CHAPTER 1

AC Commutator Motors

1.1 INTRODUCTION

AC commutator motors, like comparable DC motors, have higher starting torque and higher speed than AC induction motors. The series motor operates well above the synchronous speed of a conventional AC motor. AC commutator motors may be either single-phase or poly-phase. Since a commutator motor can operate at much higher speed than an induction motor, it can output more power than a similar size induction motor. However commutator motors are not as maintenance free as induction motors, due to brush and commutator wear. **The more common commutator motors are the series motors, universal motors, repulsion motors and the repulsion-induction motors, with various modifications and combinations**.

1.2 AC Series Motors

Direct current shunt or series motors rotate in the same direction regardless of the polarity of the supply. Thus, it might be expected that either motor would operate on alternating current. It has been found, however, that the shunt motor develops but little torque when it is connected to an ac supply. The reason of it is that the field winding, owing to its high inductance, causes the field current to lag the armature currents being the same, the main field and armature currents are in phase, therefore, theoretically same torque is developed with a given alternating currents as with a like amount of direct current in a series motor. If an ordinary dc series motor were connected to an ac supply, it would operate, but not very satisfactorily. The reasons are (i) pulsating torque due to reversal of armature and field current every half cycle, (ii) excessive eddy current losses in the field and yoke due to alternations in the field flux, (iii) heavy sparking due to induced voltages and currents in the armature coils short-circuited by the brushes when undergoing commutation and (iv) abnormal voltage drop and low power factor due to inductance of field winding. Hence some modifications are necessary for satisfactory operation on ac. These modifications are

1. 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.
2. 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.
3. A high field flux is obtained by using a low-reluctance magnetic circuit.

4. 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.
5. The operating voltage should be made low for reducing the inductance. A large number of turns will be required for high voltage motors with proportionally low current.
6. In some special cases AC series motors are designed at Low frequency. This automatically reduces inductive reactance. In case of traction motors this procedure is adopted.

The single phase ac series motor has practically the same operating characteristics as dc series motors. The torque or tractive effort varies nearly as the square of the current and the speed varies inversely as the current nearly. The inductively compensated ac series motor also operates satisfactorily on dc system and has increased output and efficiency. The speed of the motor while working on ac system can be controlled efficiently by taps on a transformer. The most important application of ac series motor is in electric traction service up to 1600 kW, 200 to 600 volts using 15-25 Hz.

1.2.1 CONSTRUCTION

The construction of en a.c. series motor is very similar to a D.C. series motor except that above modifications are incorporated [See Fig. (1.1)].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.

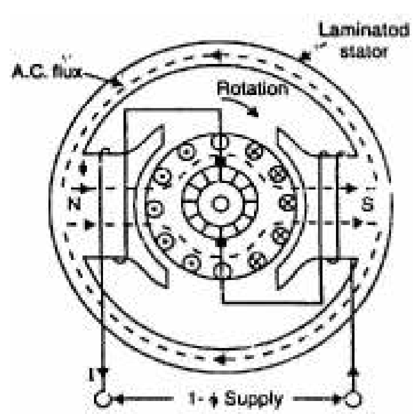


Fig 1.1 AC Series Motor

1.2.2 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

ϕ 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.

1.2.3 CHARACTERISTICS

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

1. 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.).
2. The motor torque is high for large armature currents, thus giving a high starting torque.
3. At full-load, the power factor is about 90%. However, at starting or when carrying an overload, the power factor is lower.

