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UNIT-1

SINGLE-PHASE INDUCTION MOTORS

1.1 INTRODUCTION:

There are two basic reasons for the use of single-phase motors rather than 3-phase motors.

1. For reason of economy, most houses, offices and also rural areas are supplied with single phase a.c, as power requirements of individual load items are rather small.
2. The economics of the motor and its branch circuit.
   - Fixed loads requiring not more than 0.5KW can generally be served most economically with single phase power and a single phase motor.
   - Single phase motors are simple in construction, reliable, easy to repair and comparatively cheaper in cost and therefore, find wide use in fans, refrigerators, vacuum cleaners, washing machines, other kitchen equipment, tools, blowers, centrifugal pumps, small farming appliances etc.

Because of above reasons motors of comparatively small ratings (mostly in fractional KW ratings) are manufactured in large number to operate on single phase ac at standard frequencies. An indication of the number of such motors can be had from the fact that the sum of total of all fractional kilowatt motors in use today far exceeds the total of integral kilowatt motors of all types.

1.2 TYPES OF SINGLE-PHASE MOTOR:

The Single phase motors may be of the following types:

1. **Single-phase Induction Motors:**
   A. Split-phase motors
      (i) Resistance-start motor
      (ii) Capacitor-start motor
      (iii) Permanent-split (single-value) capacitor motor
      (iv) Two-value capacitor motor.
   B. Shaded-pole induction motor.

C. Reluctance-start induction motor.
D. Repulsion-start induction motor.

2. **Commutator-Type, Single-Phase Motors:**
   A. Repulsion motor.
   B. Repulsion-induction motor.
   C. A.C series motor.
   D. Universal motor.
3. **Single-phase Synchronous Motors:**
   A. Reluctance motor.
   B. Hysteresis motor.
   C. Sub-synchronous motor.

1.3 SINGLE-PHASE INDUCTION MOTORS

Applications and Disadvantages:

1.31 Applications:

- Single phase induction motors are in very wide use in industry especially in fractional horse-power field.

  They are extensively used for electrical drive for low power constant speed apparatus such as machine tools, domestic apparatus and agricultural machinery in circumstances where a three-phase supply is not readily available.
- Single phase induction motors sizes vary from 1/400 kw to 1/25 kw are used in toys, hair dryers, vending machines etc.
- Universal motor is widely used in portable tools, vacuum cleaners& kitchen equipment.

1.32 Disadvantages:

Though these machines are useful for small outputs, they are not used for large powers as they suffer from many disadvantages and are never used in cases where three-phase machines can be adopted.

The main disadvantages of single-phase induction motors are:

1. Their output is only 50% of the three-phase motor, for a given frame size and temperature rise.

2. They have lower power factor.
3. Lower efficiency.
4. These motors do not have inherent starting torque.
5. More expensive than three-phase motors of the same output.
6. Low overload capacity.

1.4 CONSTRUCTION OF SINGLE PHASE INDUCTION MOTOR:

Single phase induction motor is very simple and robust in construction. The stator carries a distributed winding in the slots cut around the inner periphery. The stator conductors have low resistance and they are winding called Starting winding is also mounted on the stator. This winding has high resistance and its embedded deep inside the stator slots, so that they have considerable inductance. The rotor is invariably of the squirrel cage type. In practice, in order to convert temporarily the single phase motor into two-phase motor, auxiliary conductors are placed in the upper layers of stator slots. The auxiliary winding has a centrifugal switch in series with it. The function of the switch is to cut off the starting winding, when the rotor has accelerated to about 75% of its rated speed. In capacitor-start motors, an electrolytic capacitor of suitable capacitance value is also incorporated in the starting winding circuit.

The main stator winding and auxiliary (or starting) winding are joined in parallel, and there is an arrangement by which the polarity of only the starting winding can be reversed. This is necessary for changing the direction of rotation of the rotor.

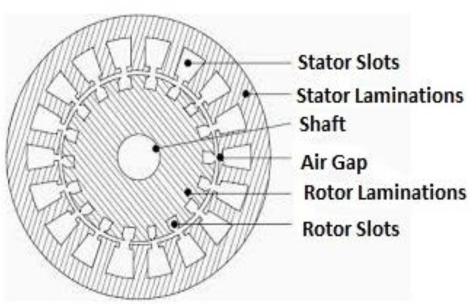


Fig: 1.41

A 1-phase induction motor is similar to a 3-phase squirrel cage induction motor in physical appearance. The rotor is same as that employed in 3-phase squirrel cage induction motor. There is uniform air gap between stator and rotor but no electrical connection between them.

Although single phase induction motor is more simple in construction and is cheaper than a 3-phase induction motor of the same frame size, it is less efficient and it operates at lower power factor.

1.5 WORKING OF SINGLE-PHASE INDUCTION MOTOR:

A single phase induction motor is inherently not self-staring can be shown easily.

Consider a single phase induction motor whose rotor is at rest. Let a single phase a.c. source be connected to the stator winding (it is assumed that there is no starting winding). Let the stator be wound for two poles.

