UNIT – III

SINGLE PHASE INDUCTION MOTORS

Single Phase Induction Motor:

The characteristics of single phase induction motors are identical to 3-phase induction motors except that single phase induction motor has no inherent starting torque and some special arrangements have to be made for making it self starting. It follows that during starting period the single phase induction motor must be converted to a type which is not a single phase induction motor in the sense in which the term is ordinarily used and it becomes a true single phase induction motor when it is running and after the speed and torque have been raised to a point beyond which the additional device may be dispensed with. For these reasons, it is necessary to distinguish clearly between the starting period when the motor is not a single phase induction motor and the normal running condition when it is a single phase induction motor. The starting device adds to the cost of the motor and also requires more space. For the same output a 1-phase motor is about 30% larger than a corresponding 3-phase motor.

Constructional features:

The single phase induction motor in its simplest form is structurally the same as a poly- phase induction motor having a squirrel cage rotor, the only difference is that the single phase induction motor has single winding on the stator which produces mmf stationary in space but alternating in time, a poly phase stator winding carrying balanced currents produces mmf rotating in space around the air gap and constant in time with respect to an observer moving with the mmf. The stator winding of the single phase motor is disposed in slots around the inner periphery of a laminated ring similar to the 3-phase motor.

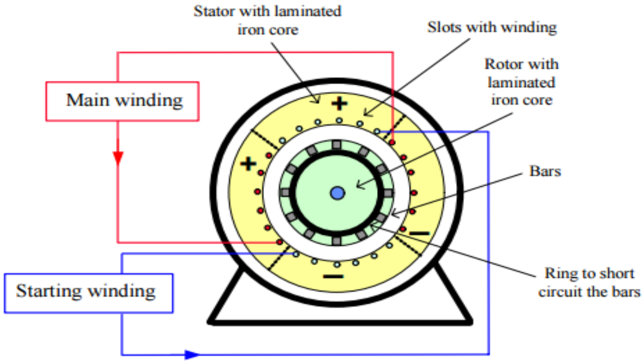

Fig.3.1. Elementary single phase induction motor.

An induction motor with a cage rotor and single phase stator winding is shown schematically in Fig. 3.1. The actual stator winding as mentioned earlier is distributed in slots so as to produce an approximately sinusoidal space distribution of mmf.

Principle of Operation

Double revolving field theory:

Suppose the rotor is at rest and 1-phase supply is given to stator winding. The current flowing in the stator winding gives rise to an mmf whose axis is along the winding and it is a pulsating mmf, stationary in space and varying in magnitude, as a function of time, varying from positive maximum to zero to negative maximum and this pulsating mmf induces currents in the short-circuited rotor of the motor which gives rise to an mmf. The currents in the rotor are induced due to transformer action and the direction of the currents is such that the mmf so developed opposes the stator mmf. The axis of the rotor mmf is same as that of the stator mmf. Since the torque developed is proportional to sine of the angle between the two mmf and since the angle is zero, the net torque acting on the rotor is zero and hence the rotor remains stationary.

For analytical purposes a pulsating field can be resolved into two revolving fields of constant magnitude and rotating in opposite directions as shown in Fig. 3.2 and each field has a magnitude equal to half the maximum length of the original pulsating phasor.

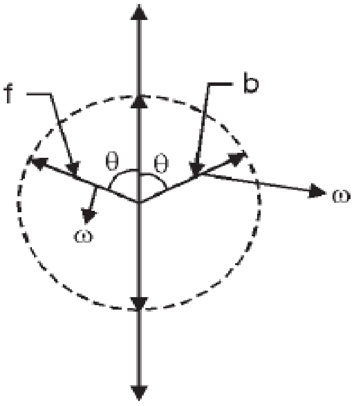

Fig. 3.2. Representation of the pulsating field by space phasors.