1.2.4 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

1.2.5 Equivalent Circuit

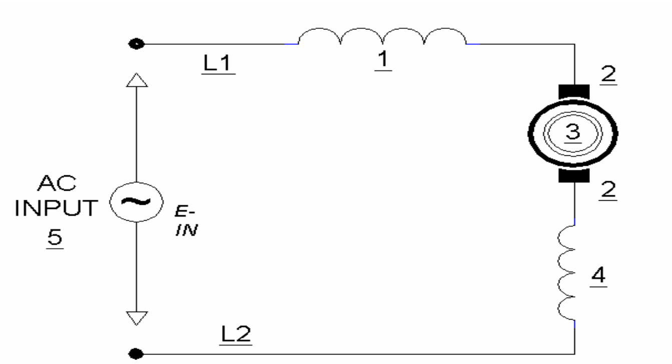
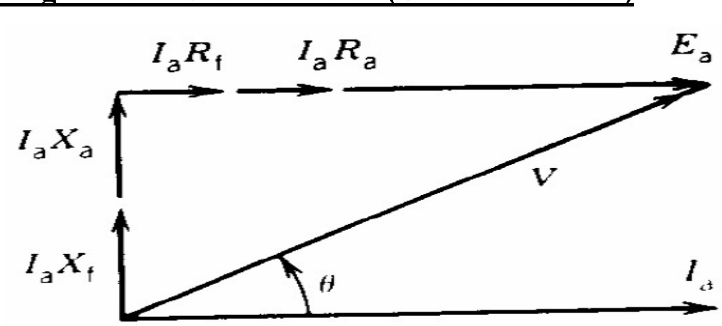
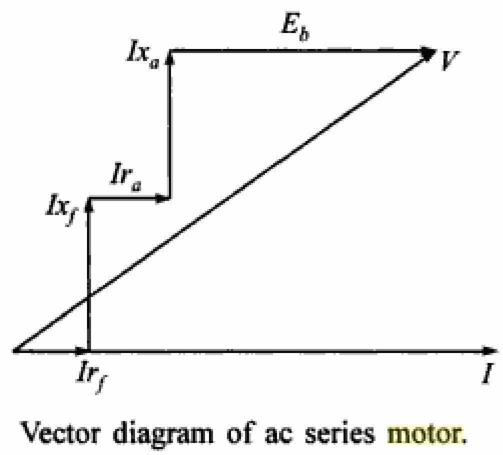


Figure 1.2 Equivalent Circuit Model of AC series motor

1.2.6 Phasor Diagram of AC series motor (Universal Motor)





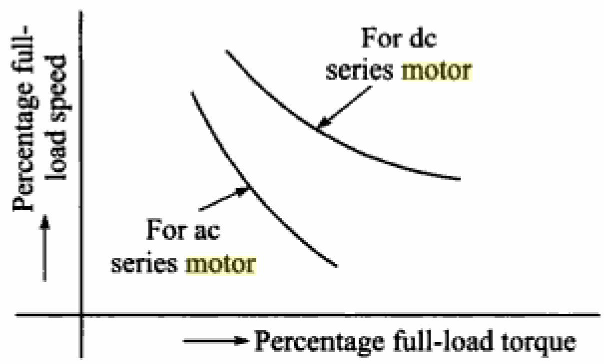


Figure 1.3 Phasor Diagram and speed Torque Characteristics of AC series motor

<u>1.2.7 Compensation winding and interpole winding Arrangements in AC series Motors</u>

In case of a single phase AC series motor, two emfs are induced in the armature conductors

- ✓ Rotating emf
- ✓ Transformer emf

Due to this reasons, the short circuited coils across the brushes may experience both the above emfs according to the position of the brushes. Thus the outcome appears as excessive sparking at the brushes and poor power factor of the motor. So, compensating winding to reduce this increased armature reaction is a must in the case of ac series motors.

Figure 1.4 and 1.5 describe the two types of compensated ac series motors. These are as follows

- ✓ Conductively compensated AC series motor
- ✓ Inductively compensated AC series motor

