7.2 Capacitor induction Motor

The capacitor-start motor is identical to a split-phase motor except that the starting winding has as many turns as the main winding. The picture of capacitor start induction motor is shows in Figure 13 (i). Moreover, a capacitor C (3-20 μF) is connected in series with the starting winding as shown in Figure 13 (ii)). The value of capacitor is so chosen that Is leads Im by about 80° which is considerably greater than 25° found in split-phase motor [See Figure 13 (iii))]. Figure 13(iv) shows typical torque speed characteristic.

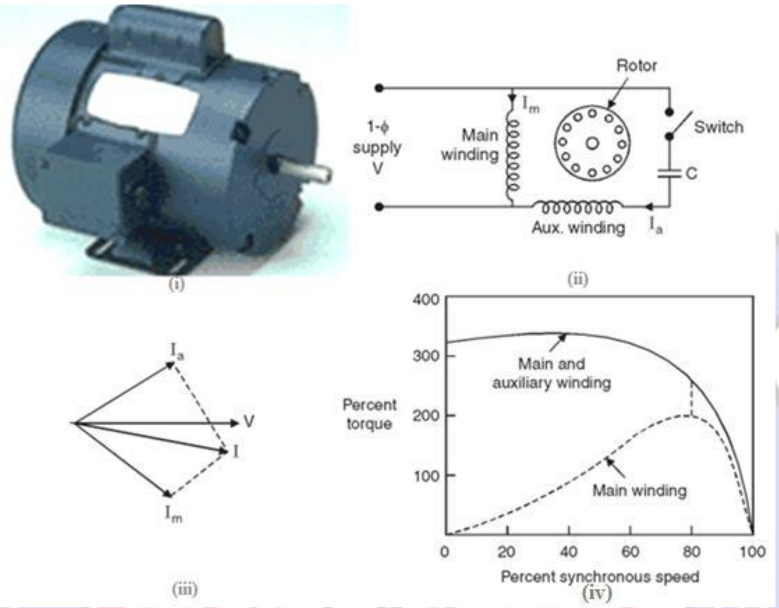

Fig. 13 Capacitor-Start Motor.

7.2.1 Operation

(i) When the two stator windings are energized from a single-phase supply, the main winding carries current Im while the starting winding carries current Is.

(ii) Due to cap acitance the currents Im and Is have a reasonable phase angle a (80°) between them.

(iii) When starting torque is much more than that of a split-phase motor Again, the starting winding is opened by the centrifugal switch when the motor attains about 80% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

7.2.2 Characteristics

(i) Although starting characteristics of a capacitor-start motor are better than those of a split-phase motor, both machines possess the same running characteristics because the main windings are identical.

(ii) The phase angle between the two currents is about 80° compared to about 25° in a split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a split-phase motor. Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.

(iii) Capacitor-start motors are used where high starting torque is required and where the starting period may be long e.g., to drive:

(a) compressors (b) large fans (c) pumps (d) high inertia loads

The power rating of such motors lies between 120 W and 7-5 kW.

7.3 Capacitor start Capacitor run induction motors

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two designs are generally used. Figure 14 (i) shows picture of capacitor start capacitor run induction motor. This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor. In the other design, two capacitors C1 and C2 are used in the starting winding as shown in Figure 14 (ii). The value of capacitor is so chosen that Is leads Im by about 80° [See Figure 14 (iii))]. The smaller capacitor C1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C2 is connected in parallel with C1 for optimum starting and remains in the circuit during starting. The starting capacitor C2 is disconnected when the motor approaches about 80% of synchronous speed. The motor then runs as two-phase induction motor. Figure 14 (iv) shows typical torque speed characteristic.

