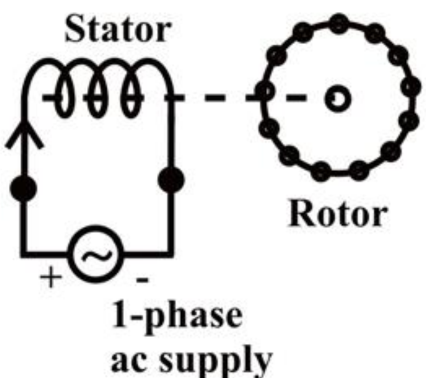
4.4

Single phase induction motor: Construction, working principle, double field revolving theory, split phase, capacitor start and shaded pole motor. applications (no derivations and numerical expected)

Single phase induction motor Construction

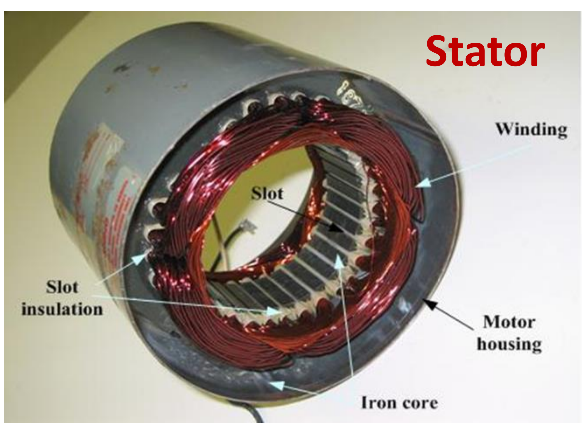
→ Single phase motors are designed to operate on single phase supply. These motors are fractional kWatts small size motors.

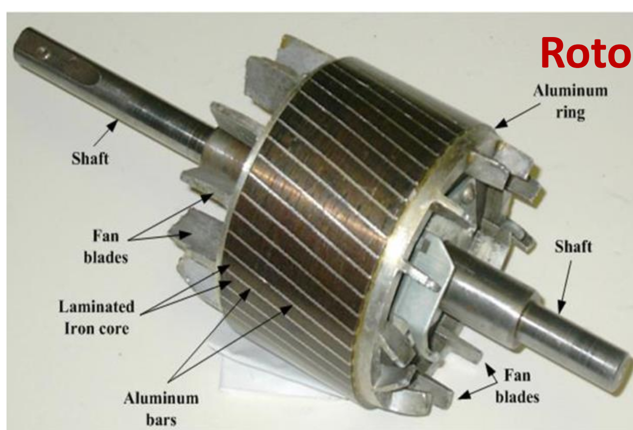
→ The single-phase induction machine is the most frequently used motor for refrigerators, washing machines, clocks, drills, compressors, pumps etc.

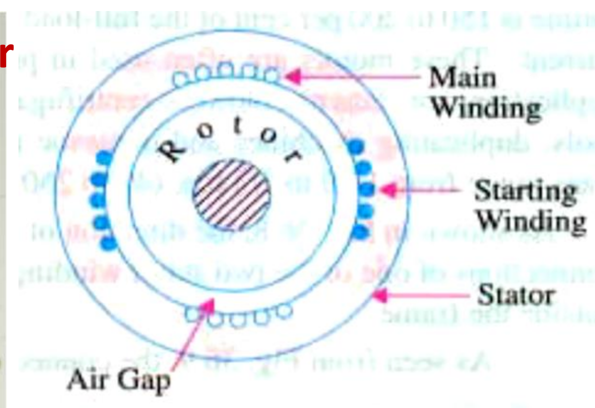


→ The winding used normally in the stator of the single-phase induction motor is a distributed one.

→ The rotor is of squirrel cage type, which is a cheap one







Single phase induction motor: Operation

- As the stator winding is fed from a single-phase supply, the flux in the air gap is alternating only, not a synchronously rotating one produced by a poly-phase motors.

- This type of alternating field cannot produce a torque, if the rotor is stationery. So, a single-phase IM is not self-starting, unlike a three-phase one.