These component waves rotate in opposite direction at synchronous speed. The forward (anticlockwise) and backward-rotating (clockwise) mmf waves f and b are shown in Fig. 3.2. In case of 3-phase induction motor there is only one forward rotating magnetic field and hence torque is developed and the motor is self-starting. However, in single phase induction motor each of these component mmf waves produces induction motor action but the corresponding torques are in opposite direction. With the rotor at rest the forward and backward field produce equal torques but opposite in direction and hence no net torque is developed on the motor and the motor remains stationary. If the forward and backward air gap fields remained equal when the rotor is revolving, each of the component fields would produce a torque-speed characteristic similar to that of a polyphase induction motor with negligible leakage impedance as shown by the dashed curves f and b in Fig. 3.3.

The resultant torque-speed characteristic which is the algebraic sum of the two component curves shows that if the motor were started by auxiliary means it would produce torque in what- ever direction it was started.

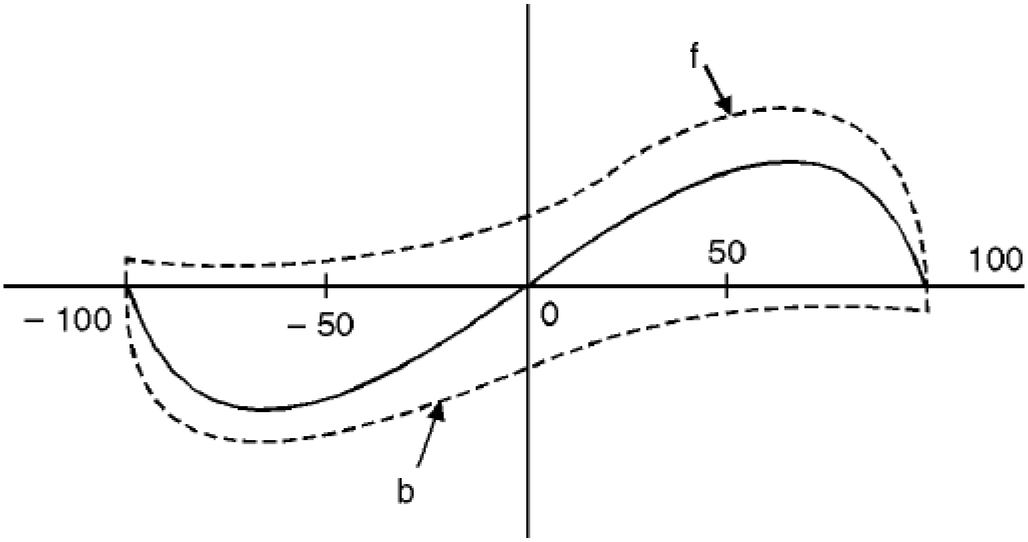

Fig. 3.3. Torque-speed characteristic of a 1-phase induction motor based on constant forward and backward flux waves

In reality the two fields, forward and backward do not remain constant in the air gap and also the effect of stator leakage impedance can't be ignored. In the above qualitative analysis the effects of induced rotor currents have not been properly accounted for.

When single phase supply is connected to the stator and the rotor is given a push along the forward rotating field, the relative speed between the rotor and the forward rotating magnetic field goes on decreasing and hence the magnitude of induced currents also decreases and hence the mmf due to the induced current in the rotor decreases and its opposing effect to the forward rotating field decreases which means the forward rotating field becomes stronger as the rotor speeds up. However for the backward rotating field the relative speed between the rotor and the backward field increases as the rotor rotates and hence the rotor emf increases and hence the mmf due to this component of current increases and its opposing effect to the backward rotating field increases and the net backward rotating field weakens as the rotor rotates along the forward rotating field. However, the sum of the two fields remains constant since it must induce the stator counter emf which is approximately constant if the stator leakage impedance drop is negligible. Hence, with the rotor in motion the torque of the forward field is greater and that of the backward field is less than what is shown in Fig. 3.3. The true situation being as is shown in Fig. 3.4.

