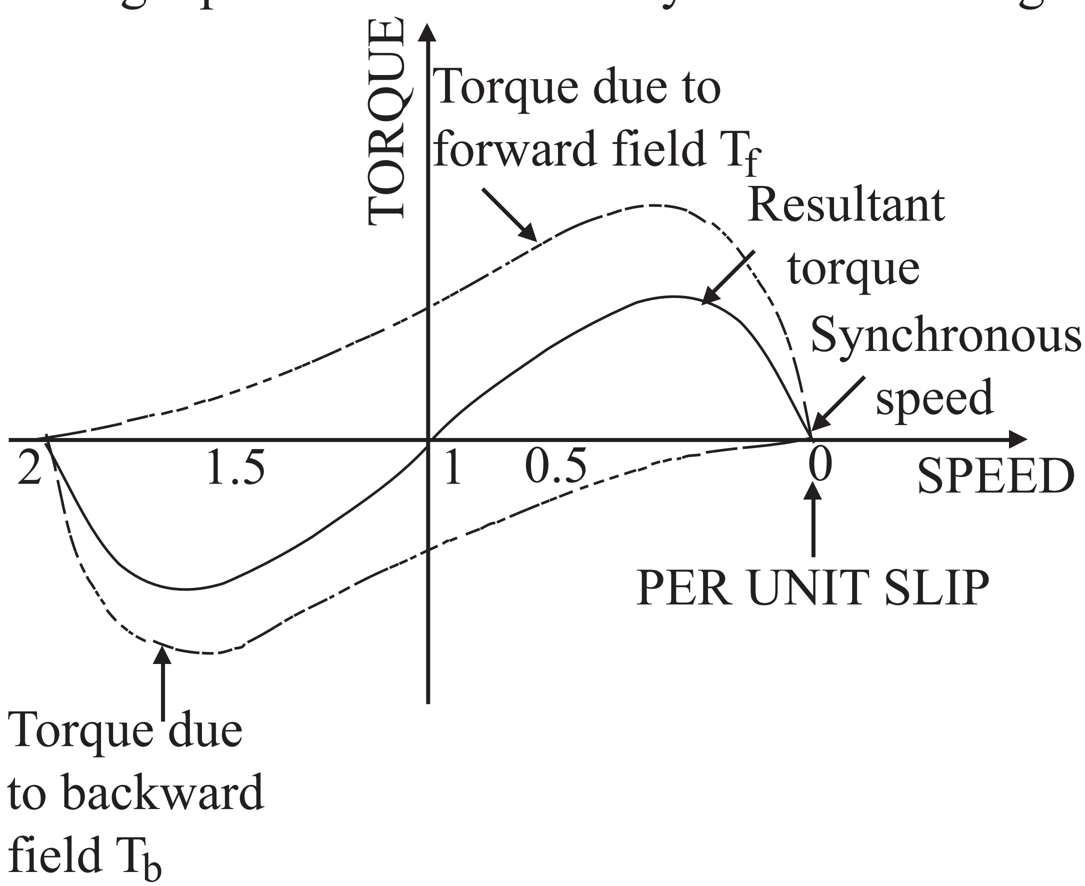


Figure : Torque-speed characteristic of a single-phase induction motor based on constant forward and back-ward flux waves.