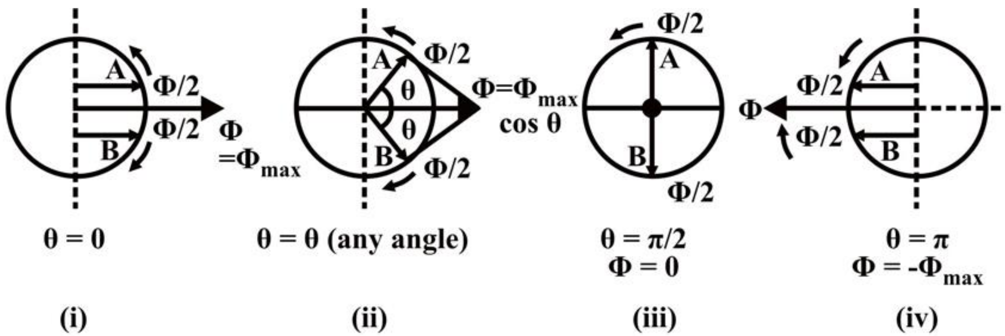
- However, if the rotor is initially given some torque in either direction, then immediately a torque is produced in the motor. The motor then accelerates to its final speed, which is lower than its synchronous speed.

- This is explained using double field revolving theory

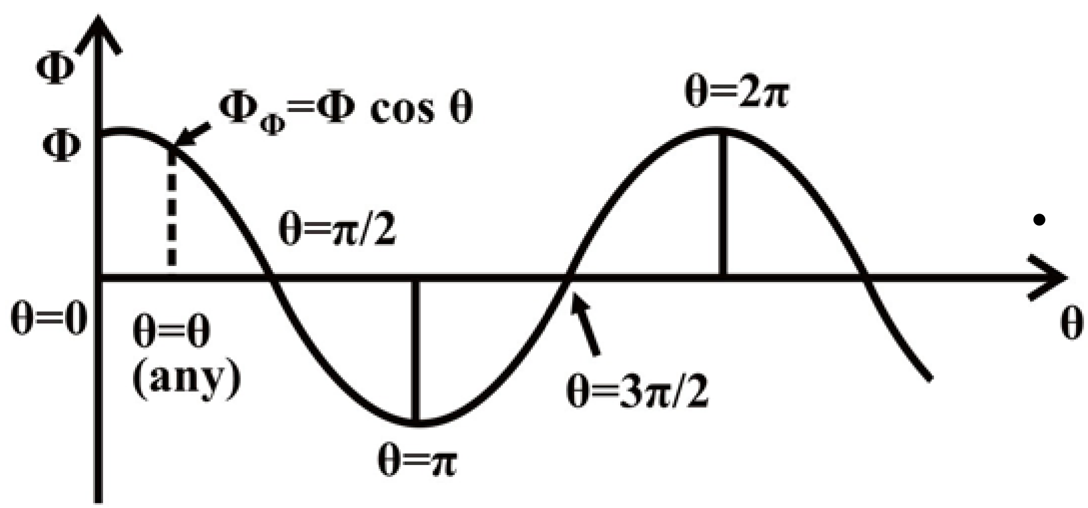
Single phase induction motor: Operation

→ Why single phase induction motor is not self starting?

Double field revolving theory



Position of the pulsating and rotating in fluxes with change in angle (θ)



Pulsating (sinusoidal) flux as a function of space angle (θ)

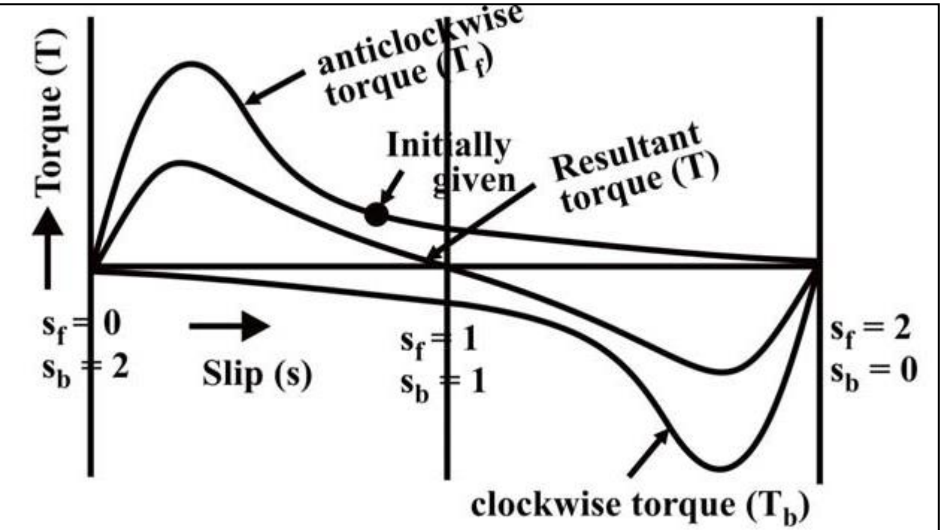
- When the stator winding carries a sinusoidal current being fed from a single-phase supply, a sinusoidal space distributed mmf, whose peak or maximum value pulsates (alternates) with time, is produced in the air gap.
- This sinusoidally varying flux (ϕ) is the sum of two rotating fluxes or fields, the magnitude of which is equal to half the value of the alternating flux (ϕ/2), and both the fluxes rotating synchronously at the speed, (*ns=2f/p*) in opposite directions.
- The resultant sum of the two rotating fluxes or fields, as the time axis (angle) is changing from θ=0 to 180°. The alternating or pulsating flux (resultant) varying with time or angle.