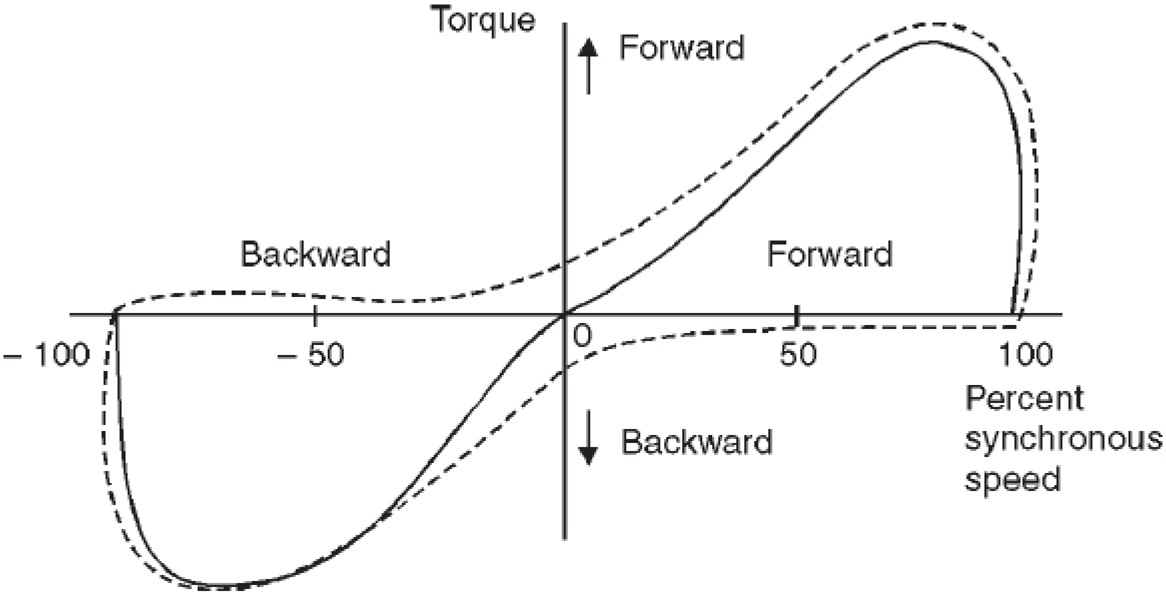

Fig. 3.4. Torque-speed characteristic of a 1-phase induction motor taking into account changes in the flux waves

In the normal running region at a few per cent slip the forward field is several times stronger than the backward field and the flux wave does not differ materially from the constant amplitude revolving field in the air gap of a balanced poly phase motor. Therefore, in the normal running range of the motor, the torque-speed characteristic of a single phase motor is not very much different from that of a poly phase motor having the same rotor and operating with the same maximum air gap flux density.

In addition to the torque shown in Fig.3.4, double-stator frequency torque pulsation are produced by the interaction of the oppositely rotating flux and mmf waves which move past each other at twice the synchronous speed. These double frequency torques produce no average torque as these pulsations are sinusoidal and over the complete cycle the average torque is zero. However, sometimes these are additive to the main torque and for another half a cycle these are subtractive and therefore a variable torque acts on the shaft of the motor which makes the motor noisier as compared to a poly phase induction motor where the total torque is constant. Such torque pulsations are unavoidable in single phase circuits. Mathematically

$$T \propto I^2 \tag{1}$$

$$\text{Let } I = I_m \sin \omega t$$

$$T = K\, I_m{}^2 \sin^2 \omega t \tag{2}$$

So the expression for torque contains a constant term superimposed over by a pulsating torque with pulsation frequency twice the supply frequency.

Types of Single Phase Induction Motors:

The single phase induction motors are classified based on the method of starting method and in fact are known by the same name descriptive of the method. Appropriate selection of these motors depends upon the starting and running torque requirements of the load, the duty cycle and limitations on starting and running current drawn from the supply by these motors. The cost of single phase induction motor increases with the size of the motor and with the performance such as starting torque to current ratio (higher ratio is desirable), hence, the user will like to go in for a smaller size (hp) motor with minimum cost, of course, meeting all the operational requirements. However, if a very large no. of fractional horsepower motors are required, a specific design can always be worked out which might give minimum cost for a given performance requirements. Following are the starting methods.