When power supply for the stator is switched on, an alternating current flows through the stator winding. This sets up an alternating flux. This flux crosses the air gap and links with the rotor conductors. By electromagnetic induction e.m.f.'s are induced in the rotor conductors. Since the rotor forms a closed circuit, currents are induced in the rotor bars. Due to interaction between the rotor induced currents and the stator flux, a torque is produced. It is readily seen that if all rotor conductors in the upper half come under a stator N pole, all rotor conductors in the lower half come under a stator S pole. Hence the upper half of the rotor is subjected to a torque which tends to rotate it in one direction and the lower half of the rotor is acted upon by an equal torque which tends to rotate it in the opposite direction. The two equal and opposite torques cancel out, with the result that the net driving torque is zero. Hence the rotor remains stationary. Thus the single phase motor fails to develop starting torque.

This argument holds good irrespective of the number of stator poles and the polarity of the stator winding. The net torque acting on the rotor at standstill is zero.

If, however, the rotor is in motion in any direction when supply for the stator is switched on, it can be shown that the rotor develops more torque in that direction. The net torque then, would have non-zero value, and under its impact the rotor would speed up in its direction.

The analysis of the single phase motor can be made on the basis of two theories:

i. Double revolving field theory, and

ii. Cross field theory.

1.51 DOUBLE REVOLVING FIELD THEORY:

This theory makes use of the idea that an alternating uni-axial quantity can be represented by two oppositely-rotating vectors of half magnitude. Accordingly, an alternating sinusoidal flux can be represented by two revolving fluxes, each equal to half the value of the alternating flux and each rotating synchronously (N_s=$\frac{120\,f}{P}$) in opposite direction.

As shown in figure: (a) let the alternating flux have a maximum value of ϕ_m. Its component fluxes A and B will each equal to ϕ_m/2 revolving in anti-clockwise and clockwise directions respectively.

After some time, when A and B would have rotated through angle +Θ and – Θ, as in figure: (b), the resultant flux would be

$$= 2*\frac{\phi_m}{2}\cos\frac{2\theta}{2} = \phi_m \cos\theta$$

After a quarter cycle of rotation, fluxes A and B will be oppositely-directed as shown in figure: (c) so that the resultant flux would be zero.

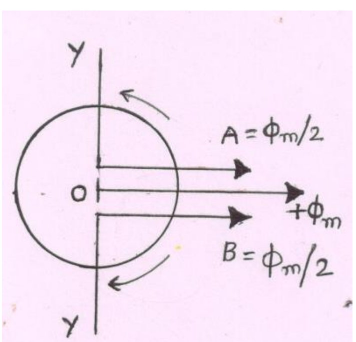


Fig: 1.51(a)

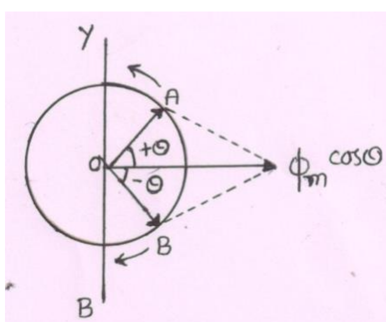


Fig: 1.51(b)

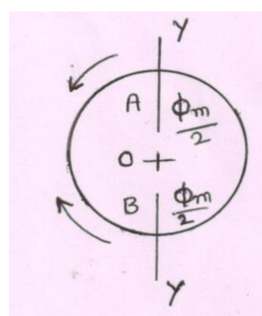
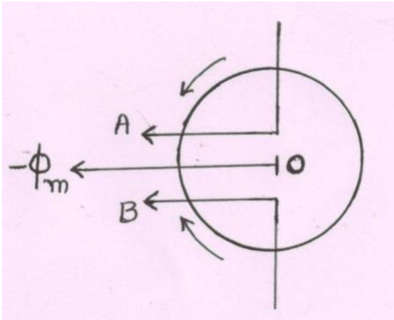


Fig:1.51 (c)



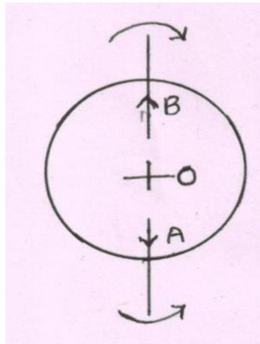


Fig: 1.51 (d) **Fig**: 1.51(e)

After half a cycle, fluxes A and B will have a resultant of -2*$\frac{\phi_m}{2} = -\phi_m$. After three quarters of a cycle, again the resultant is zero, as shown in figure: (e) and so on. If we plot the values of resultant flux against ϴ between limits ϴ=0^0 to ϴ=360^0, then a curve similar to the one shown in figure: (f) is obtained. That is why an alternating flux can be looked upon as

composed of two revolving fluxes, each of half the value and revolving synchronously in opposite directions.

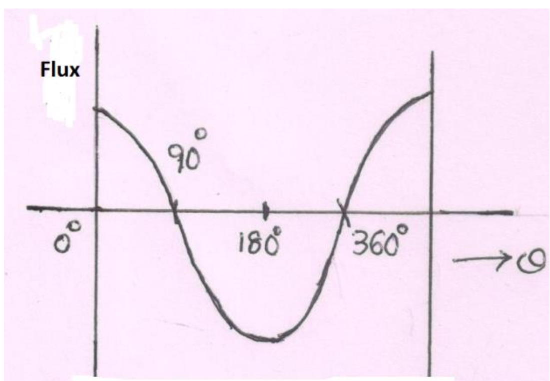


Fig: 1.51(f)

It may be noted that if the slip of the rotor is S with respect to the forward rotating flux (i.e. one which rotates in the same direction as rotor) then its slip with respect to the backward rotating flux is (2-S).