Single phase induction motor: Operation

→ Why single phase induction motor is not self starting?

Double field revolving theory

Slip of IM $S = \frac{N_s - N}{N_s} \times 100$



Speed-torque characteristics of single phase induction motor

- The flux or field rotating at synchronous speed, say, in the anticlockwise direction, i.e. the same direction, as that of the motor (rotor) taken as positive, induces emf (voltage) in the rotor conductors. The rotor is a squirrel cage one, with bars short circuited via end rings. The current flows in the rotor conductors, and the electromagnetic torque is produced in the same direction as given above, which is termed as positive (+ve).
- The other part of flux or field rotates at the same speed in the opposite (clockwise) direction, taken as negative. So, the torque produced by this field is negative (-ve), as it is in the clockwise direction, same as that of the direction of rotation of this field.
- Two torques are in the opposite direction, and the resultant (total) torque is the difference of the two torques produced.
- If the rotor is stationary, the slip due to forward (anticlockwise) rotating field is Sf=1.0. Similarly, the slip due to backward rotating field is also Sb=1.0 .

The two torques are equal and opposite, and the resultant torque is 0.0 (zero). So, there is no starting torque in a single-phase IM.

Single phase induction motor: Operation

→ Why single phase induction motor is not self starting?

Double field revolving theory

- But, if the motor (rotor) is started or rotated somehow, say in the anticlockwise (forward) direction, the forward torque is more than the backward torque, with the resultant torque now being positive. The motor accelerates in the forward direction, with the forward torque being more than the backward torque. The resultant torque is thus positive as the motor rotates in the forward direction.
- The motor speed is decided by the load torque supplied, including the losses (specially mechanical loss).

Single phase induction motor: Operation

→ Why single phase induction motor is not self starting?

Double field revolving theory

- Mathematically, the mmf, which is distributed sinusoidally in space, with its peak value pulsating with time, is described as (F=Fpeak cosθ) where θ (space angle) measured from the winding axis.
- Now, Fpeak= Fmax cosωt . So, the mmf is distributed both in space and time, i.e.

$$F = F_{max} \cos\omega t \cos\theta$$

This can be expressed as

$$F = (F_{max}/2)\cdot\cos(\theta-\omega t)+(F_{max}/2)\cdot\cos(\theta+\omega t)$$

which shows that a pulsating field can be considered as the sum of two synchronously rotating fields ($\omega_s = 2\pi n_s$). The forward rotating field is, $F_f = (F_{max}/2)\cdot\cos(\theta-\omega t)$, and the backward rotating field is, $F_b = (F_{max}/2)\cdot\cos(\theta+\omega t)$. Both the fields have the same amplitude equal to $(F_{max}/2)$, where F_{max} is the maximum value of the pulsating mmf along the axis of the winding.

Single phase induction motor: Operation

→ Why single phase induction motor is not self starting?

Double field revolving theory

When the motor rotates in the forward (anticlockwise) direction with angular speed ($\omega_r = 2\pi n_r$), the slip due to the forward rotating field is,

$$s_f = (\omega_s - \omega_r)/\omega_s = 1 - (\omega_r/\omega_s), \text{ or } \omega_r = (1 - s_f)\omega_s.$$

Similarly, the slip due to the backward rotating field, the speed of which is ($-\omega_s$), is,

$$s_b = (\omega_s + \omega_r)/\omega_s = 1 + (\omega_r/\omega_s) = 2 - s_b,.$$

The torques produced by the two fields are in opposite direction. The resultant torque is,

