



Electrical Machines

Single Phase Induction Motors

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Single Phase Induction Motors

CONSTRUCTION

Similar to a d.c. motor, single phase induction motor has basically two main parts, one rotating and other stationary. The stationary part in single phase induction motors is called stator while the rotating part is called rotor.

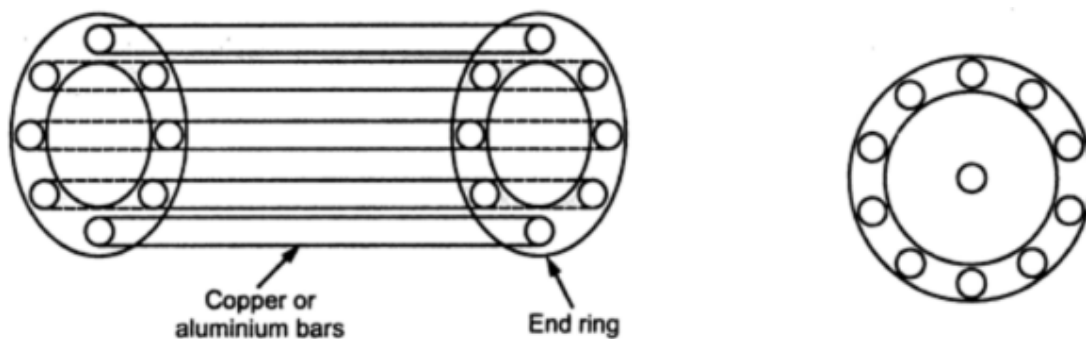
The stator has laminated construction, made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding or main winding. This is excited by a single phase a.c. supply. The laminated construction keeps iron losses to minimum. The stampings are made up of material like silicon steel which minimises the hysteresis loss. The stator winding is wound for certain definite number of poles means when excited by single phase a.c. supply, stator produces the magnetic field which creates the effect of certain definite number of poles. The number of poles for which stator winding is wound, decides the synchronous speed of the motor. The synchronous speed is denoted as N_s and it has a fixed relation with supply frequency f and number of poles P .

The relation is given by

$$N_s = \frac{120f}{P} \text{ r.p.m.}$$

The induction motor never rotates with the synchronous speed but rotates at a speed which is slightly less than the synchronous speed.

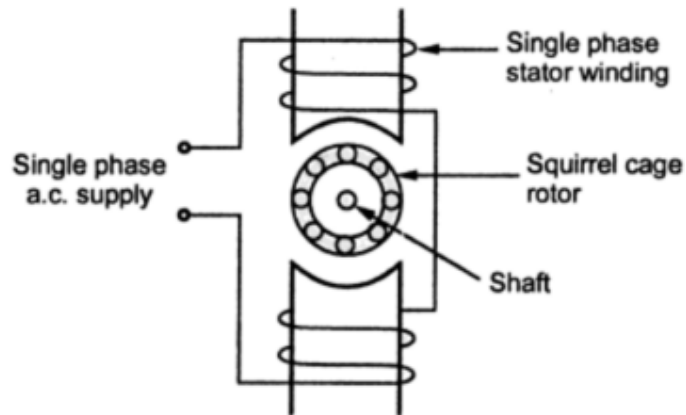
The rotor construction is of squirrel cage type. In this type, rotor consists of uninsulated copper or aluminium bars, placed in the slots. The bars are permanently shorted at both the ends with the help of conducting rings called end rings. The entire structure looks like cage hence called squirrel cage rotor. The construction and symbol is shown in following figure.



As the bars are permanently shorted to each other, the resistance of the entire rotor is very-very small. The air gap between stator and rotor is kept uniform and as small as possible. The main feature of this rotor is that it automatically adjusts itself for same number of poles as that of the stator winding.

ELECTRICAL MACHINES**SINGLE PHASE INDUCTION MOTORS**

The schematic representation of two pole single phase induction motor is shown in following figure.



Single-phase motors when compared with 3-phase Induction motors has the following disadvantages.