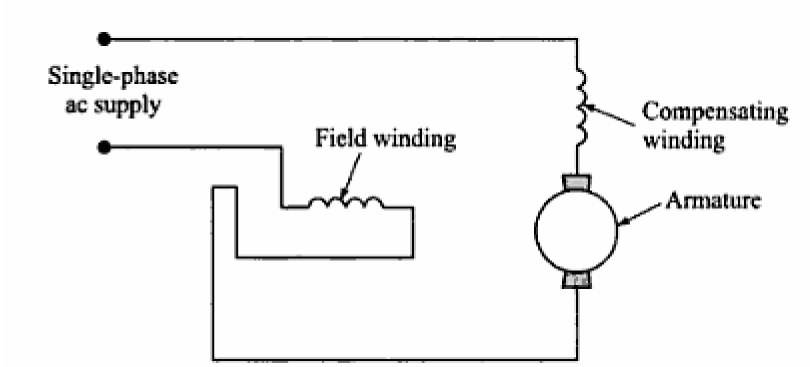


Figure 1.4, conductively compensated AC series motor

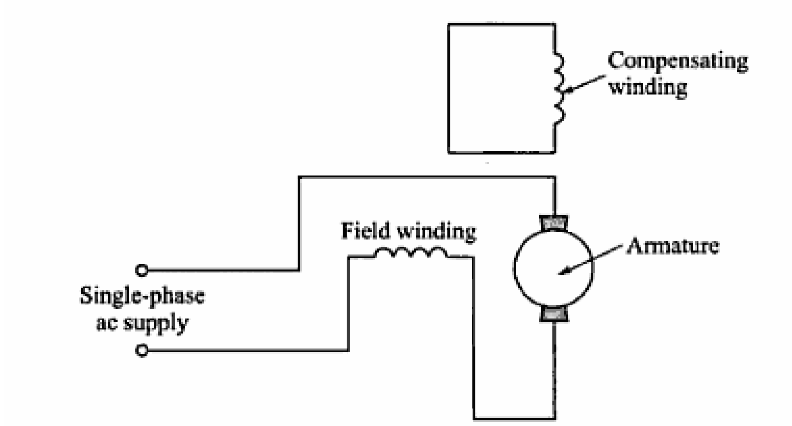


Figure 1.5, inductively compensated AC series motor

The performances of both the conductive and inductive compensations are similar. In case of conductive compensation the same current flows through the compensating winding and the armature winding. But in case of inductive compensation, the current developed in the compensating winding is totally by the method of induction. So, if properly designed and constructed, the same performance characteristics can be obtained both for conductively compensated and inductively compensated AC series motors.

To reduce sparking at the brushes on account of the transformer emf, high resistance leads to reduce circulating currents can be connected between the armature coils and the commutator segments. But the main problem arises due to the high resistive drop caused by the main armature current. That is why, with the compensating winding, the interpole motors are widely used in sewing machines, table fans, vacuum cleaners, portable drills, hair dryers and several kitchen appliances

1.3 SINGLE-PHASE REPULSION MOTOR

A repulsion motor is similar to an a.c. series motor except that:

1. Brushes are not connected to supply but are short-circuited [See Fig. (1.6)]. consequently, currents are induced in the armature conductors by transformer action.
2. The field structure has non-salient pole construction.

By adjusting the position of short-circuited brushes on the commutator, the starting torque can be developed in the motor.

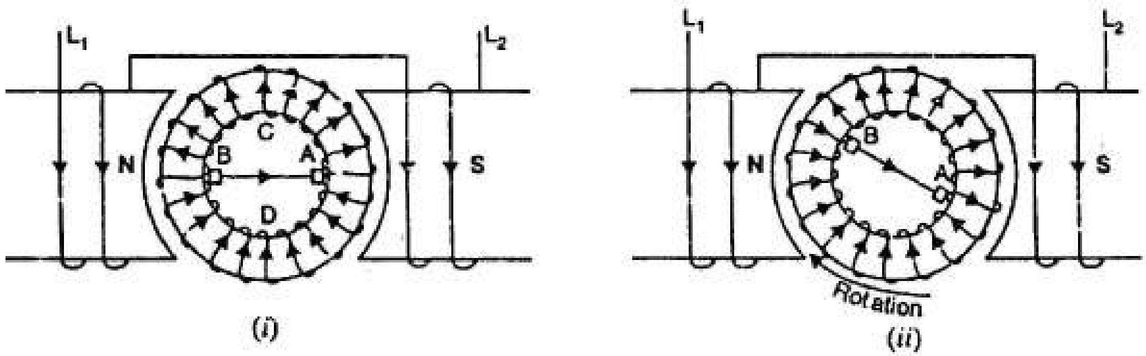


Fig 1.6 Repulsion Motors

1.3.1 CONSTRUCTION

The field of stator winding is wound like the main winding of a split-phase motor and is connected directly to a single-phase source. The armature or rotor is similar to a D.C. motor armature with drum type winding connected to a commutator (not shown in the figure). However, the brushes are not connected to supply but are connected to each other or short-circuited. Short-circuiting the brushes effectively makes the rotor into a type of squirrel cage. The major difficulty with an ordinary single-phase induction motor is the low starting torque. By using a commutator motor with brushes short-circuited, it is possible to vary the starting torque by changing the brush axis. It has also better power factor than the conventional single-phase motor.

1.3.2 PRINCIPLE OF OPERATION

The principle of operation is illustrated in Fig. (1.6) which shows a two-pole repulsion motor with its two short-circuited brushes. The two drawings of Fig. (1.6) represent a time at which the field current is increasing in the direction shown so that the left-hand pole is N-pole and the right-hand pole is S-pole at the instant shown.