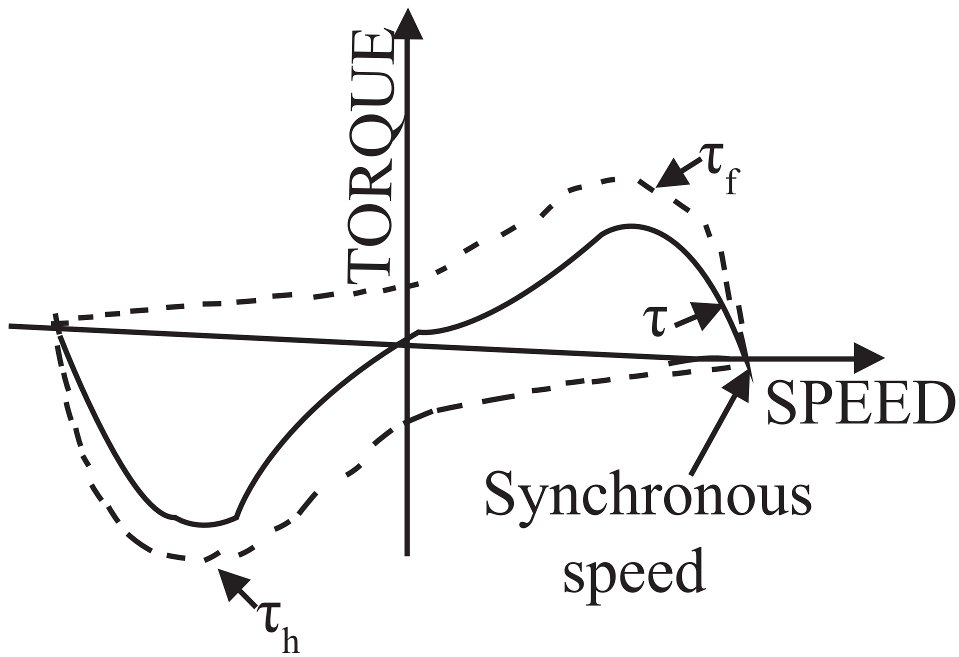


Figure : Actual torque-speed characteristics of a single phase induction motor taking into account changes in forward and backward flux waves

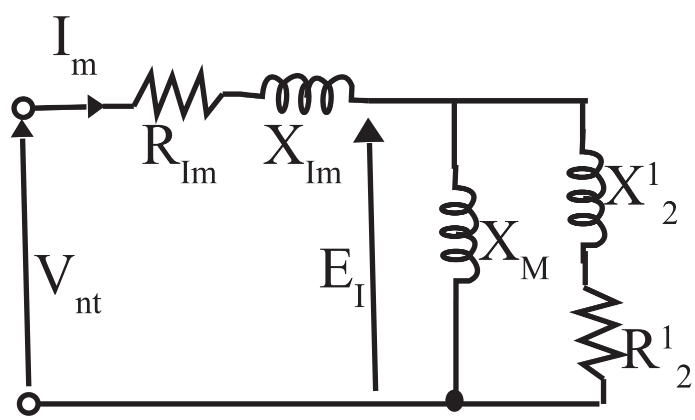


Figure : Equivalent circuit of a single-phase IM at standstill

Three Phase Induction Motor

Principle of three phase induction motor

When a conductor carrying current is put in a magnetic field a force is produced on it. Thus, a force is produced on the rotor conductor. The direction of this force can be found by left hand rule so that the force acting on the conductor is in the same direction as the direction of the rotating magnetic field. The rotor conductor is in a slot on the circumference of the rotor, this force is free to move, It starts rotaing in the same direction as the rotating magnetic field. Thus a three phase induction motor self starting.