Each of the two component fluxes, while revolving round the stator, cuts the rotor, induces an e.m.f. and this produces its own torque. Obviously, the two torques (called forward and backward torques) are oppositely-directed, so that the net or resultant torques is equal to their difference as shown in fig: (g)

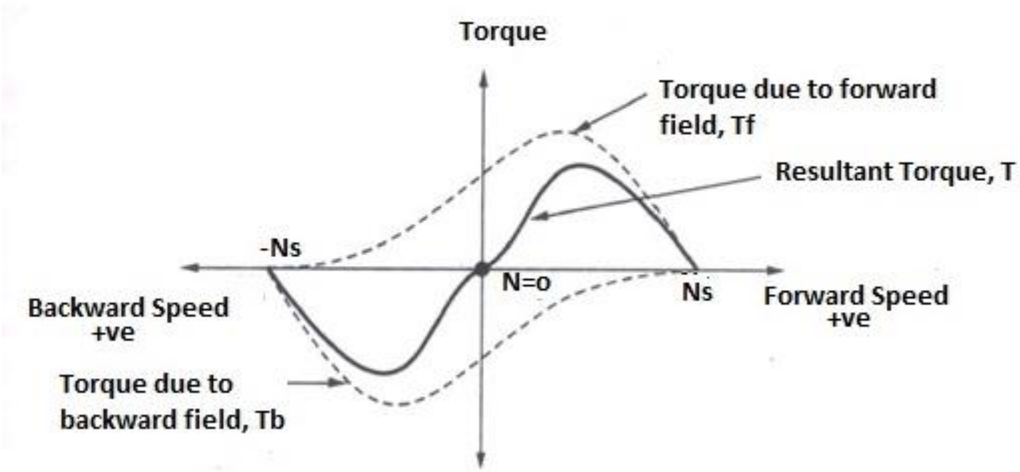


Fig: 1.51(g) Torque-Speed characteristics

Now, power developed by a rotor is $P_g = \left(\frac{1-S}{S}\right) I_2^2 R_2$

If N is the rotor r.p.s., then torque is given by , $T_g = \frac{1}{2\Pi N}\left(\frac{1-S}{S}\right) I_2^2 R_2$

Now, $N = N_s (1-S)$

Therefore, $T_g = \frac{1}{2\Pi N_s} \frac{I_2^2 R_2}{S} = k \frac{I_2^2 R_2}{S}$

Hence, the forward and backward torques are given by

$$T_f = k \frac{I_2^2 R_2}{S} \quad \text{and} \quad T_b = -k \frac{I_2^2 R_2}{(2-S)}$$

or $$T_f = \frac{I_2^2 R_2}{S} \text{ synch. Watt} \quad \text{and} \quad T_b = -\frac{I_2^2 R_2}{(2-S)} \text{ synch. Watt}$$

Total torque $\mathbf{T} = T_f + T_b$

Fig: (g) shows both torques and the resultant torque for slips between zero and +2. At standstill, S=1 and (2-S) =1. Hence, T_f and T_b are numerically equal but, being oppositely directed, produce no resultant torque. That explains why there is no starting torque in a single-phase induction motor.

However, if the rotor is started somehow, say, in the clockwise direction, the clockwise torque starts increasing and, at the same time, the anticlockwise torque starts decreasing. Hence, there is a certain amount of net torque in the clockwise direction which accelerates the motor to full speed.

1.6 EQUIVALENT CIRCUIT:

The equivalent circuit of a single phase induction motor can be developed on the basis of two revolving field theory. To develop the equivalent circuit it is necessary to consider standstill or blocked rotor conditions.

The motor with a blocked rotor merely acts like a transformer with its secondary short circuited and its equivalent circuit will be as shown in fig: 1.6 (a), E_m being e.m.f. induced in the stator.

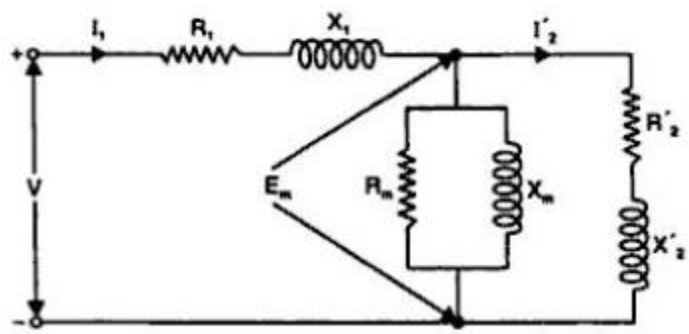


Fig:1.6 (a) Equivalent Circuit of a Single Phase Induction Motor

The motor may now be viewed from the point of view of the two revolving field theory. The two flux components induce e.m.f. E_{mf} and E_{mb} in the respective stator winding. Since at standstill the two oppositely rotating fields are of same strength, the magnetizing and rotor impedances are divided into two equals halves connected in series as shown in figure:1.6(b)