1. In Fig. (1.2 (i)), the brush axis is parallel to the stator field. When the stator winding is energized from single-phase supply, e.m.f. is induced in the armature conductors (rotor) by induction. By Lenz's law, the direction of the e.m.f. is such that the magnetic effect of the resulting armature currents will oppose the increase in flux. The direction of current in armature conductors will be as shown in Fig. (1.6 (i)).With the brush axis in the position shown in Fig. (1.6 (i)), current will flow from brush B to brush A where it enters the armature and flows back to brush B through the two paths ACB and ADB. With brushes set in this position, half of the armature conductors under the N-pole carry current inward and half carry current outward. The same is true under S-pole. Therefore, as much torque is developed in

one direction as in the other and the armature remains stationary. The armature will also remain stationary if the brush axis is perpendicular to the stator field axis. It is because even then net torque is zero.

2. If the brush axis is at some angle other than 0° or 90° to the axis of the stator field, a net torque is developed on the rotor and the rotor accelerates to its final speed. Fig. (1.2 (ii)) represents the motor at the same instant as that in Fig. (1.6 (i)) but the brushes have been shifted clockwise through some angle from the stator field axis. Now e.m.f. is still induced in the direction indicated in Fig. (1.6 (i)) and current flows through the two paths of the armature winding from brush A to brush B. However, because of the new brush positions, the greater part of the conductors under the N pole carry current in one direction while the greater part of conductors under S-pole carry current in the opposite direction. With brushes in the position shown in Fig. 1.6 (ii), torque is developed in the clockwise direction and the rotor quickly attains the final speed.

3. The direction of rotation of the rotor depends upon the direction in which the brushes are shifted. If the brushes are shifted in clockwise direction from the stator field axis, the net torque acts in the clockwise direction and the rotor accelerates in the clockwise direction. If the brushes are shifted in anti-clockwise direction as in Fig. (1.7). the armature current under the pole faces is reversed and the net torque is developed in the anti-clockwise direction. Thus a repulsion motor may be made to rotate in either direction depending upon the direction in which the brushes are shifted.

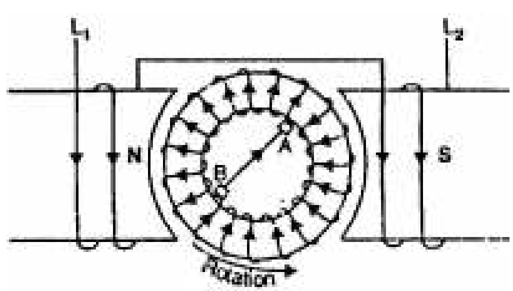


Fig 1.7

4. The total armature torque in a repulsion motor can be shown to be

$$T_a \; \alpha \; \sin\alpha$$

Where α = angle between brush axis and stator field axis for maximum torque, 2α = 90° or α = 45°

Thus adjusting α to 45° at starting, maximum torque can be obtained during the starting period. However, a has to be adjusted to give a suitable running speed.

1.3.3 CHARACTERISTICS

1. The repulsion motor has characteristics very similar to those of an a.c. series motor i.e., it has a high starting torque and a high speed at no load.
2. The speed which the repulsion motor develops for any given load will depend upon the position of the brushes.
3. In comparison with other single-phase motors, the repulsion motor has a high starring torque and relatively low starting current.