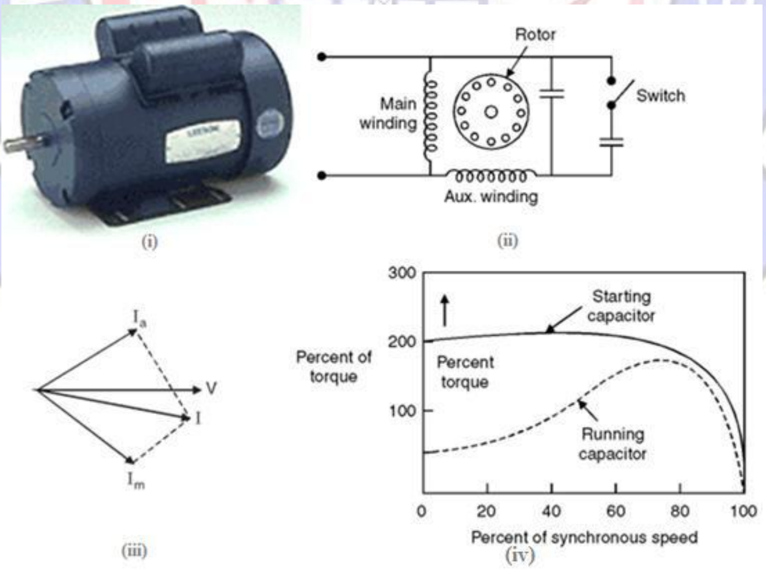

Fig. 14 Capacitor start Capacitor run induction motors.

7.3.1 Operation

(i) When the two stator windings are energized from a single-phase supply, the main winding carries current IM while the starting winding carries current Is.

(ii) Due to capacitance C1 the currents Im and Is have a reasonable phase angle a (80°) between them.
(iii) When The starting capacitor C2 is disconnected when the motor approaches about 80% of synchronous speed. The motor then runs as two-phase induction motor.

7.3.2 Characteristics

(i) The starting winding and the capacitor can be designed for perfect 2-phase operation at any load. The motor then produces a constant torque and not a pulsating torque as in other single-phase motors.
(ii) Because of constant torque, the motor is vibration free and can be used in: (a) hospitals (b) studios and (c) other places where silence is important.

7.4 Shaded-pole induction motors

A picture of shaded pole induction motor are shows in Figure 15 (i). A typical shaded-pole motor with a cage rotor is shown in Figure 15 (ii). 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 sinusoidal varying flux created by ac (single-phase) excitation of the main winding induces 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. as shown in Figure 15 (iii) and lags the flux $\varphi_m{}'$ of the remaining pole by the angle α . The two sinusoidal varying fluxes $\varphi_m{}'$ and $\varphi_{sp}{}'$ 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. It is seen from the phasor diagram (Figure 15 (iii) that the net flux in the shaded portion of the pole (φ_{sp}) lags the flux ($\varphi_m{}'$) in the unshaded portion of the pole resulting in a net torque, which causes the rotor to rotate from the unshaded to the shaded portion of the pole. The motor thus has a definite direction of rotation, which cannot be reversed. Atypical torque speed characteristic are shows in Figure 15 (iv).

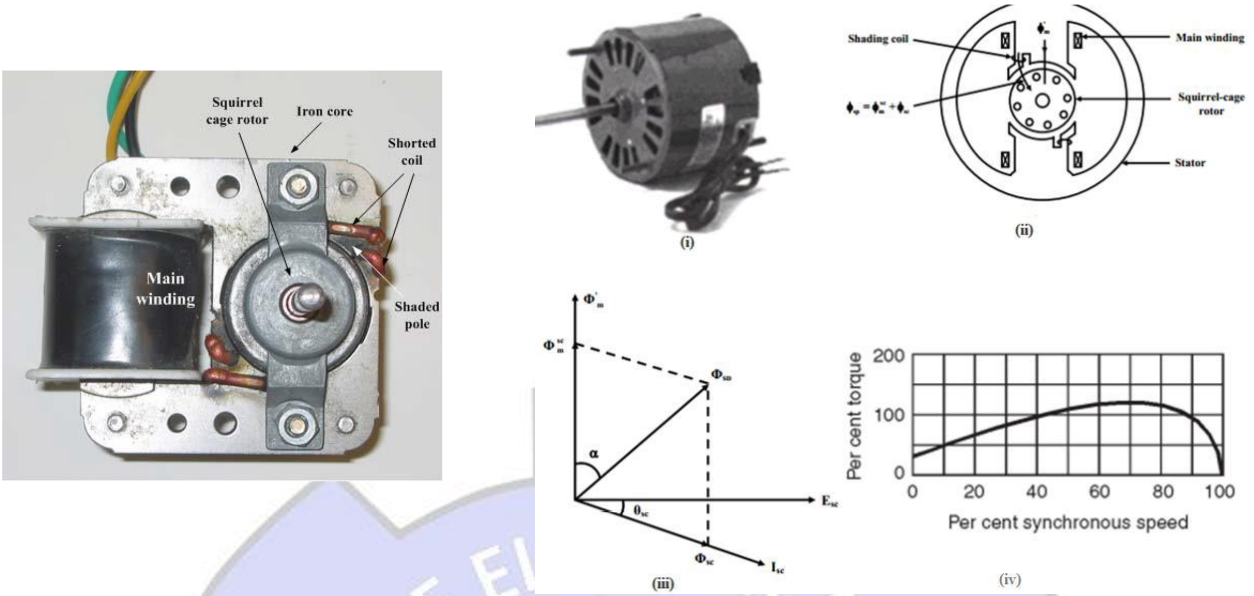

Fig. 15 Shaded-pole induction motors.