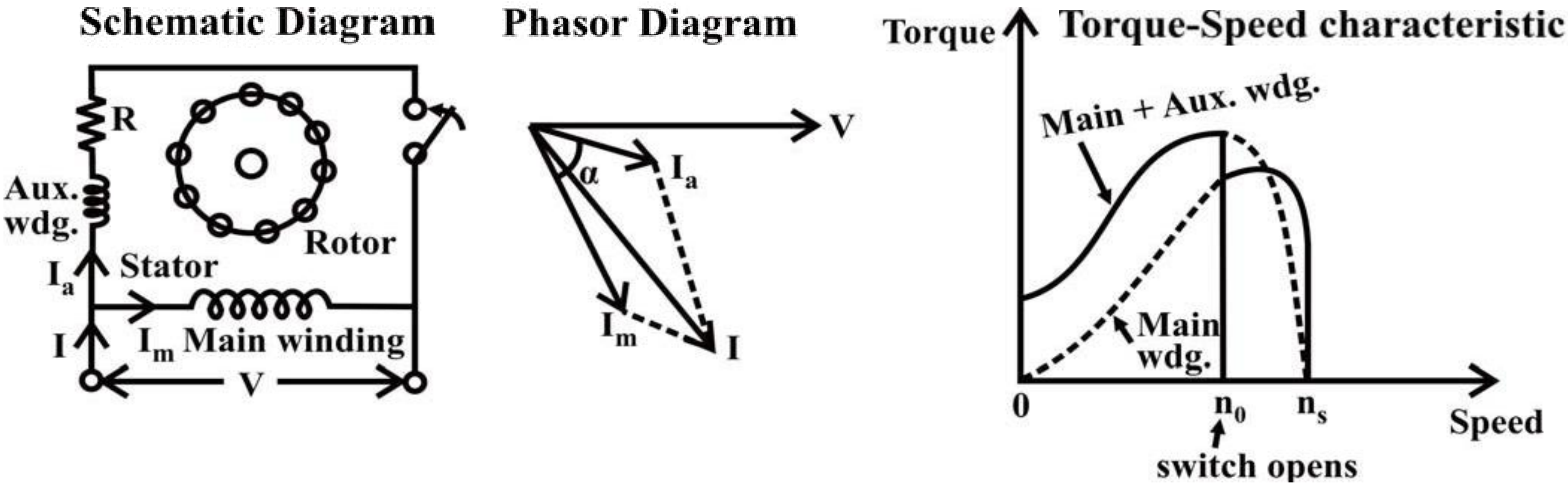
$$T = T_f - T_b$$

It was earlier shown that, when the rotor is stationary, $T_f = T_b$, with both $s_f = s_b = 1.0$, as $\omega_r = 0.0$ or $n_r = 0.0$. Therefore, the resultant torque at start is 0.0 (zero).

How to make Single phase induction motor self starting?

- The single-phase IM has no starting torque, but has resultant torque, when it rotates at any other speed, except synchronous speed.
- It is also known that, in a balanced two-phase IM having two windings, each having equal number of turns and placed at a space angle of 90^0 (electrical), and are fed from a balanced two-phase supply, with two voltages equal in magnitude, at an angle of 90^0, the rotating magnetic fields are produced, as in a three-phase IM.
- The torque-speed characteristic is same as that of a three-phase one, having both starting and also running torque.
- So, in a single-phase IM, if an auxiliary winding is introduced in the stator, in addition to the main winding, but placed at a space angle of 90^0(electrical), starting torque is produced.
- The currents in the two (main and auxiliary) stator windings also must be at an angle of 90^0 , to produce maximum starting torque.
- Thus, rotating magnetic field is produced in such motor, giving rise to starting torque. The various starting methods used in a single-phase IM.