- For the same frame size and temperature rise single-phase motors can develop only about 50% of the output of that of 3-phase motors.
- Single-phase motors have lower power-factor
- Lower efficiency
- Low starting torque
- Expensive than the 3-phase motors of the same capacity.

WORKING

For the motoring action, there must exist two fluxes which interact with each other to produce the torque. In d.c motors, field winding produces the main flux while d.c. supply given to armature is responsible to produce armature flux. The main flux and armature flux interact to produce the torque.

In the single phase induction motor, single phase a.c. supply is given to the stator winding. The stator winding carries an alternating current which produces the flux which is also alternating in nature. This flux is called *main flux*. This flux links with the rotor conductors and due to transformer action e.m.f. gets induced in the rotor. The induced e.m.f. drives current through the rotor as rotor circuit is closed circuit. This rotor current produces another flux called *rotor flux* required for the motoring action- Thus second flux is produced according to induction principle due to induced e.m.f. hence the motor is called induction motor. As against this in d.c. motor a separate supply is required to armature to produce armature flux. This is an important difference between d.c. motor and an induction motor.

DOUBLE REVOLVING FIELD THEORY

Let us see why single phase induction motors are not self starting with the help of a theory called *double revolving field theory*.

ELECTRICAL MACHINES**SINGLE PHASE INDUCTION MOTORS**

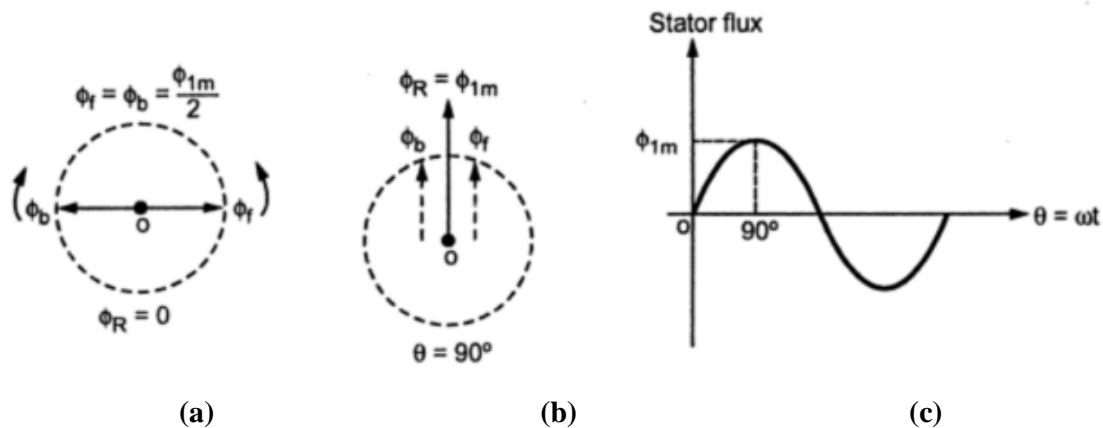
According to this theory, any alternating quantity can be resolved into two rotating components which rotate in opposite directions and each having magnitude as half of the maximum magnitude of the alternating quantity.

In case of single phase induction motors, the stator winding produces an alternating magnetic field having maximum magnitude of ϕ_{1m} .

According to double revolving field theory, consider the two components of the stator flux, each having magnitude half of maximum magnitude of stator flux i.e. $(\phi_{1m}/2)$. Both these components are rotating in opposite directions at the synchronous speed N_s which is dependent on frequency and stator poles.

Let ϕ_f is forward component rotating in anticlockwise direction while ϕ_b is the backward component rotating in clockwise direction. The resultant of these two components at any instant gives the instantaneous value of the stator flux at that instant. So resultant of these two is the original stator flux.

Following figure shows the stator flux and its two components ϕ_f and ϕ_b .