7.4.1 Operation

The operation of the motor can be understood by referring to Figure (16) which shows one pole of the motor with a shading coil.

(i) During the portion OA of the alternating-current cycle [See Figure (16)], the flux begins to increase and an EMF. is induced in the shading coil. The resulting current in the shading coil will be in such a direction so as to oppose the change in flux. Thus the flux in the shaded portion of the pole is weakened while that in the unshaded portion is strengthened as shown in Figure (16 (ii)).

(ii) During the portion AB of the alternating-current cycle, the flux has reached almost maximum value and is not changing. Consequently, the flux distribution across the pole is uniform [See Figure (16 (iii))] since no current is flowing in the shading coil. As the flux decreases (portion BC of the alternating current cycle), current is induced in the shading coil so as to oppose the decrease in current. Thus the flux in the shaded portion of the pole is strengthened while that in the unshaded portion is weakened as shown in Figure (16 (iv)).

(iii) The effect of the shading coil is to cause the field flux to shift across the pole face from the unshaded to the shaded portion. This shifting flux is like a rotating weak field moving in the direction from unshaded portion to the shaded portion of the pole.

(iv) The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed. As soon as this torque starts to revolve the rotor, additional torque is produced by single-phase induction-motor action. The motor accelerates to a speed slightly below the synchronous speed and runs as a single-phase induction motor.

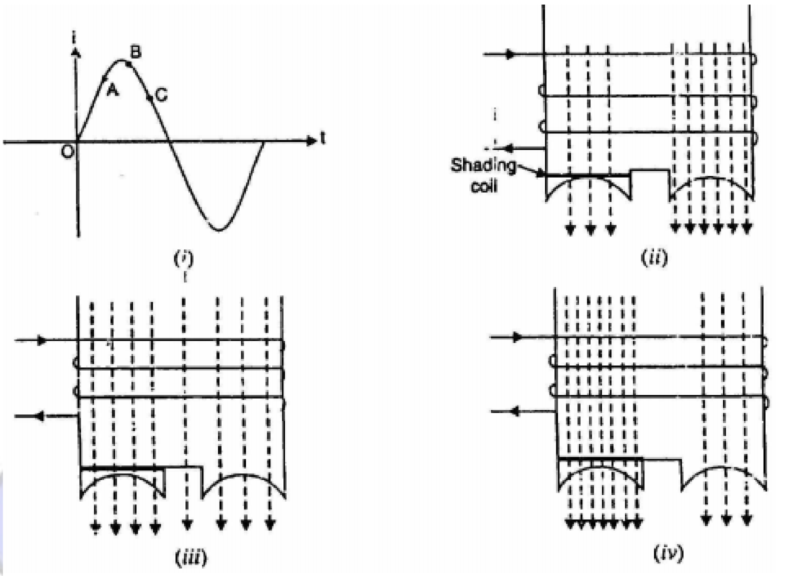

Fig. 16 one pole of the motor with a shading coil.

7.4.2 Characteristics

(i) The salient features of this motor are extremely simple construction and absence of centrifugal switch.

(ii) The motor efficiency is poor, but it is cheap.

(iii) Since starting torque, efficiency and power factor are very low, these motors are only suitable for low power applications e.g., to drive:

(a) Small fans (6) toys (c) hair driers (d) desk fans etc.

8 Equivalent circuit of single phase induction motor

When the stator of single phase induction motor is connected to single – phase supply, the stator current produces a pulsating flux. According to the double – revolving field theory, the pulsating air – gap flux in the motor at standstill can be resolved into two equal and opposite fluxes with the motor. Since the magnitude of each rotating flux is one – half of the alternating flux, it is convenient to assume that the two rotating fluxes are acting on two separate rotors. Thus, a single – phase induction motor may be considered as consisting of two motors having a common stator winding and two imaginary rotors, which rotate in opposite directions.