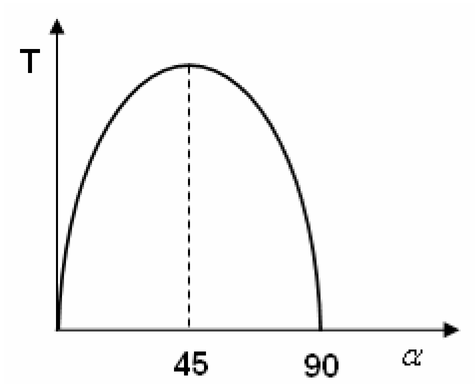


Fig 1.8 Torque Vs Brush Position Angle

1.3.4 Equivalent Circuit

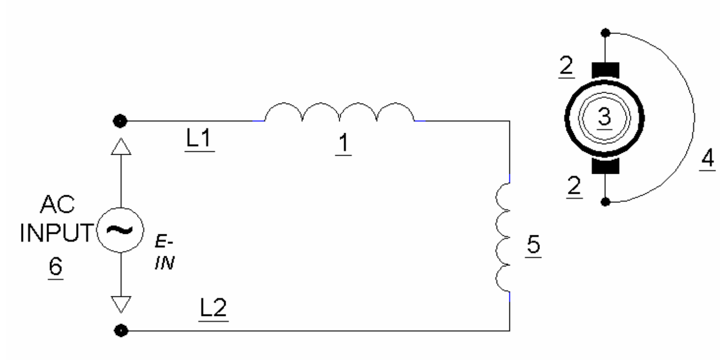


Figure 1.9 Equivalent Circuit Model of Repulsion motor

1.4 REPULSION-START INDUCTION-RUN MOTOR

Sometimes the action of a repulsion motor is combined with that of a single phase induction motor to produce repulsion-start induction-run motor (also called repulsion-start motor). The machine is started as a repulsion motor with a corresponding high starting torque. At some predetermined speed, a centrifugal device short-circuits the commutator so that the machine then operates as a single-phase induction motor.

The repulsion-start induction-run motor has the same general construction of a repulsion motor. The only difference is that in addition to the basic repulsion motor construction, it is equipped with a centrifugal device fitted on the armature shaft. When the motor reaches 75% of its full pinning speed, the centrifugal device forces a short-circuiting ring to come in contact with the inner surface of the commutator. This snortcircuit the entire commutator bars. The rotor then resembles squirrel-cage type and the motor runs as a single-phase induction motor. At the same time, the centrifugal device raises the brushes from the commutator which reduces the wear of the brushes and commutator as well as makes the operation quiet.

1.4.1 CHARACTERISTICS

1. The starting torque is 2.5 to 4.5 times the full-load torque and the starting current is 3.75 times the full-load value.
2. Due to their high starting torque, repulsion-motors were used to operate devices such as refrigerators, pumps, compressors etc.

However, they posed a serious problem of maintenance of brushes, commutator arid the centrifugal device. Consequently, manufacturers have stopped making them in view of the development of capacitor motors which are small in size, reliable and low-priced.

1.5 REPULSION-INDUCTION MOTOR

The repulsion-induction motor produces a high starting torque entirely due to repulsion motor action. When running, it functions through a combination of induction-motor and repulsion motor action.

1.5.1 CONSTRUCTION

Fig. (1.10) shows the connections of a 4-pole repulsion-induction motor for 230 V operations. It consists of a stator and a rotor (or armature).

1. The stator carries a single distributed winding fed from single-phase supply.
2. The rotor is provided with two independent windings placed one inside the other. The inner winding is a squirrel-cage winding with rotor bars permanently short-circuited. Placed over the squirrel cage winding is a repulsion commutator armature winding. The repulsion winding is connected to a commutator on which ride short-circuited brushes. There is no centrifugal device and the repulsion winding functions at all times.

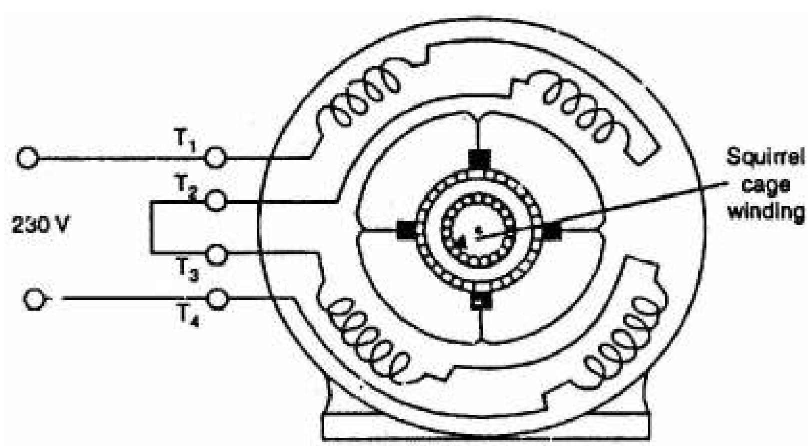


Fig 1.10 Repulsion induction motor

1.5.2 OPERATION

1. When single-phase supply is given to the stator winding, the repulsion winding (i.e., outer winding) is active. Consequently, the motor starts as a repulsion motor with a corresponding high starting torque.
2. As the motor speed increases, the current shifts from the outer to inner winding due to the decreasing impedance of the inner winding with increasing speed. Consequently, at running speed, the squirrel cage winding carries the greater part of rotor current. This shifting of repulsion motor action to induction-motor action is thus achieved without any switching arrangement.
3. It may be seen that the motor starts as a repulsion motor. When running, it functions through a combination of principle of induction and repulsion; the former being predominant.