(i) Split-phase induction motor:

The stator of a split phase induction motor has two windings, the main winding and the auxiliary winding. These windings are displaced in space by 90 electrical degrees as shown in Fig. 3.5 (a). The auxiliary winding is made of thin wire (super enamel copper wire) so that it has a high R/X ratio as compared to the main winding which has thick super enamel copper wire. Since the two windings are connected across the supply the current Im and Ia in the main winding and auxiliary winding lag behind the supply voltage V, Ia leading the current Im as shown in Fig. 3.5(b). This means the current through auxiliary winding reaches maximum value first and the mmf or flux due to Ia lies along the axis of the auxiliary winding and after some time the current Im reaches maximum value and the mmf or flux due to Im lies along the main winding axis. Thus the motor becomes a 2-phase unbalanced motor. It is unbalanced since the two currents are not exactly 90 degrees apart. Because of these two fields a starting torque is developed and the motor becomes a self-starting motor. After the motor starts, the auxiliary winding is disconnected usually by means of centrifugal switch that operates at about 75 per cent of synchronous speed. Finally the motor runs because of the main winding. Since this being single phase some level of humming noise is always associated with the motor during running. A typical torque speed characteristic is shown in Fig. 3.5 (c). It is to be noted that the direction of rotation of the motor can be reversed by reversing the connection to either the main winding or the auxiliary windings.