At start both the components are shown opposite to each other in the Fig. (a). Thus the resultant $\phi_R = 0$. This is nothing but the instantaneous value of stator flux at start. After 90° , as shown in the Fig. (b), the two components are rotated in such a way that both are pointing in the same direction. Hence the resultant ϕ_R is the algebraic sum of the magnitudes of the two components. So $\phi_R = (\phi_{1m}/2) + (\phi_{1m}/2) = \phi_{1m}$. This is nothing but the instantaneous value of the stator flux at $\theta = 90^\circ$ as shown in the Fig. (c). Thus continuous rotation of the two components gives the original alternating stator flux.

Both the components are rotating and hence get cut by the rotor conductors. Due to cutting of flux, e.m.f. gets induced in rotor which circulates rotor current. The rotor current produces rotor flux. This flux interacts with forward component ϕ_f to produce a torque in one particular direction say anticlockwise direction. While rotor flux interacts with backward component ϕ_b to produce a torque in the clockwise direction. So if anticlockwise torque is positive then clockwise torque is negative.

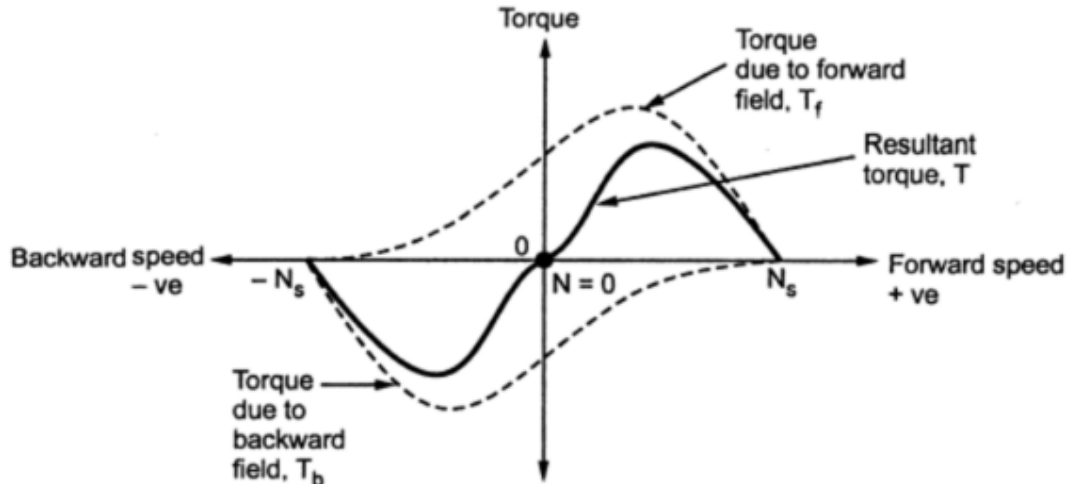
ELECTRICAL MACHINES**SINGLE PHASE INDUCTION MOTORS**

At start these two torques are equal in magnitude but opposite in direction. Each torque tries to rotate the rotor in its own direction.

Thus net torque experienced by the rotor is zero at start. And hence the single phase induction motors are not self starting.

TORQUE-SPEED CHARACTERISTICS

The two oppositely directed torques and the resultant torque can be shown effectively with the help of torque-speed characteristics. It is shown in following figure.



It can be seen that at start $N = 0$ and at that point resultant torque is zero. So single phase motors are not self starting.

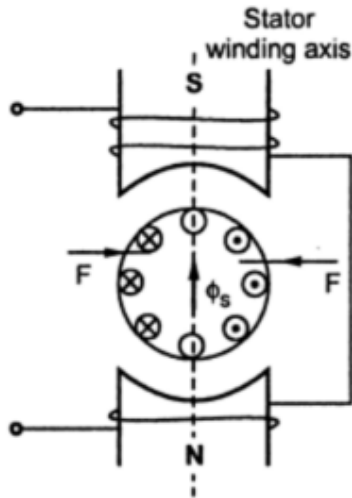
However if the rotor is given an initial rotation in any direction, the resultant average torque increases in the direction in which rotor is initially rotated. And motor starts rotating in that direction. But in practice it is not possible to give initial torque to rotor externally hence some modifications are done in the construction of single phase induction motors to make them self starting.