1.5.3 CHARACTERISTICS

1. The no-load speed of a repulsion-induction motor is somewhat above the synchronous speed because of the effect of repulsion winding. However, the speed at full-load is slightly less than the synchronous speed as in an induction motor.
2. The speed regulation of the motor is about 6%.
3. The starting torque is 2.25 to 3 times the full-load torque; the lower value being for large motors. The starting current is 3 to 4 times the full-load current.

1.6 UNIVERSAL MOTOR

A universal motor is defined as a motor which may be operated either on direct or single phase ac supply at approximately the same speed and output.

In fact, it is a smaller version of AC series motor. Being series wound motor, it has high starting torque and a variable speed characteristics. It runs at dangerously high speed on no load. That is why such motors are built into the device they drive.

Generally universal motors are manufactured in to two types

1. Concentrated pole, non compensated type (low power rating)
2. Distributed field compensated type (high power rating)

The non compensated motor has two salient poles and is just like a two pole series motor expect that whole of its magnetic path is laminated. (Fig 1.11). The laminated stator is necessary because the flux is alternating when motor is operated from a.c supply. The armature is wound type and is similar to that of a small DC motor. It consists essential of a laminated core having either straight or skewed slots and a commutator to which the leads of the armature winding are connected. The distributed field compensated type motor has a stator core similar to that of a split phase motor and a wound armature similar to that of a small dc motor. The compensating winding is used to reduce the reactance voltage present in the armature when motor runs on AC supply. This voltage is caused by the alternating flux by transformer action.

In a 2 pole non compensated motor, the voltage induced by transformer action in a coil during its commutation period is not sufficient to cause any serious commutation trouble. Moreover, high resistance brushes are used to aid commutation.

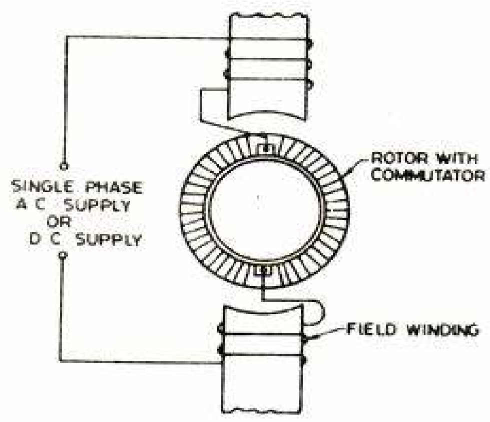


Fig 1.11 Universal Motor

1.6.1 SPEED/TORQUE CHARACTERISTICS

The speed of a universal motor varies just like a DC series motor (i.e) low at full load and high at no load. In fact on no load the speed is limited only by its own friction and windage load. Fig 1.12 shows the typical torque characteristics of universal motor both for dc and ac supply .Usually gear trains are used to reduce the actual load speeds to proper values.

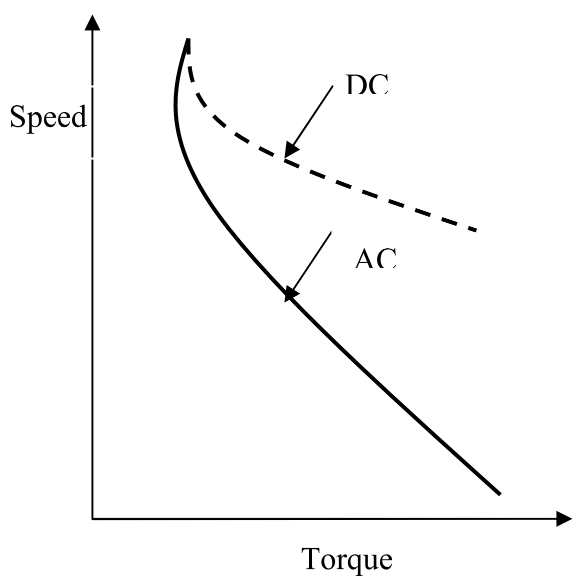


Fig 1.12 Speed Torque Characteristics of Universal motor

2 MARKS Questions and Answers

1. What is meant by AC commutator motors?

The commutator is a feature of dc motors, but ac motors having wound rotor with brushes and commutator arrangements, are called commutator motors which work on single phase AC supply. Such motors are called AC commutator motors.