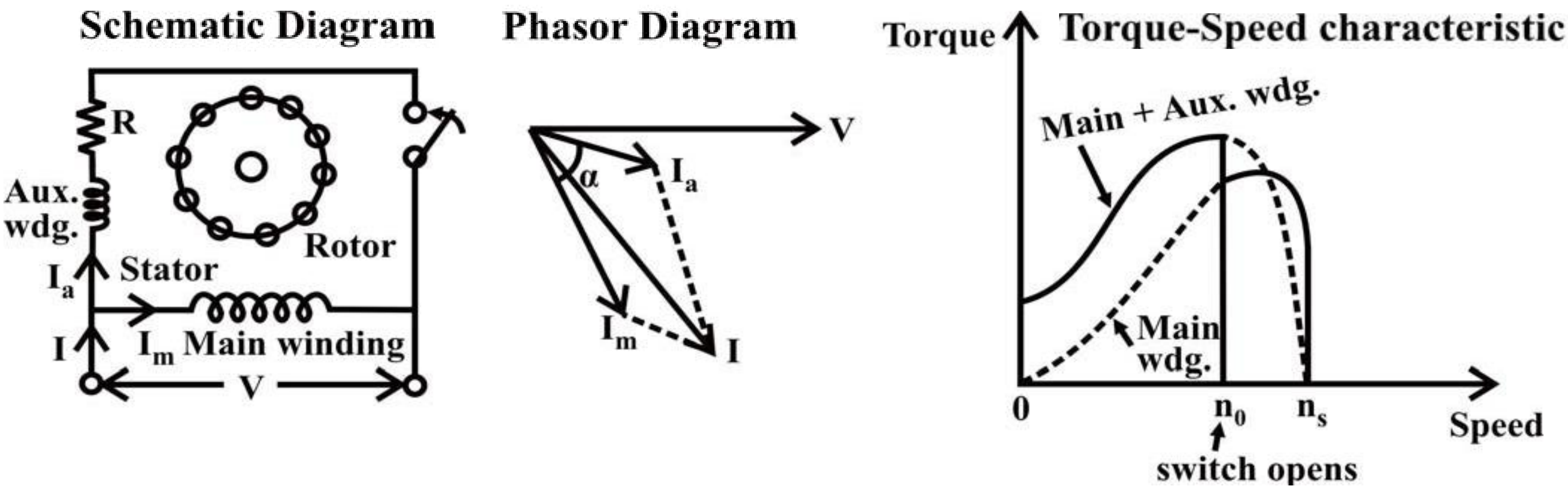
1. Resistance Split-phase Motor



- An auxiliary winding with a high resistance in series is to be added along with the main winding in the stator. This winding has higher resistance to reactance (Ra/Xa) ratio as compared to that in the main winding, and is placed at a space angle of 90^o from the main winding.

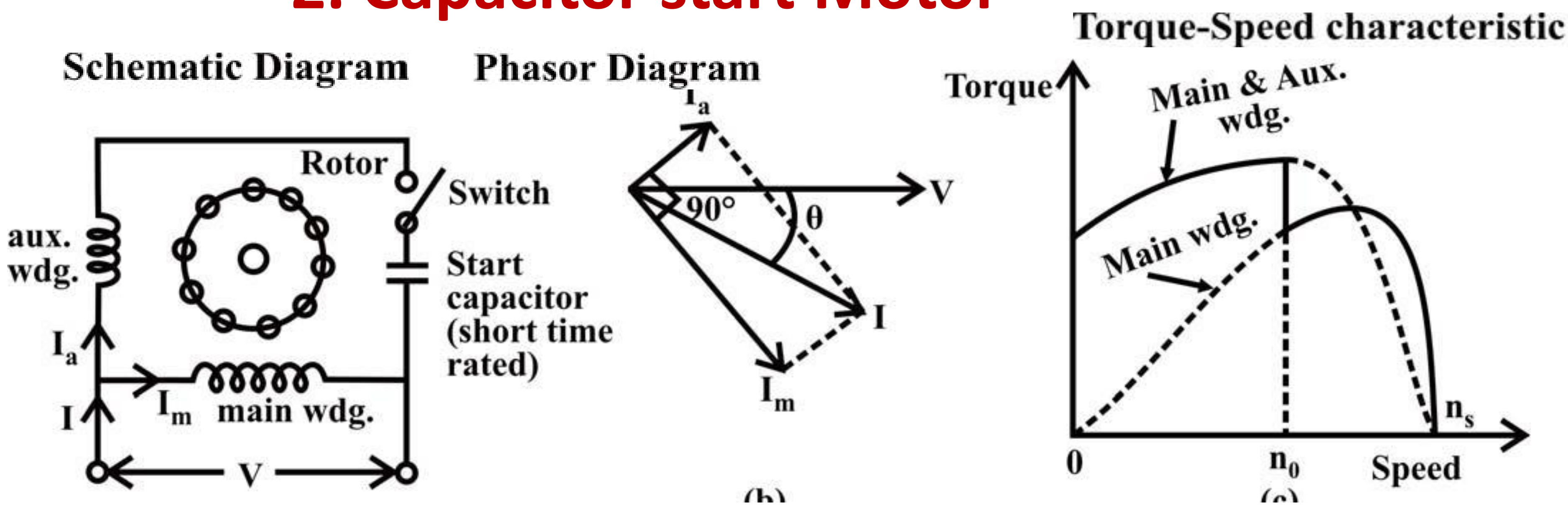
- The phasor diagram of the currents in two windings and the input voltage is shown. The current (Ia) in the auxiliary winding lags the voltage (*V*) by an angle, , which is small, whereas the current (Im) in the main winding lags the voltage (*V*) by an angle, ϕm, which is nearly 90^o .