CROSS FIELD THEORY

Another theory which can also be used to explain why single phase induction motor is not self starting is *cross-field theory*.

Consider a single phase induction motor with standstill rotor as shown in following figure.

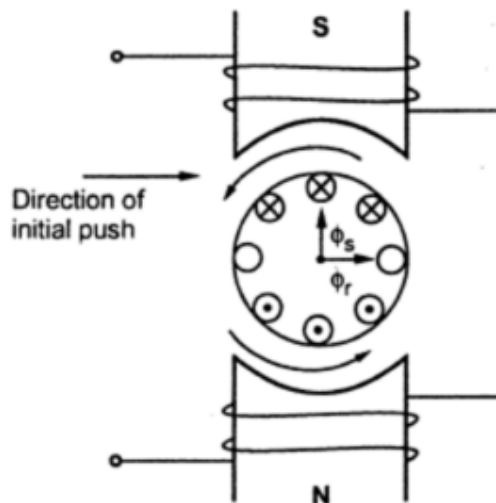
The stator winding is excited by the single phase a.c. supply. This supply produces an alternating flux ϕ_f which acts along the axis of the stator winding. Due to this flux, e.m.f., gets induced in the rotor conductors due to transformer action. As rotor is closed one, this e.m.f. circulates current through the rotor conductors. The direction of the rotor current is as shown in the Fig. The direction of rotor current is so as to oppose the cause producing it, which is stator flux ϕ_s .



Now Fleming's left hand rule can be used to find the direction of the force experienced by the rotor conductors. It can be seen that when ϕ_s acts in upward direction and increasing positively, the conductors on left experience force from left to right while conductors on right experience force from right to left. Thus overall, the force experienced by the rotor is zero. Hence no torque exists on the rotor and rotor cannot start rotating.

We have seen that there must exist two fluxes separated by some angle so as to produce rotating magnetic field. According to cross field theory, the stator flux can be resolved into two components which are mutually perpendicular. One acts along axis of the stator winding and other acts perpendicular to it.

Assume now that an initial push is given to the rotor in anticlockwise direction. Due to the rotation, rotor physically cuts the stator flux and dynamically e.m.f. gets induced in the rotor. This is called speed e.m.f. or *rotational e.m.f.* The direction of such e.m.f. can be obtained by Fleming's right hand rule and this e.m.f. is in phase with the stator flux ϕ_s . The direction of e.m.f. is shown in following figure.



ELECTRICAL MACHINES**SINGLE PHASE INDUCTION MOTORS**

This e.m.f. is denoted as E_2 . This e.m.f. circulates current through rotor which is I_{2N} . This current produces its own flux called rotor flux ϕ_r . This axis of ϕ_r is at 90° to the axis of stator flux hence this rotor flux is called cross-field.

Due to very high rotor reactance, the rotor current I_{2N} and ϕ_r lags the rotational e.m.f. by almost 90° .

Thus ϕ_r is in quadrature with ϕ_s in space and lags ϕ_s by 90° in time phase. Such two fluxes produce the rotating magnetic field.

The direction of this rotating magnetic field will be same as the direction of the initial push given- Thus rotor experiences a torque in the same direction as that of rotating magnetic field i.e. the direction of initial push. So rotor accelerates in the anticlockwise direction under the case considered and attains a subsynchronous speed in the steady state.

TYPES OF SINGLE PHASE INDUCTION MOTORS

Depending upon the methods of producing rotating stator magnetic flux, the single phase induction motors are classified as,

- Split phase induction motor
- Capacitor start induction motor
- Capacitor start capacitor run induction motor
- Shaded pole induction motor.