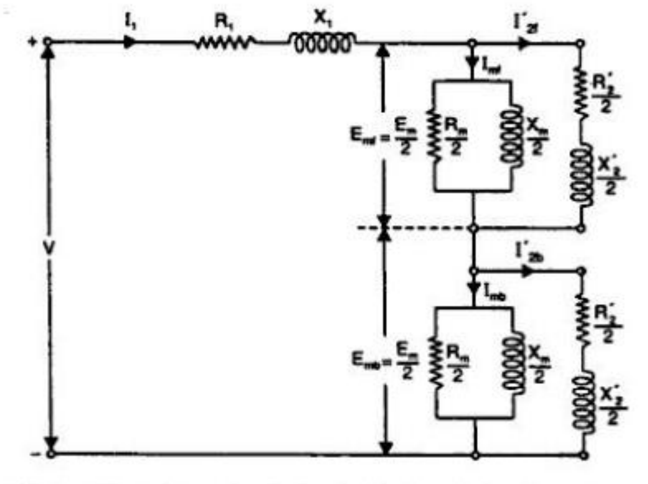


Fig:1.6 (b) Equivalent Circuit of Single Phase Induction Motor at Standstill on the basis of Two Revolving Field Theory

When the rotor runs at speed N with respect to forward field, the slip is S w.r.t. forward field and (2-S) w.r.t. backward field and the equivalent circuit is as shown in fig:1.6(c)

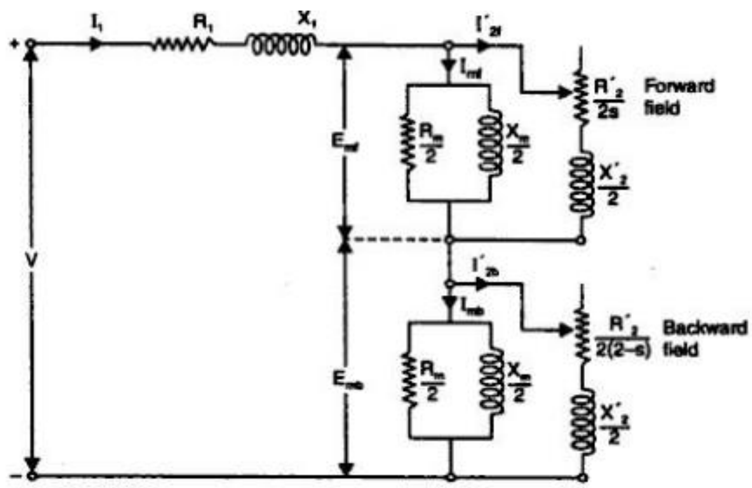


Fig:1.6 (c) Equivalent Circuit of a Single Phase Induction Motor Under Normal Operating Conditions

If the core losses are neglected the equivalent circuit is modified as shown in fig:1.6(d). The core losses, here, are handled as rotational losses and subtracted from the power converted into mechanical power; the amount of error thus introduced is relatively small.

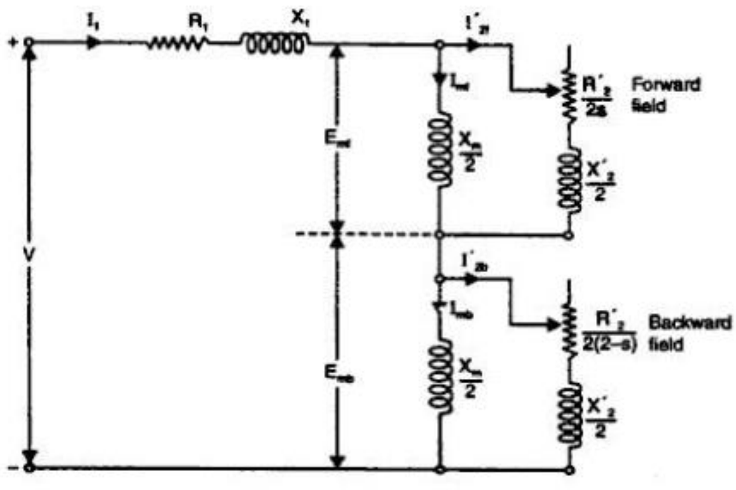


Fig:1.6 (d) Approximate Equivalent Circuit of a Single Phase Induction Motor Under Normal Operating Conditions

1.7 STARTING METHODS OF SINGLE-PHASE INDUCTION MOTORS:

A single-phase induction motor with main stator winding has no inherent starting torque, since main winding introduces only stationary, pulsating air-gap flux wave. For the development of starting torque, rotating air-gap field at starting must be introduced. Several methods which have been developed for the starting of single-phase induction motors, may be classified as follows:

a) Split-phase starting.
b) Shaded-pole starting.
c) Repulsion-motor starting and
d) Reluctance starting.

A single-phase induction motor is commonly known by the method employed for its starting. The selection of a suitable induction motor and choice of its starting method, depend upon the following:

(i) Torque-speed characteristic of load from standstill to the normal operating speed.
(ii) The duty cycle and
(iii)The starting and running line-current limitations as imposed by the supply authorities.