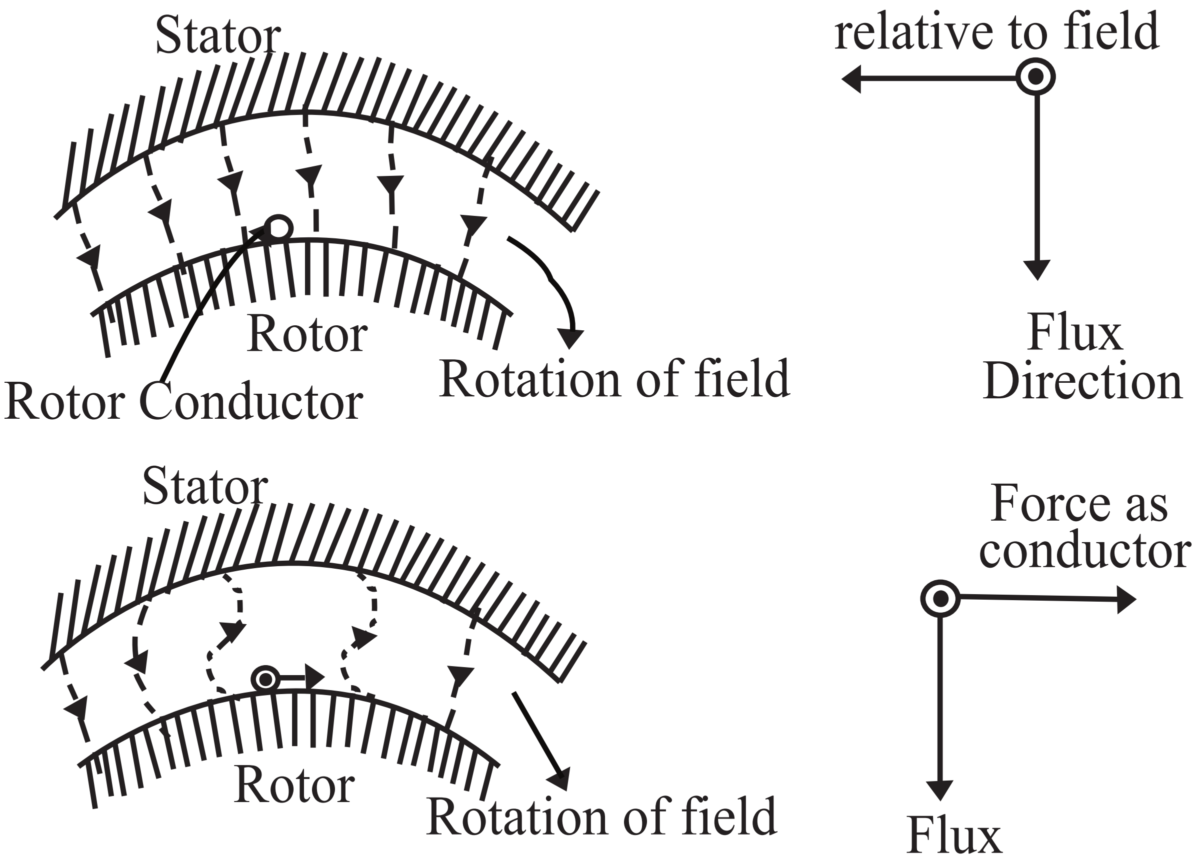


Figure : Production of torque

$$\frac{\text{total } I^2R \text{ loss in rotor}}{\text{input power to rotor}} = \frac{R\pi(n_s - n_r)\tau_d}{2\pi n_s \tau_d} = S$$

where, τ_d = developed torque = torque exerted on the rotor byrotating flux

n_s = synchronous speed (r.p.s)

n_r = rotor speed (r.p.s)

- Rotor copper loss = s × rotor input

$$P_{fc} = sP_{gen} = sP_{ir}$$

- Rotor input = mechanical power developed + rotor copper loss
- $P_{gan}\ P_{te}\ P_{md} = 1:s:(1-s)$

- Torque Developed (τ_d)

$$\tau_d = \frac{\text{mechanical power developed}}{\text{Mechanical angular velocity of the rotor}} = \frac{P_{md}}{\omega_r}$$

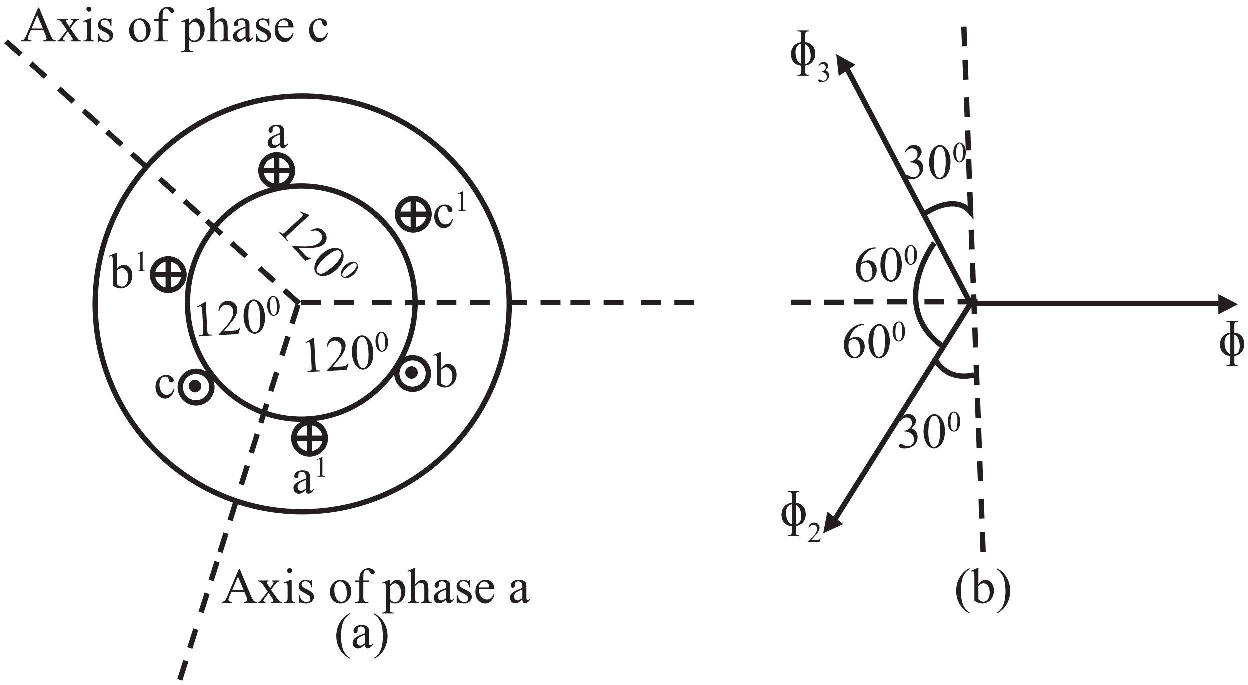
- Output power, $P_0 = \omega_r \tau_{load}$