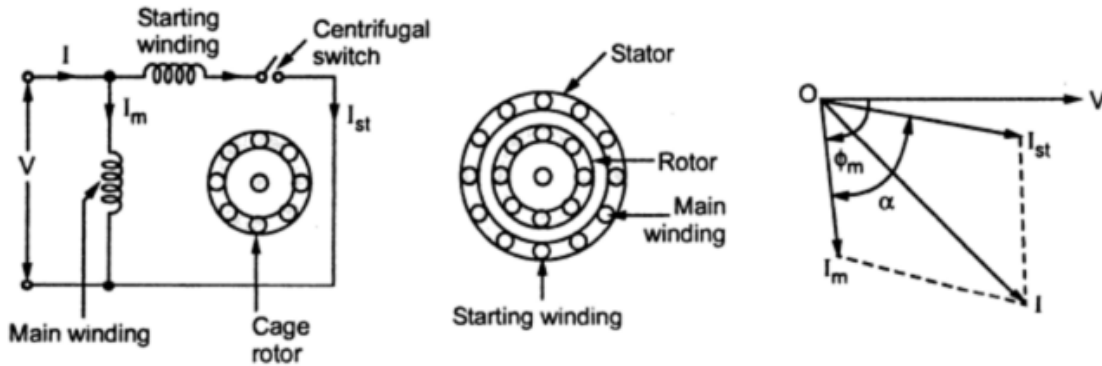
Split Phase Induction Motor

This type of motor has single phase stator winding called main winding. In addition to this, stator carries one more winding called auxiliary winding or starting winding. The auxiliary winding carries a series resistance such that its impedance is highly resistive in nature. The main winding is inductive in nature.

Let I_m = Current through main winding

and I_{st} = Current through auxiliary winding

As main winding is inductive, current I_m lags voltage V by a large angle ϕ_m while I_{st} is almost in phase in V as auxiliary winding is highly resistive. Thus there exists a phase difference of α between the two currents and hence between the two fluxes produced by the two currents. This is shown in the Fig. (c).



(a) Circuit diagram

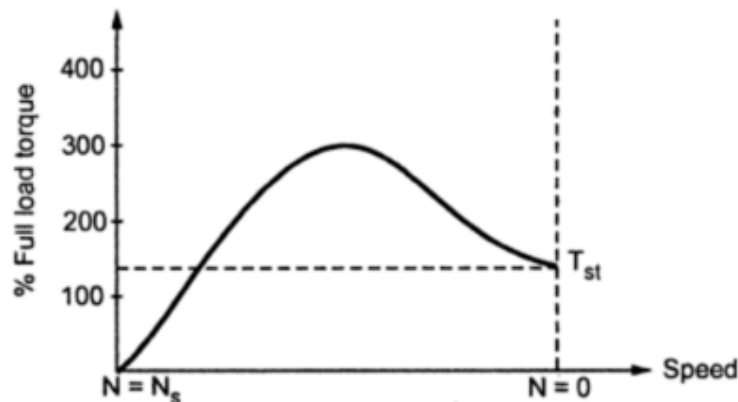
(b) Representation

(c) Phasor diagram

The resultant of these two fluxes is a rotating magnetic field. Due to this, the starting torque, which acts only in one direction is produced.

The auxiliary winding has a centrifugal switch in series with it. When motor gathers a speed upto 75 to 80% of the synchronous speed, centrifugal switch gets opened mechanically and in running condition auxiliary winding remains out of the circuit. So motor runs only on stator winding. So auxiliary winding is designed for short time use while the main winding is designed for continuous use. As the current I_m and I_{st} split from each other by angle ' α ' at start, the motor is commonly called split phase motor.

Torque speed characteristics are shown below.



These motors have low starting current and moderate starting torque. These are used for easily started loads like fans, blowers, grinders, centrifugal pumps, washing machines, oil burners, office equipments etc. These are available in the range of 1/20 to 1/2 kW.