1.7 (a) SPLIT-PHASE STARTING:

Single-phase induction motors employing this method of starting are called Split-phase motors. All the split-phase motors have two stator windings, a main (or running) winding and an auxiliary (or starting) winding. Both these windings are connected in parallel but their magnetic axes are space displaced by 90^0 electrical.

It is known that when two windings spaced 90^0 apart on the stator, are excited by two alternating e.m.f. that are 90^0 displaced in time phase, a rotating magnetic field is produced. If two windings so placed are connected in parallel to a single phase source, the field produced will alternate but will not revolve since the two windings are equivalent to one single phase winding. If impedance is connected in series with one of these windings, the currents may be made to differ in time phase, thereby producing a rotating field. This is the principle of phase splitting. Split phase motors are of following types.

1. Resistor-split phase motors
2. Capacitor split-phase motors
3. Capacitor start and run motors
4. Capacitor-run motors

1.71 RESISTOR SPLIT-PHASE MOTORS:

The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main or running winding M. The starting winding is located 90° electrical from the main winding [See figure: 1.71(a)] and operates only during the brief period when the motor starts up. The two windings are so designed that the starting winding S has a high resistance and relatively small reactance while the main winding M has relatively low resistance and large reactance as shown in the schematic connections in figure: 1.71(b). Consequently, the currents flowing in the two windings have reasonable phase difference (25° to 30°) as shown in the phasor diagram in figure: 1.71(c).

Operation

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

(ii) Since main winding is made highly inductive while the starting winding highly resistive, the currents I_m and I_s have a reasonable phase angle a (25° to 30°) between them as shown in figure: 1.71(c).Consequently, a weak revolving field approximating to that of a 2-phase machine is produced which starts the motor. The starting torque is given by;

$$Ts = k\, I_m\, I_s \sin\phi$$

Where k is a constant whose magnitude depends upon the design of the motor .

When the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed of the motor is below the synchronous speed and depends upon the load on the motor.

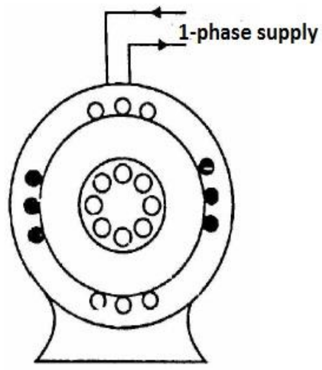
Characteristics:

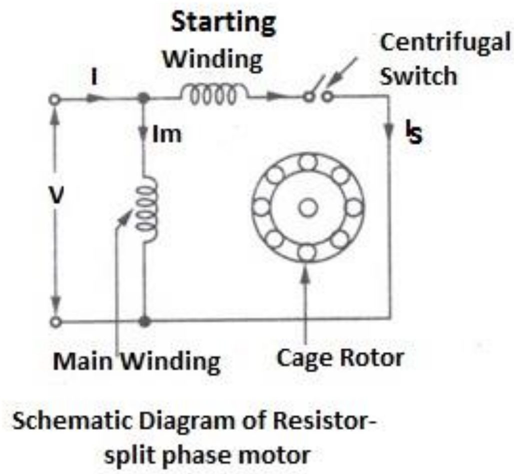
(i) The sinning torque is 15 to 2 times the full-loud torque mid (starting current is 6 to 8 times the full-load current.

(ii) Due to their low cost, split-phase induction motors are most popular single phase motors in the market.

(iii) Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built-in-thermal relay. This motor is, therefore, suitable where starting periods are not frequent.

An important characteristic of these motors is that they are essentially constant-speed motors. The speed variation is 2-5% from no-load to full-load





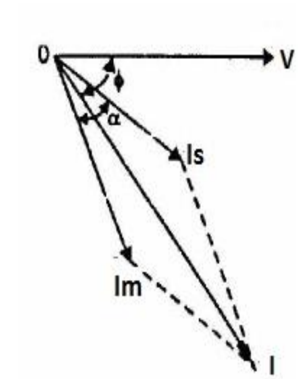
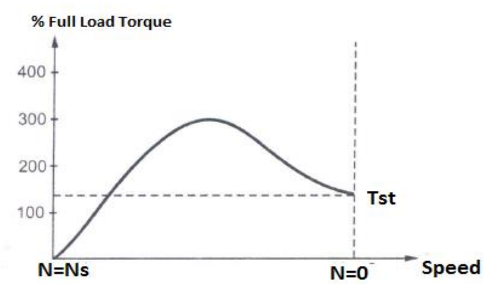


Fig: 1.71(a) **Fig:** 1.71(b) **Fig:** 1.71(c)



Applications:

These motors are suitable where a moderate starting torque is required and where starting periods are infrequent e.g., to drive:

a. Fans
b. washing machines
c. oil burners
d. Small machine tools etc.

The power rating of such motors generally lies between 60 W and 250 W .