2. What are the different types of AC commutator motors?

The more common commutator motors are

a. The series motors,
b. Universal motors,
c. Repulsion motors
d. Repulsion-induction motors, with various modifications and combinations

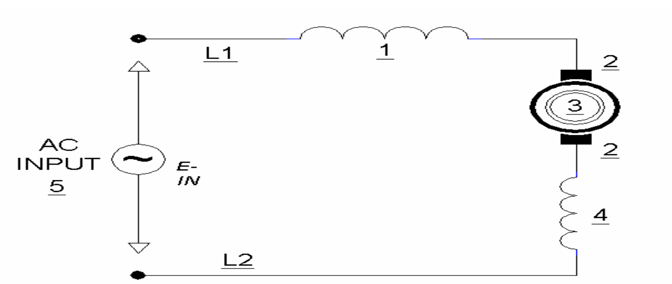
3. Mention few applications of AC series motors **(or universal motor)**

Electric Traction, Hoists , Locomotives , High HP applications, Vacuum cleaners, food processors and mixers, Hair driers. Coffee grinders, electric shavers etc.

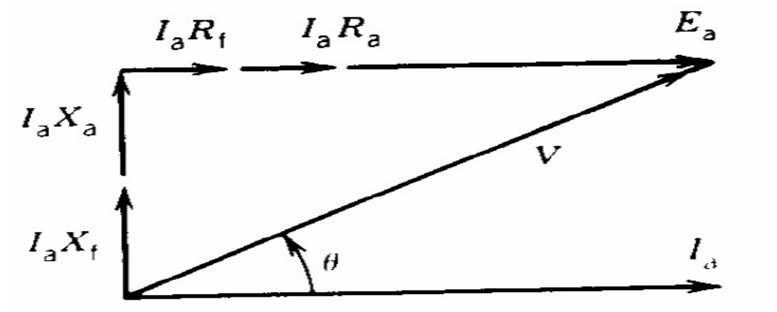
4. What modifications have to be done on DC series motor to make it to work with single phase AC supply?

a. 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.
b. 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.
c. A high field flux is obtained by using a low-reluctance magnetic circuit.
d. 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.

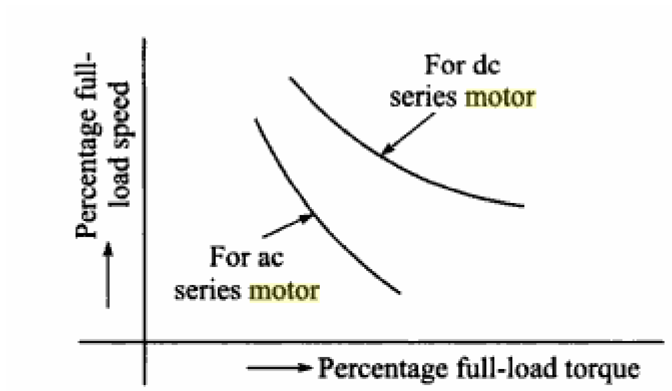
5. Draw the equivalent circuit diagram of AC series motor



6. Draw the phasor diagram of AC series motor



7. Draw the speed torque characteristics of AC series motor **(or Universal Motor)**

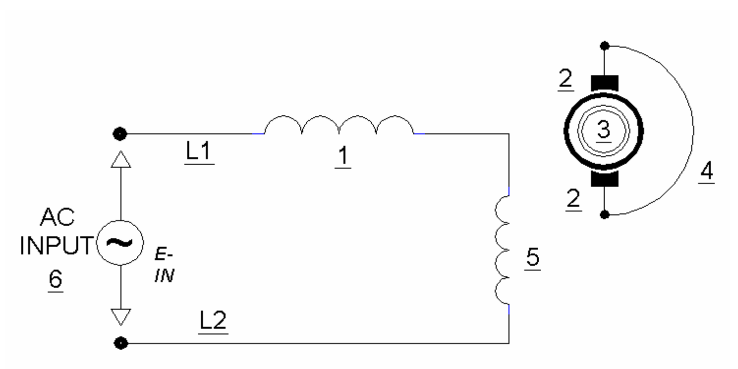


8. What are the types of AC series motor

   a. Conductively compensated AC series motor

   b. Inductively compensated AC series motor

9. Draw the equivalent circuit diagram of Repulsion motor



10. Draw the torque Vs Brush Position characteristics of Repulsion motor