Capacitor Start Induction Motors

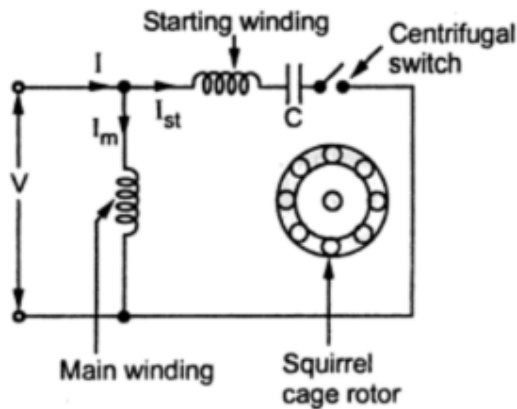
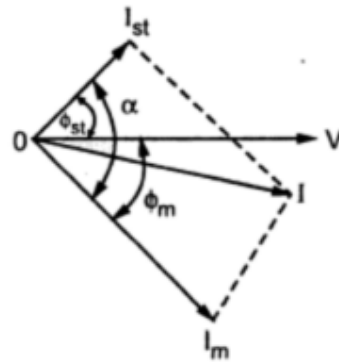
The construction of this type of motor is similar to the resistance split phase type. The difference is that in series with the auxiliary winding the capacitor is connected. The capacitive circuit draws a leading current, this feature used in this type to increase the split phase angle α between the two currents I_m and I_{st} .

ELECTRICAL MACHINES**SINGLE PHASE INDUCTION MOTORS**

Depending upon whether capacitor remains in the circuit permanently or is disconnected from the circuit using centrifugal switch, these motors are classified as,

1. Capacitor start motors and
2. Capacitor start capacitor run motors

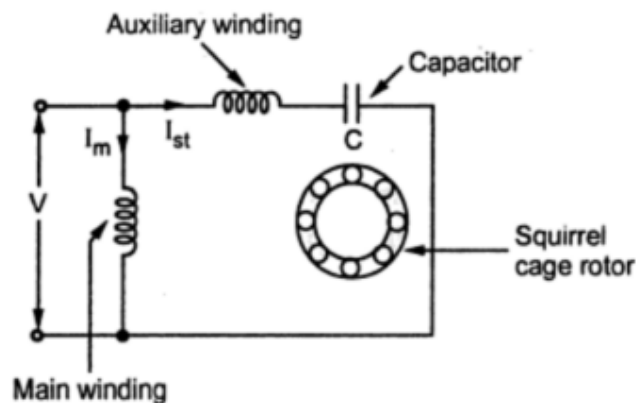
The construction of capacitor start motor is shown in the Fig. (a). The current I_m lags the voltage by angle ϕ_m while due to capacitor the current I_{st} leads the voltage by angle ϕ_{st} . Hence there exists a large phase difference between the two currents which is almost 90° , which is an ideal case. The phasor diagram is shown in the Fig. (b).

**(a) Schematic representation****(b) Phasor diagram**

The starting torque is proportional to ' α ' and hence such motors produce very high starting torque.

When speed approaches to 75 to 80% of the synchronous speed, the starting winding gets disconnected due to operation of the centrifugal switch. The capacitor remains in the circuit only at start hence it is called capacitor start motors.

The schematic representation of such motor is shown in following figure.

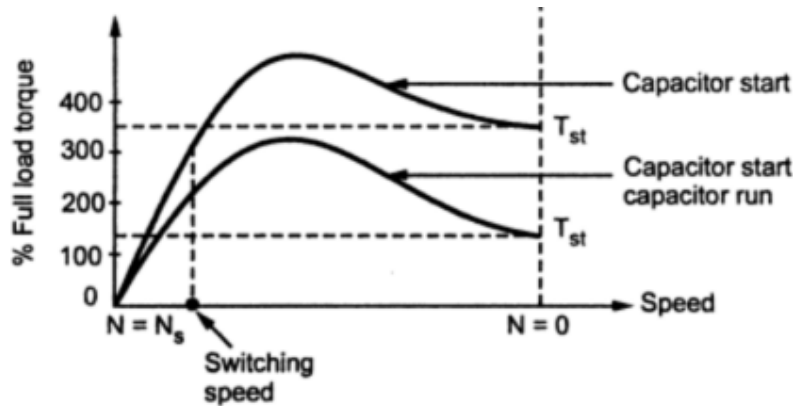


The phasor diagram remains same as shown in the Fig. (b). The performance not only at start but in running condition also depends on the capacitor C hence its value is to be designed so as to compromise between best starting and best running condition. Hence the starting torque