8.1 At standstill condition

The equivalent circuit of single – phase induction motor is shown in Figure 17

Where :

R1 = resistance of stator winding

X 1 = leakage reactance of stator winding

Xm = total magnetizing reactance

R2 = resistance of rotor referred to the stator

X2 = leakage reactance of rotor referred to the stator

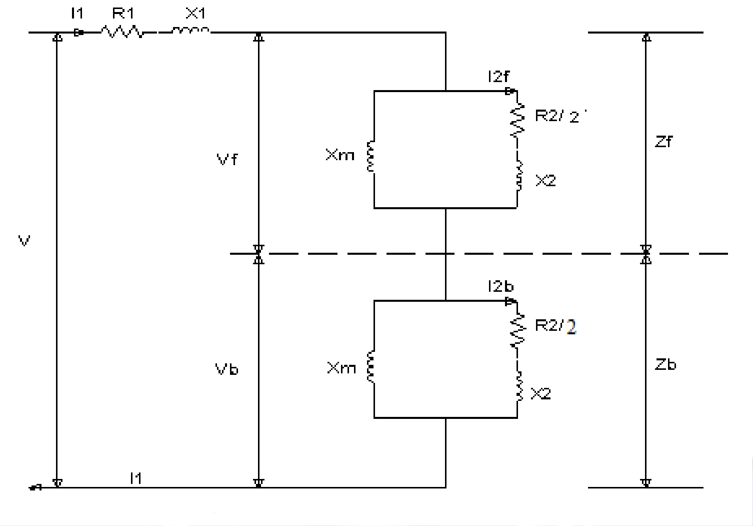

Fig. 17 Equivalent Circuit of Single Phase Induction Motor at Standstill.

At standstill,

φf = φb Therefore, Vf = Vb

Vb = I1Zf

Vb = I1Zb

Zf = Zb

Zf= impedance of forward parallel branch

Zb = impedance of backward parallel branch

$$\boldsymbol{I_1} = \frac{\boldsymbol{V}}{\boldsymbol{Z_t}}$$

Where Zt = Z1 + Zf + Zb

Z1= R1+X1

Zf = Zb

$$\mathrm{Zf} = \frac{JXm\,.\,(\frac{\mathrm{R2}}{2} + j\frac{X2}{2})}{\frac{R2}{2} + j(\,Xm + \frac{X2}{2})}$$

The torque of the backward field is in opposite direction to that of the forward field, and therefore the total air – gap power in a single phase induction motor is

Pg = Pf - Pb

Where Pf = air – gap power for forward field

Pf = I2Rf

Pb= air – gap power for backward field

Pb= I2Rb

The torque produced by the forward field is

$$Tf = \frac{Pf}{w} = \frac{Pf}{2\pi n}$$

The torque produced by the backward field

$$Tb = \frac{Pb}{ws} = \frac{Pb}{2\pi n}$$

The resultant electromagnetic or induced torque Tin is the difference between the torque Tf and Tb

$$Tin = Tf - Tb$$

8.2 At running condition

Now consider that the motor is pinning at some speed in the direction of the forward revolving field, the slip being s. The rotor current produced by the forward field will have a frequency sf where f is the stator frequency. Also, the rotor current produced by the backward field will have a frequency of (2 − s)f. Figure 18 shows the equivalent circuit of a single-phase induction motor when the rotor is rotating at slip s. It is clear, from the equivalent circuit that under running conditions, Ef becomes much greater than Eb because the term R'2/2s increases very much as s tends towards zero. Conversely, E^ falls because the term R'2/2(2 − s) decreases since (2 − s) tends toward 2. Consequently, the forward field increases, increasing the driving torque while the backward field decreases reducing the opposing torque.