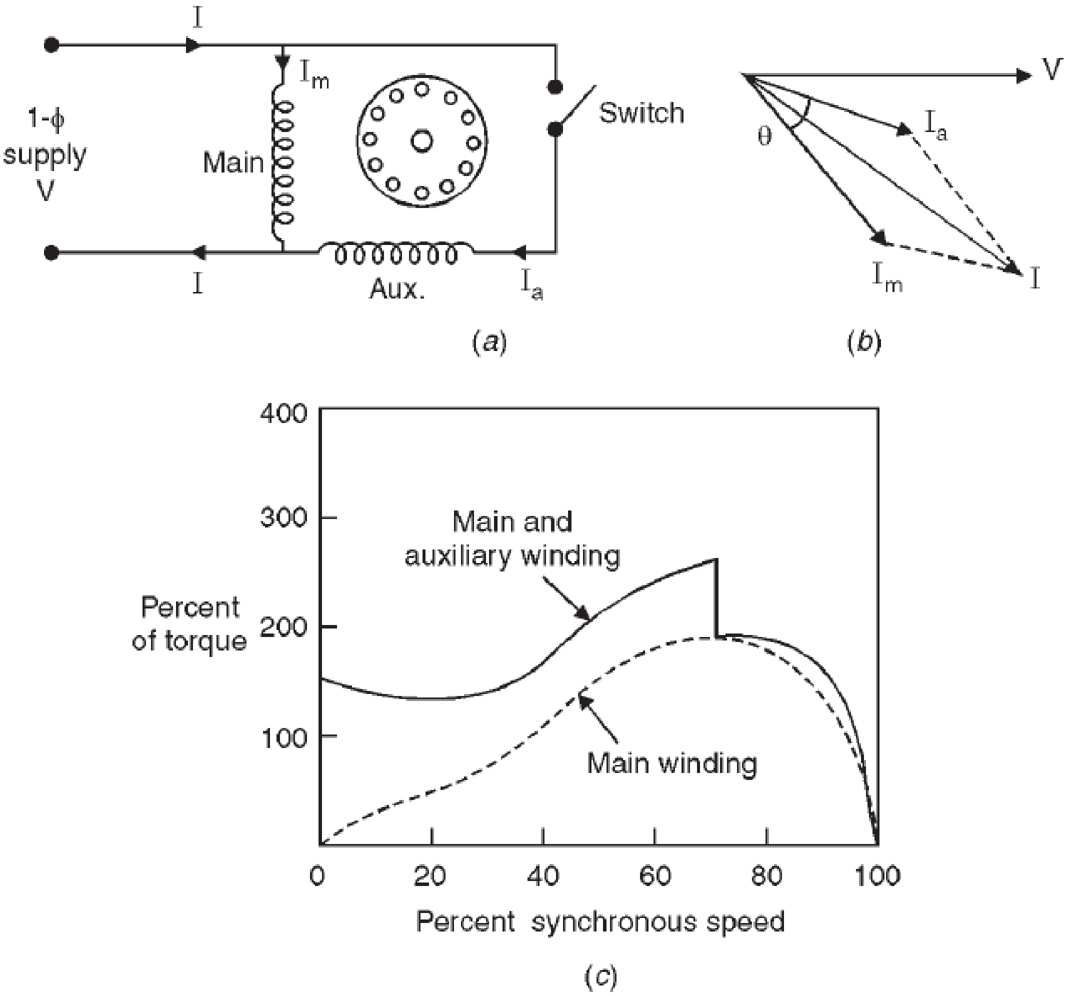

Fig. 3.5. Split phase induction motor (a) Connection (b) Phasor diagram at starting (c) Typical torque-speed characteristic.

(ii) Capacitor start induction motor:

Capacitors are used to improve the starting and running performance of the single phase inductions motors. The capacitor start induction motor is also a split phase motor. The capacitor of suitable value is connected in series with the auxiliary coil through a switch such that Ia the current in the auxiliary coil leads the current Im in the main coil by 90 electrical degrees in time phase so that the starting torque is maximum for certain values of Ia and Im. This becomes a balanced 2- phase motor if the magnitude of Ia and Im are equal and are displaced in time phase by 90° electrical degrees. Since the two windings are displaced in space by 90 electrical degrees as shown in Fig. 3.6 maximum torque is developed at start. However, the auxiliary winding and capacitor are disconnected after the motor has picked up 75 per cent of the synchronous speed. The motor will start without any humming noise. However, after the auxiliary winding is disconnected, there will be some humming noise.