Resistance Split-phase Motor…



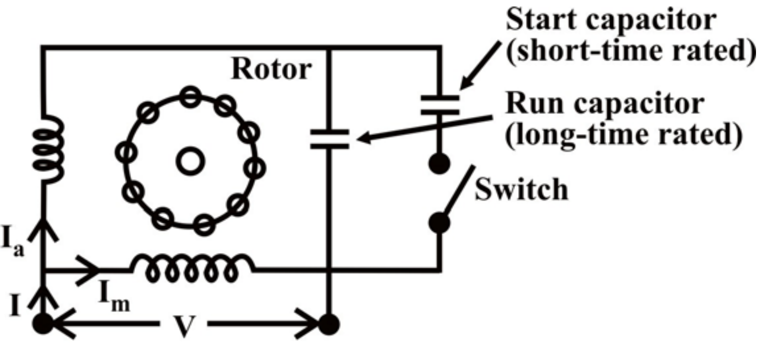
- The phase angle between the two currents is $(90^\circ-\phi_a)$, which should be at least 30°. This results in a small amount of starting torque.
- The switch, S (centrifugal switch) is in series with the auxiliary winding. It automatically cuts out the auxiliary or starting winding, when the motor attains a speed close to full load speed.
- The motor has a starting torque of 100−200% of full load torque, with the starting current as 5-7 times the full load current.
- The torque-speed characteristics of the motor with/without auxiliary winding are shown.
- The change over occurs, when the auxiliary winding is switched off. The direction of rotation is reversed by reversing the terminals of any one of two windings, but not both, before connecting the motor to the supply terminals.
- This motor is used in applications, such as fan, saw, small lathe, centrifugal pump, blower, office equipment, washing machine, etc.

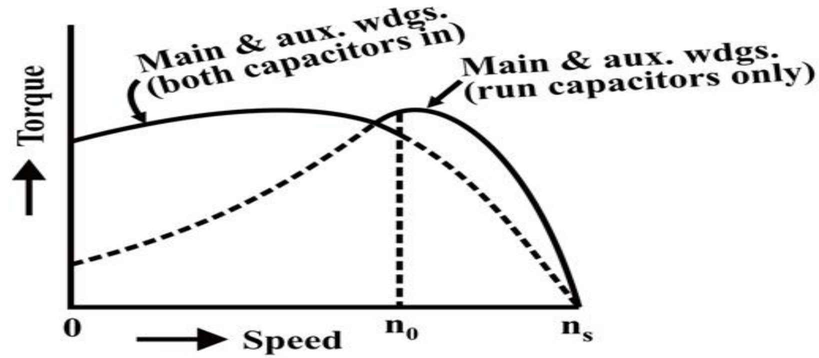
2. Capacitor start Motor

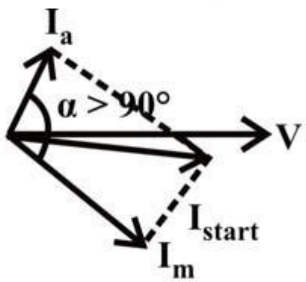


- To get high starting torque, the phase difference required is 90° when the starting torque will be proportional to the product of the magnitudes of two currents.
- As the current in the main winding is lagging by ϕm, the current in the auxiliary winding has to lead the input voltage by ϕa, with (ϕm + ϕa=90°). ϕa is taken as negative (-ve), while ϕm is positive (+ve). This can be can be achieved by having a capacitor in series with the auxiliary winding, which results in additional cost, with the increase in starting torque.
- A capacitor along with a centrifugal switch is connected in series with the auxiliary winding.
- This motor is used in applications, such as compressor, conveyor, machine tool drive, refrigeration and air-conditioning equipment, etc.

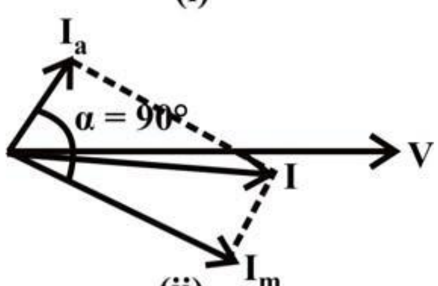
3. Capacitor-start and Capacitor-run Motor







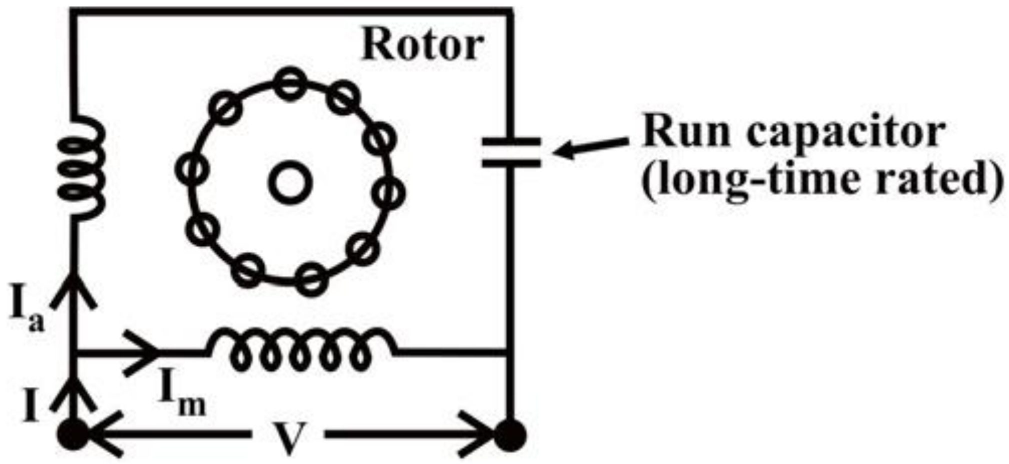
(i)