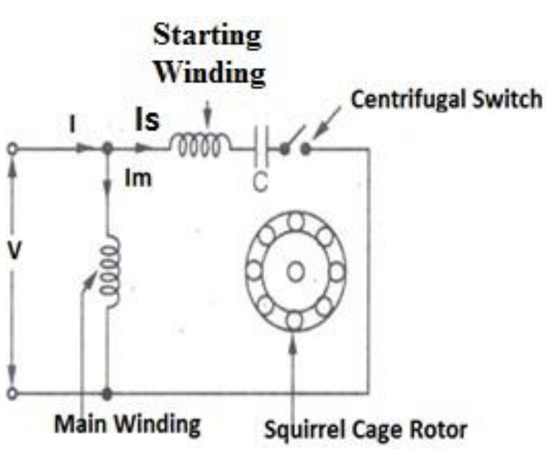
1.72 Capacitor split-phase motors (or) Capacitor start motors:

The capacitor split-phase motor is identical to a resistor split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a capacitor C is connected in series with the starting winding as shown in figure: 1.72(a).The value of capacitor is so chosen that I_s leads I_m by about 80° (i.e., $\phi \sim 80°$) which is considerably greater than 25° found in resistor split-phase motor [See figure: 1.72(b).Consequently, starting torque ($T_s = k\, I_m\, I_s \sin\phi$) 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 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

Characteristics

(i) Although starting characteristics of a capacitor-start motor are better than those of a resistor 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 resistor split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a resistor 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.



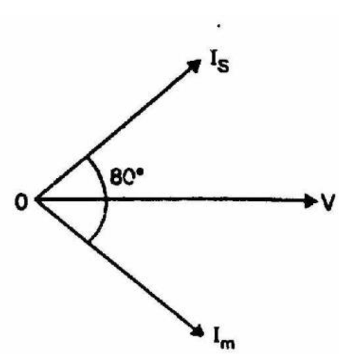


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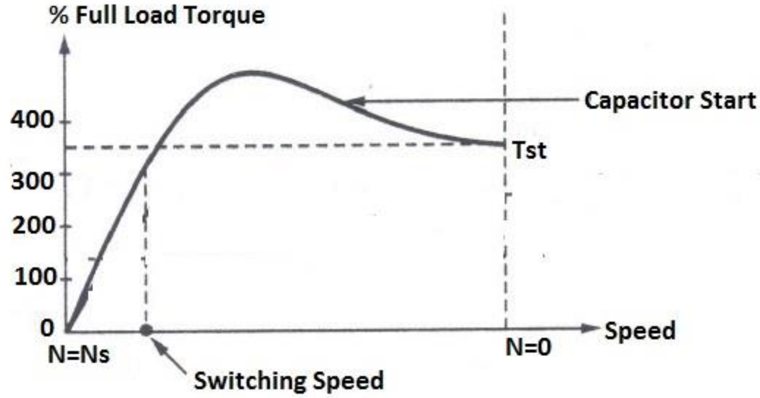
Fig: 1.72(a) **Fig**: 1.72(b)



Applications:

Since the motors possess high-starting torque, these motors are used for

a. Refrigerators
b. Air-conditioners
c. Compressors
d. Reciprocating pumps
e. Other loads requiring high-starting torques.

The power rating of such motors lies between 120 W and 750W.

1.73 Capacitor-Start and Capacitor-Run 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.

(i) In one design, a single capacitor C is used for both starting and running as shown in fig: 1.73(a).This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.

(ii) In the other design, two capacitors C1 and C2 are used in the starting winding as shown in fig: 1.73(b).. 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 C1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.

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.

Applications:

a. Hospitals
b. Studios and
c. Other places where silence is important.

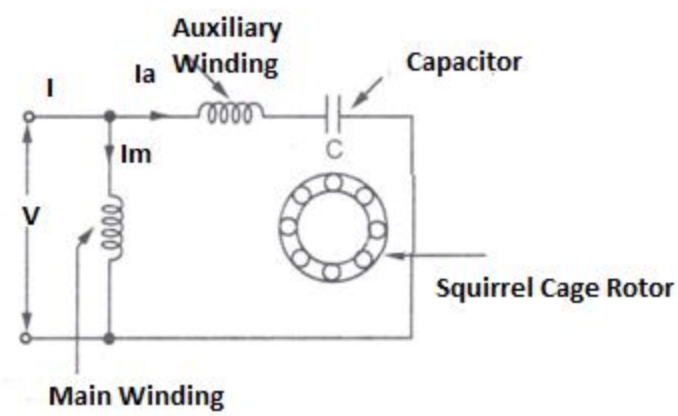


Fig: 1.73(a)

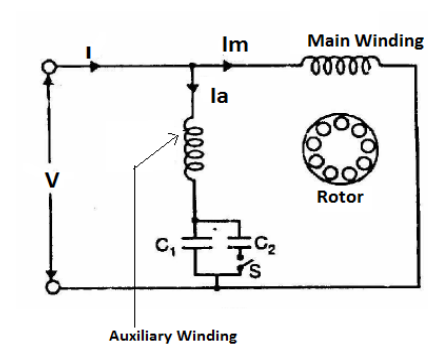
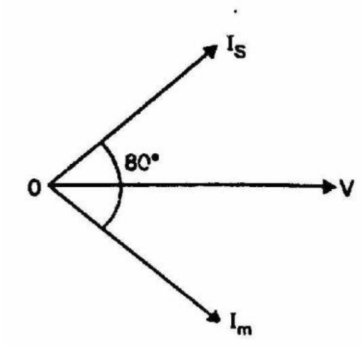