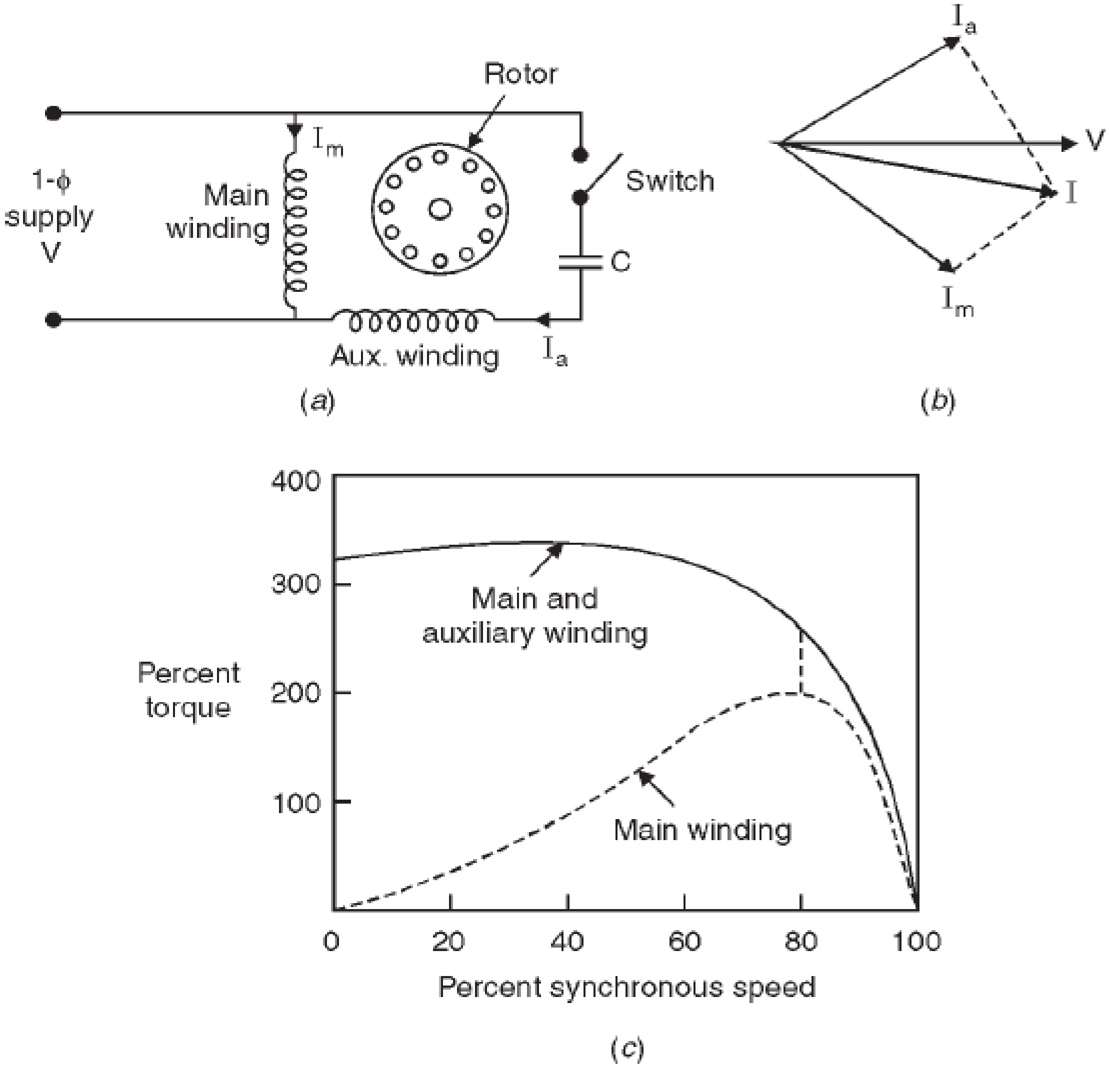

Fig. 3.6 Capacitor start motor (a) Connection (b) Phasor diagram at start (c) Speed torque curve

Since the auxiliary winding and capacitor are to be used intermittently, these can be designed for minimum cost. However, it is found that the best compromise among the factors of starting torque, starting current and costs results with a phase angle somewhat less than 90° between Im and Ia. A typical torque-speed characteristic is shown in Fig. 3.6.(c) high starting torque being an outstanding feature.

(iii) Permanent-split capacitor motor:

In this motor the auxiliary winding and capacitor are not disconnected from the motor after starting, thus the construction is simplified by the omission of the switch as shown in Fig. 3.7(a).

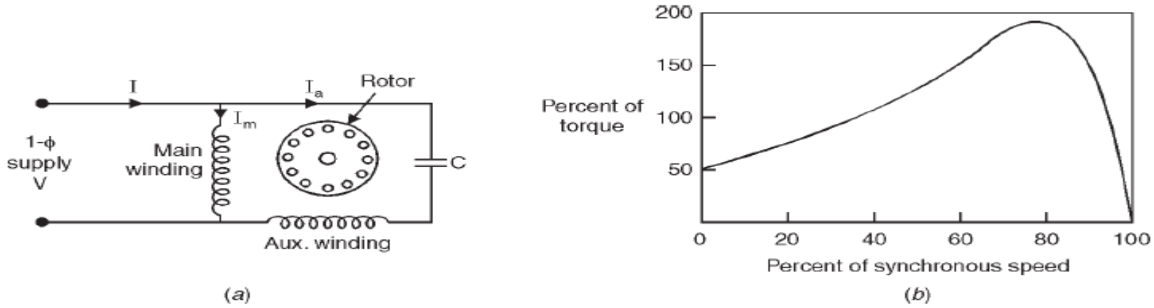

Fig. 3.7 Permanent split capacitor motor (a) Connection (b) Torque-speed characteristic

Here the auxiliary winding and capacitor could be so designed that the motor works as a perfect 2-phase motor at any one desired load. With this the backward rotating magnetic field would be completely eliminated. The double stator frequency torque pulsations would also be eliminated; thereby the motor starts and runs as a noise free motor. With this there is improvement in p.f. and efficiency of the motor. However, the starting torque must be sacrificed as the capacitance is necessarily a compromise between the best starting and running characteristics. The torque-speed characteristic of the motor is shown in Fig. 3.7(b).