ELECTRICAL MACHINES

SINGLE PHASE INDUCTION MOTORS

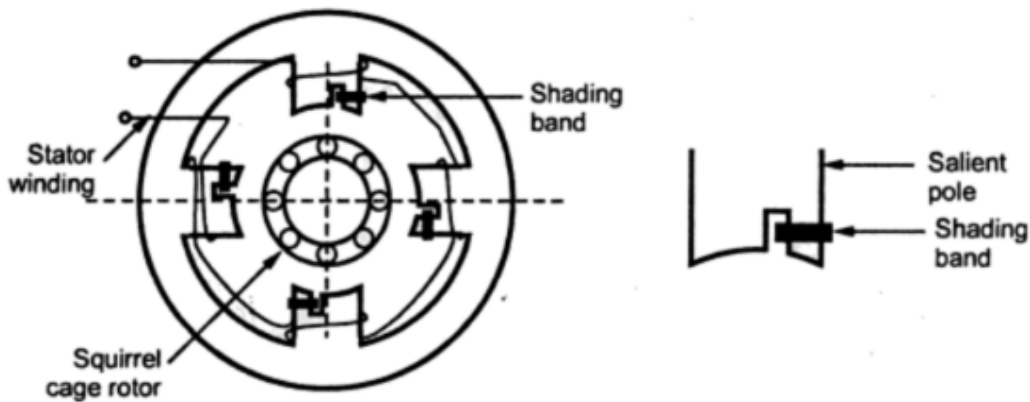
available in such type of motor is about 50 to 100% of full load torque. The torque-slip characteristics is shown in following figure.



These motors have high starting torque and hence are used for hard starting loads. These are used for compressors, conveyors, grinders, fans, blowers, refrigerators, air conditioners etc. These are most commonly used motors. The capacitor start capacitor run motors are used in ceiling fans, blowers and air-circulators. These motors are available upto 6 kW.

Shaded Pole Induction Motors

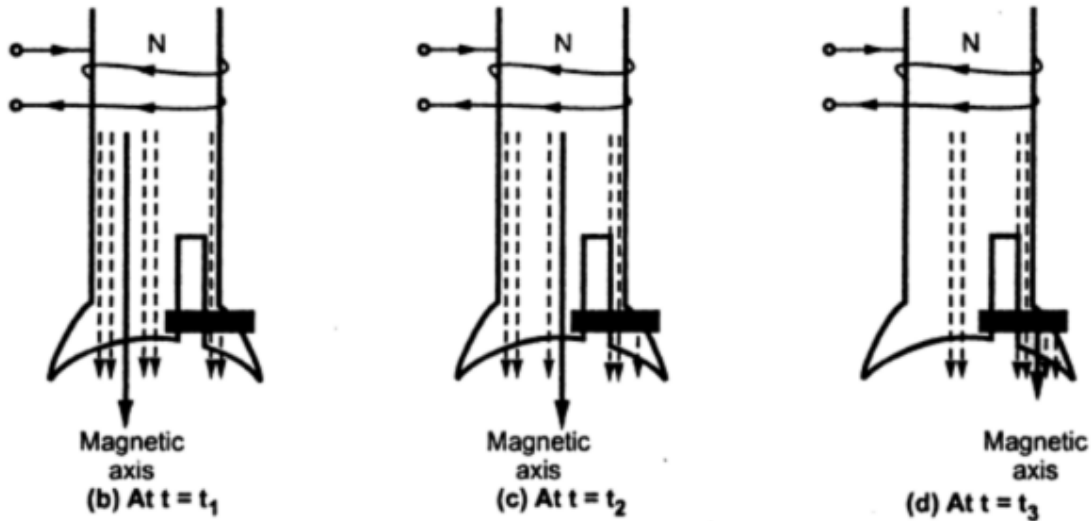
This type of motor consists of a squirrel cage rotor and stator consisting of salient poles i.e. projected poles. The poles are shaded i.e. each pole carries a copper band on one of its unequally divided part called shading band. Fig. (a) shows 4 pole shaded pole construction while Fig. (b) shows a single pole consisting of copper shading band.