Fig: 1.73 (b)



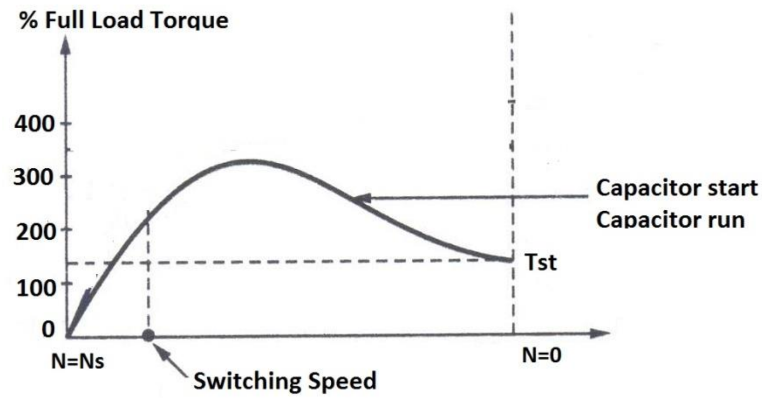


Fig: 1.73 (c) **Fig:** 1.73 (d)

The power rating of such motors lies between 100 to 400 watts

1.74 Capacitor-run motors:

This motor is also called permanent split capacitor motor. The same capacitor is kept permanently in series with auxiliary winding both at starting and under running conditions as illustrated in figure: 1.74 (a). There is no centrifugal switch. At a particular desired load, the capacitor and auxiliary winding can be so designed as to result in 90^0 time-phase displacement between the two winding currents. In such a case, the motor would operate as a balanced two phase induction motor, backward rotating flux would, therefore, be absent and the motor would have improved efficiency and better operating power factor. Since backward rotating field can be reduced to zero, the pulsating torque due to interaction between forward and backward rotating fields is absent and this results in a quiet motor.

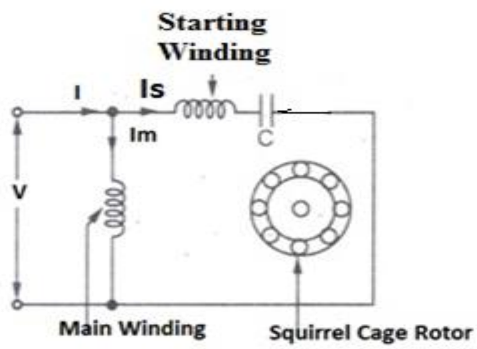


Fig: 1.74 (a)

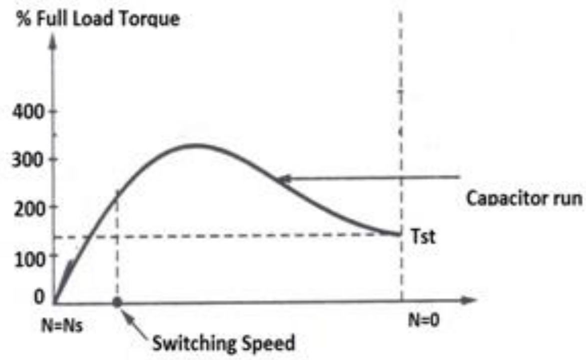


Fig: 1.74 (b)

In these motors, the value of permanent capacitor is so chosen as to obtain a compromise between the best starting and running conditions. A typical torque-speed characteristic is shown in fig: 1.74 (b)

These motors are used where quiet operation is essential as in

a. Offices
b. Class rooms
c. Theaters
d. Ceiling fans, in which the value of capacitance varies from 2 to 3µF.

1.8 Shaded-Pole Motor:

The shaded-pole motor is very popular for ratings below 0.05 H.P. (~40 W) because of its extremely simple construction. It has salient poles on the stator excited by single-phase supply and a squirrel cage rotor as shown in figure: 1.8(a). A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil.

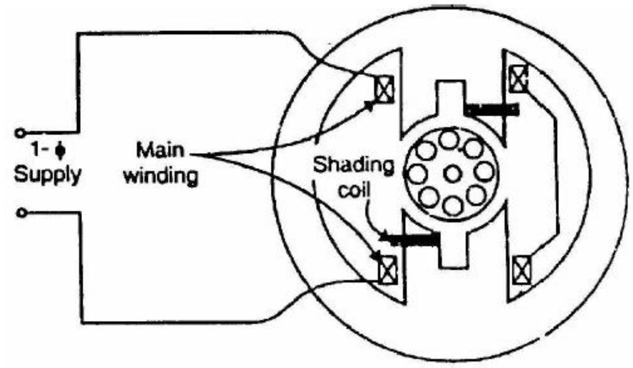


Fig: 1.8(a)

The operation of the motor can be understood by referring to figure: 1.8(b) which shows one pole of the motor with a shading coil.