(ii)

- Two capacitors – for starting Cs, and for running Cr, are used.
- The first capacitor is rated for intermittent duty, being used only for starting. A centrifugal switch is also needed here.
- The second one is to be rated for continuous duty, as it is used for running.
- The phasor diagram of two currents in both cases, and the torque-speed characteristics with two windings having different values of capacitors.
- The phase difference between the two currents is ($\phi m + \phi a > 90^o$) in the first case (starting), while it is for second case (running).
- In the second case, the motor is a balanced two phase one, the two windings having same number of turns and other conditions as given earlier, are also satisfied. So, only the forward rotating field is present, and the no backward rotating field exists.
- The efficiency of the motor under this condition is higher. Hence, using two capacitors, the performance of the motor improves both at the time of starting and then running. This motor is used in applications, such as compressor, refrigerator, etc.

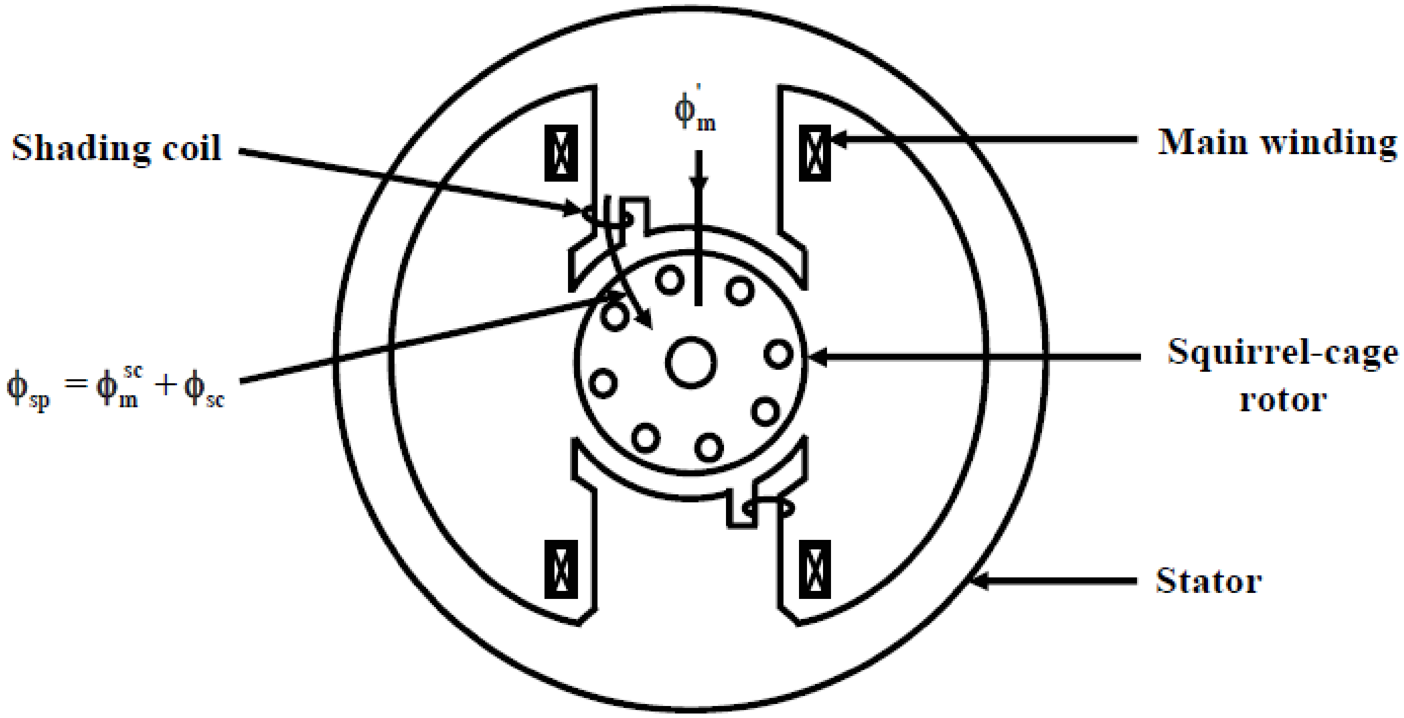
4. Capacitor-run Motor



Schematic Diagram of Capacitor-run Induction Motor

- A Permanent Capacitor Motor with the same capacitor being utilized for both starting and running, is also used.
- The power factor of this motor, when it is operating (running), is high. The operation is also quiet and smooth.
- This motor is used in applications, such as ceiling fans, air circulator, blower, etc.