$$\tau_{load} = \frac{P_0}{\omega_r} = \frac{P_{md} - P_{rot}}{\omega_r}$$

where, P_{md} = machanical power developed

Condition for maximum torque

- Maximum torque is independent of rotor circuit resistance.
- Maximum torque varies inversely as standstill reactance of the rotor.
- The slip at which the maximum torque depends upon the rotor resistance ($s_m = R_2/X_2$).
- The speed of the rotor at maximum torque is



$\phi_1 = \phi_m \sin\omega t$

$\phi_2 = \phi_m \sin(\omega t - 120^o)$

$\phi_3 = \phi_m \sin(\omega t + 120^o)$

The synchronous speed N_S of the rotating magnetic field is given as

$$N_S = \frac{120f}{p} \text{ revolutions per minute.}$$

Speed and Slip

Ship speed expresses the speed of the rotor relative to the field.

If N_S = synchronos speed in r.p.m.

N_r = actual rotor speed in r.p.m.

the slip speed = $N_S - N_r$ r.p.m.

$$s = \frac{N_S - N_r}{N_S} \text{ per unit (p.u.)}$$

* Percentage slip $= \frac{N_S - N_r}{N_S} \times 100$

* The rotor frequency is given by $f_r = \dfrac{P(N_s - N_r)}{120}$

* Rotor currrent frequency = per unit slip × supply frequency.

$$N_r = 0,\ s = \frac{N_s - N_r}{N_s} = 1 \text{ and } f_r = f.$$

Functions of Starter

(i) To reduce the heavy starting current.

(ii) To provide overload and under-voltage protection.

Starting of Cage Motors

Let,

I_{st} = Starting current drawn from the supply mains per phase.

I_{f1} = Full-load current drawn from the supply mains per phase.

τ_{est} = Starting torque τ_{ef1} = Full load torque

s_{f1} = Slip at full load

(i) Direct on-line starter : The motor is connected by means of a starter across the full supply voltage.

$$\frac{\tau_{est}}{\tau_{ef1}} = \left(\frac{I_{sc}}{I_{f1}}\right)^2 s_{f1}$$

(ii) Star-delta starter : It is designed to run normally on delta-connected stator winding.

$$\frac{\text{starting torque with star-delta starting}}{\text{full-load torque wih stator winding in delta}} = \left(\frac{I_{st\gamma p}}{I_{fl\Delta p}}\right)^2 s_{f1}$$

$$= \frac{1}{3}\left(\frac{I_{st\gamma p}}{I_{fl\Delta p}}\right)^2 s_{f1}$$

(iii) Auto transformer starter : It is suitable for both star and delta-connected motors. The starting current is limited by using a three-phase auto-transformer to reduce the initial stator applied voltage.

$$\frac{\tau_{est}}{\tau_{ef1}} = x^2 \left(\frac{I_{sc}}{I_{f1}}\right)^2 s_{f1}$$

Speed Control of Induction Motor

(i) By changing the applied frequency :
Synchronous speed of an induction motor is given by $N_s = \frac{120f}{P}$.

(ii) By changing the number of stator poles :
Changing of number of poles is achieved by having two or more independent stator winding's in the same slots.

(iii) Rotor Rheostat control : Addition of external resistance in the rotor circuit. It is applicable to slip ring motor.

(iv) Cascade Connection : The slip power is supplied to an auxiliary induction motor mechanically coupled to the main or primary motor.
If f is supply frequency and P_1 and P_2 are number of poles of the two motors. Then speed,

Main motor : $\frac{f}{P_1}$

Auxiliary motor : $\frac{f}{P_2}$

Differential cascade : $\frac{f}{(P_1 - P_2)}$

Cummulative cascade : $\frac{f}{(P_1 + P_2)}$

$$N_r = (1 - s)N_s \qquad N_s = \frac{120f}{P}$$

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* Synchronous speed of the h^{th} space harmonic wave is

$$n_{s(h)} = \frac{n_s}{h} = \frac{120f}{h \times P}$$

where, f = supply frequency

P = Number of poles of the stator.

* **Crawling of motor :** Tendency of the motor to run at stable speed as low as one-seventh of the normal speed N_s and being unable to pick up its normal speed.

* **Cogging :** Magnetic locking between the number of poles and of stator and rotor slots in cage motors. In this condition machine may refuse to start at all.