(iv) Capacitor start capacitor run motor:

If two capacitors are used with the auxiliary winding as shown in Fig. 3.8(a), one for starting and other during the start and run, theoretically optimum starting and running performance can both be achieved.

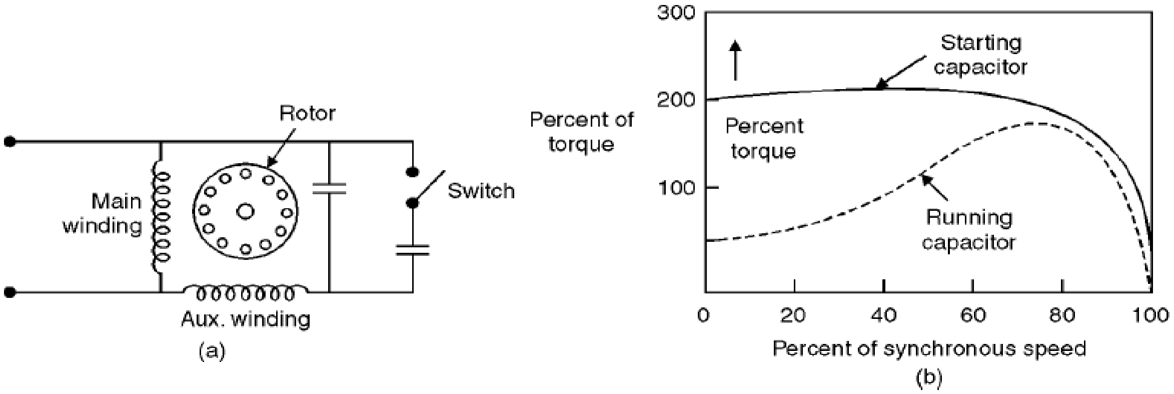

Fig. 3.8 (a) Capacitor start capacitor run motor (b) Torque-speed characteristic

The small value capacitor required for optimum running conditions is permanently connected in series with the auxiliary winding and the much larger value required for starting is obtained by a capacitor connected in parallel with the running capacitor. The starting capacitor is disconnected after the motor starts.

The value of capacitor for a capacitor start motor is about $300\mu F$ for 1 H.P motor. Since this capacitor must carry current for a short starting period, the capacitor is a special compact ac electrolytic type made for motor starting duty. However, the capacitor permanently connected has a typical rating of 40 μF; since it is connected permanently, the capacitor is an ac paper, foil and oil type. The cost of the motor is related to the performance; the permanent capacitor motor is the lowest cost, the capacitor start motor next and the capacitor start capacitor run has the highest cost.

Applications:

The split phase induction motors are used for fans, blowers, centrifugal pumps and office equipments. Typical ratings are $\frac{1}{20}$ to $\frac{1}{2}$ hp; in this range they are the lowest cost motors available. The capacitor start motors are used for compressors, pumps, refrigeration and air-conditioning equipments and other hard to start-loads.

The capacitor start capacitor run motors are manufactured in a number of sizes from $\frac{1}{8}$ to $\frac{3}{4}$ hp and are used in compressors, conveyors, pumps and other high torque loads. The permanent split capacitor motors are manufactured in the range of $\frac{1}{20}$ hp to $\frac{3}{4}$ hp and are used for direct connected fans, blowers, centrifugal pumps and loads requiring low starting torque.

The shaded pole motors are used in toys, hair driers, desk fans etc.