5. Shaded-pole Motor



- This is a single-phase induction motor, with main winding in the stator.
- A small portion of each pole is covered with a short-circuited, single-turn copper coil called the shading coil.
- The sinusoidally varying flux created by ac (single-phase) excitation of the main winding induces emf in the shading coil.
- As a result, induced currents flow in the shading coil producing their own flux in the shaded portion of the pole.

5. Shaded-pole Motor..

Let the main winding flux be $\phi_m = \phi_{\max} \sin \omega t$

where

$$\phi_m = \phi_m^{sc} \text{ (flux component linking shading coil)}$$
$$+ \phi_m' \text{ (flux component passing down the air-gap of the rest of the pole)}$$

The emf induced in the shading coil is given by

$$e_{sc} = \frac{d\phi_m^{sc}}{dt} \text{ (since single-turn coil)} = \phi_{\max}^{sc}\, \omega \cos \omega t$$

Let the impedance of the shading coil be $Z_{sc} \angle \theta_{sc} = R_{sc} + j X_{sc}$

The current in the shading coil can then be expressed as

$$i_{sc} = \left[\left(\phi_{\max}^{sc}\, \omega \right) / Z_{sc} \right] \cos(\omega t - \theta_{sc})$$

The flux produced by i_{sc} is

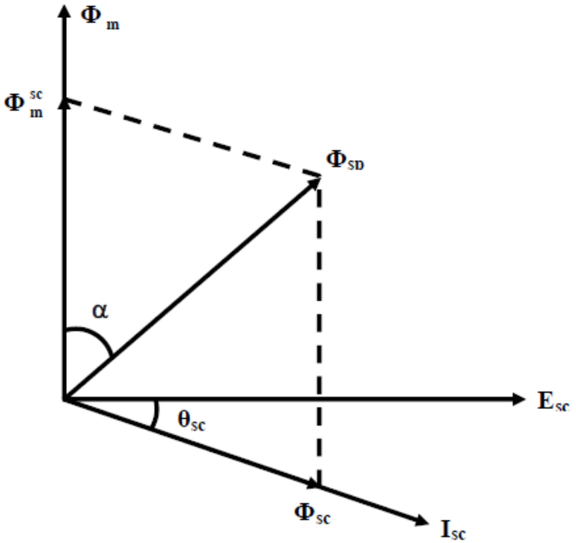
$$\phi_{sc} = \frac{1 \times i_{sc}}{R} = \frac{\omega\, \phi_{\max}^{sc}}{Z_{sc}\, R} \cos(\omega t - \theta_{sc})$$

where $R =$ reluctance of the path of ϕ_{sc}

5. Shaded-pole Motor..

As per the above equations, the shading coil current (I_{sc}) and flux (ϕ_{sc}) phasors lag behind the induced emf (E_{sc}) by angle θ_{sc} ; while the flux phasor leads the induced emf (E_{sc}) by $90°$. Obviously the phasor ϕ'_m is in phase with ϕ_m^{sc}. The resultant flux in the shaded pole is given by the phasor sum

$\phi_{sp} = \phi_m^{sc} + \phi_{sc}$ and lags the flux ϕ'_m of the remaining pole by the angle α.



two sinusoidally varying fluxes ϕ'_m and ϕ'_{sp} are displaced in space as well as have a time phase difference (α), thereby producing forward and backward rotating fields, which produce a net torque. It may be noted that the motor is self-starting unlike a single-phase single-winding motor.

5. Shaded-pole Motor..

- The reversal of the direction of rotation, where desired, can be achieved by providing two shading coils, one on each end of every pole, and by open-circuiting one set of shading coils and by short-circuiting the other set.
- The fact that the shaded-pole motor is single-winding (no auxiliary winding) self-starting one, makes it less costly and results in rugged construction.
- The motor has low efficiency and is usually available in a range of 1/300 to 1/20 kW.
- It is used for domestic fans, record players and tape recorders, humidifiers, slide projectors, small business machines, etc..