(i) During the portion OA of the alternating-current cycle [See figure: 1.8(b)(i)], the flux begins to increase and an e.m.f. is induced in the shading coil. The resulting current in the shading coil will be in such a direction (Lenz's law) 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: 1.8(b)(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: 1.8(b)(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: 1.8(b)(iv)

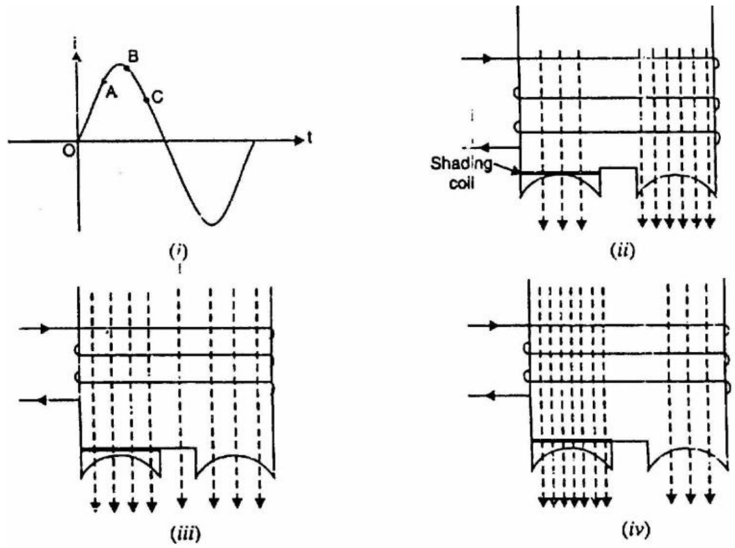


Fig: 1.8(b)

(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.

Characteristics

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

(ii) Starting torque, efficiency and power factor are very low

Applications:

These motors are only suitable for low power applications e.g., to drive:

a. small fans
b. Toys
c. Hair driers
d. Desk fans etc.

The power rating of such motors is upto about 30 W.

1.9 A.C. SERIES MOTOR (or) UNIVERSAL MOTOR:

A d.c. series motor will rotate in the same direction regardless of the polarity of the supply. One can expect that a d.c. series motor would also operate on a single-phase supply. It is then called an a.c. series motor. However, some changes must be made in a d.c. motor that is to operate satisfactorily on a.c. supply. The changes effected are:

(i) The entire magnetic circuit is laminated in order to reduce the eddy current loss. Hence an a.c. series motor requires a more expensive construction than a d.c. series motor.

(ii) The series field winding uses as few turns as possible to reduce the reactance of the field winding to a minimum. This reduces the voltage drop across the field winding.

(iii) A high field flux is obtained by using a low-reluctance magnetic circuit.

(iv) There is considerable sparking between the brushes and the commutator when the motor is used on a.c. supply. It is because the alternating flux establishes high currents in the coils short-circuited by the brushes. When the short-circuited coils break contact from the commutator, excessive sparking is produced. This can be eliminated by using high-resistance leads to connect the coils to the commutator segments.

Construction:

The construction of an a.c. series motor is very similar to a d.c. series motor except that above modifications are incorporated [See figure:1.91]. such a motor can be operated either on a.c. or d.c. supply and the resulting torque-speed curve is about the same in each case. For this reason, it is sometimes called a universal motor.

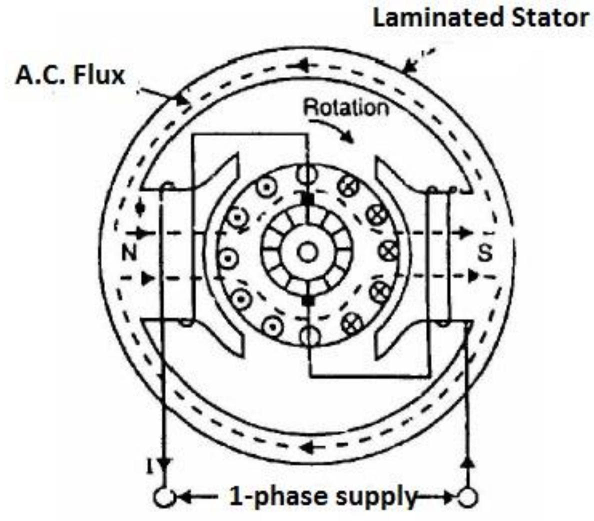


Fig: 1.91

Operation

When the motor is connected to an a.c. supply, the same alternating current flows through the field and armature windings. The field winding produces an alternating flux □ that reacts with the current flowing in the armature to produce a torque. Since both armature current and flux reverse simultaneously, the torque always acts in the same direction. It may be noted that no rotating flux is produced in this type of machines; the principle of operation is the same as that of a d.c. series motor.

Characteristics

The operating characteristics of an a.c. series motor are similar to those of a d.c. series motor.

(i) The speed increases to a high value with a decrease in load. In very small series motors, the losses are usually large enough at no load that limits the speed to a definite value (1500 - 15,000 r.p.m.).

(ii) The motor torque is high for large armature currents, thus giving a high starting torque.

(iii) At full-load, the power factor is about 90%. However, at starting or when carrying an overload, the power factor is lower.

Applications

The fractional horsepower a.c. series motors have high-speed (and corresponding small size) and large starting torque. They can, therefore, be used to drive:

a) high-speed vacuum cleaners

b) sewing machines
c) electric shavers
d) drills
e) Machine tools etc.