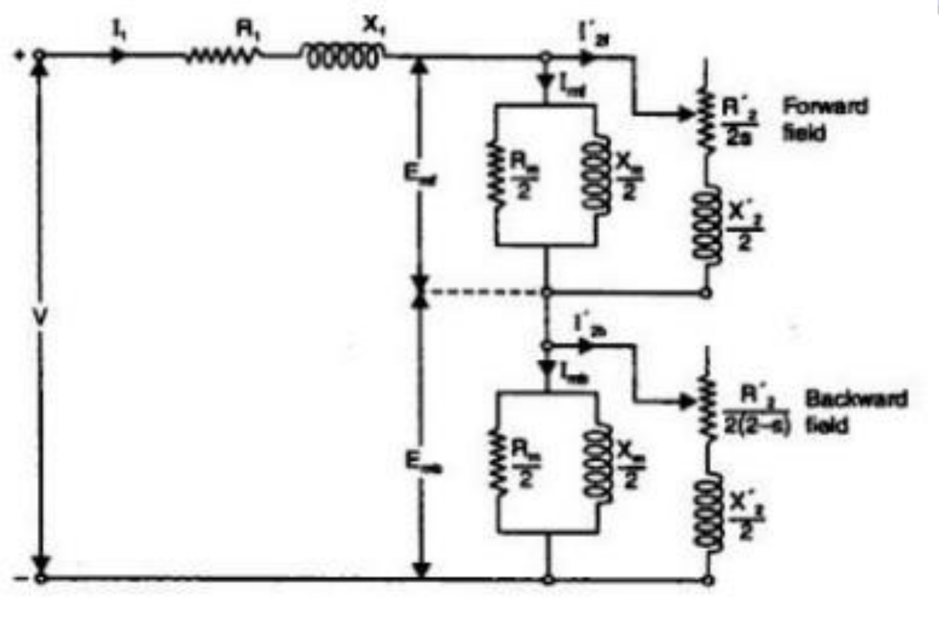

Fig. 18 equivalent circuit of single phase induction motor at operation without core loss.

Zt = Z1 + Zf + Zb

Z1= R1+X1

$$\mathrm{Zf} = \frac{JXm\,.\,(\frac{\mathrm{R2}}{2S} + j\frac{X2}{2})}{\frac{R2}{2S} + j(\,Xm + \frac{X2}{2})}$$

$$\mathrm{Zb} = \frac{JXm\,.\,(\frac{\mathrm{R2}}{2(2-S)} + j\frac{X2}{2})}{\frac{R2}{2(2-S)} + j(\,Xm + \frac{X2}{2})}$$

The total copper loss is the sum of rotor copper loss due to the forward field and the rotor copper loss due to the backward field.

Pcu = Pcuf + Pcub
Where
*Pcu= Slip * Pg*
Pcu= S Pgf -+ (2-S) Pgb
The power converted from electrical to mechanical form in a single phase induction motor is given by
Pmech = (1-S)Pg
Shaft output power
Pout =Pmech – friction loss – windage loss

Example 1: A 230 V, 50 Hz, 4 – pole single phase induction motor has the following equivalent circuit impedances:
R1 = 2.2Ω, R2 = 4.5Ω, X1 = 3.1Ω, X2 = 2.6Ω, Xm = 80Ω,
Friction, windage and core loss = 40 W . For a slip of 0.03pu, calculation (a) input current, (b) power factor, (c) developed power, (d) output power, (e) efficiency

Solution:
R2/2S = 4.5/2* 0.03 = 75 Ω
R2/2(2-S) = 4.5/2*(2 -0.03) = 1.142 Ω
X2 /2 = 2.6/2 = 1.3 Ω
Xm/2 = 80/2 = 40 Ω

$$\mathrm{Zf} = \frac{JXm\,.\,(\frac{\mathrm{R2}}{2S} + j\frac{X2}{2})}{\frac{R2}{2S} + j(\,Xm + \frac{X2}{2})} = 16.37 + \mathrm{j}30.98$$

$$\mathrm{Zb} = \frac{JXm\,.\,(\frac{\mathrm{R2}}{2(2-S)} + j\frac{X2}{2})}{\frac{R2}{2(2-S)} + j(\,Xm + \frac{X2}{2})} = 1.07 + \mathrm{j}1.92$$

$Z_1 = R_1 + X_1 = 2.2 + j3.1$

$Zt = Z_1 + Zf + Zb = 19.64 + j\,35.37 = 40.457 < 60.96$

a) Input current

I = V/ Zt = 230 < 0 / 40.457 < 60.96 = 5.685 < -60.69 A

b) Power factor

cos (-60.69) = 0.485 Lag

c) Developed power

Pconv = Pmech = I2 (Rf – Rb) (1-S) = (5.685)2 (16.37 – 1.07) (1 – 0.03)

= 479.65 W

d) Output power

Pout = Pmech - loss = 479.65 - 40 = 439.65 W

Input power = VI cos φ = 230 * 5.685 * 0.485 = 634.9 W

e) Efficiency = Pout / Pin*100% = 0.692 %