(a) 4 - pole shaded pole construction (b) Salient pole with shading band

The production of rotating magnetic held can be explained as below:

The current carried by the stator winding is alternating and produces alternating flux. The waveform of the flux is shown in the Fig. (a). The distribution of this flux in the pole area is greatly influenced by the role of copper shading band. Consider the three instants say t_1 , t_2 and t_3 during first half cycle of the flux as shown, in the Fig. (a).

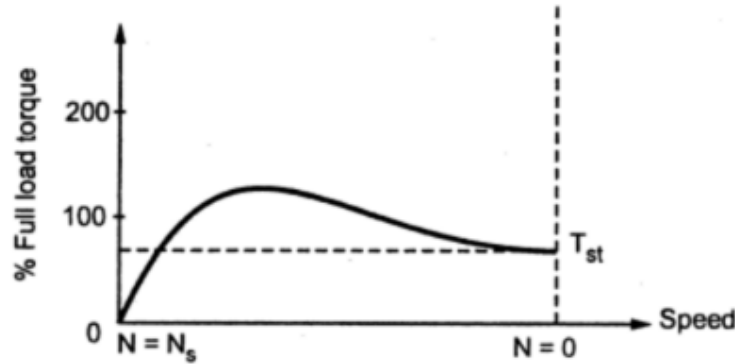


At instant $t = t_1$, rate of rise of current and hence the flux is very high. Due to the transformer action, large e.m.f. gets induced in the copper shading band. This circulates current through shading band as it is short circuited, producing its own flux. According to Lenz's law, the direction of this current is so as to oppose the cause i.e. rise in current. Hence shading ring flux is opposing to the main flux. Hence there is crowding of flux in non shaded part while weakening of flux in shaded part. Overall magnetic axis shifts in non shaded part as shown in the Fig. (b).

At instant $t = t_2$ rate of rise of current and hence the rate of change of flux is almost zero as flux almost reaches to its maximum value. So $d\phi/dt = 0$. Hence there is very little induced e.m.f. in the shading ring. Hence the shading ring flux is also negligible, hardly affecting the distribution of the main flux. Hence the main flux distribution is uniform and magnetic axis lies at the centre of the pole face as shown in the Fig. (c).

At instant $t = t_3$ the current and the flux is decreasing. The rate of decrease is high which again induces a very large e.m.f. in the shading ring. This circulates current through the ring which produces its own flux. Now direction of the flux produced by the shaded ring current is so as to oppose the cause which is decrease in flux. So it oppose the decrease in flux means its direction is same as that of main flux, strengthening it. So there is crowding of flux in the shaded part as compared to non shaded part. Due to this the magnetic axis shifts to the middle of the shaded part of the pole. This is shown in the Fig. (d).

This sequence keeps on repeating for negative half cycle too. Consequently this produces an effect of rotating magnetic field, the direction of which is from non shaded part of the pole to the shaded part of the pole. Due to this, motor produces the starting torque and starts rotating. The starting torque is low which is about 40 to 50% of the full load torque for this type of motor. The torque speed characteristics is shown in following figure.



Due to absence of centrifugal switch the construction is simple and robust but this type of motor has a lot of limitations as :

- The starting torque is poor.
- The power factor is very low.
- Due to I^2R , copper losses in the shading ring the efficiency is very low.
- The speed reversal is very difficult. To achieve the speed reversal, the additional set of shading rings is required. By opening one set and closing other, direction can be reversed but the method is complicated and expensive.
- The size and power rating of these motors is very small. These motors are usually available in a range of 1/300 to 1/20 kW.

These motors are cheap but have very low starting torque, low power factor and low efficiency. These motors are commonly used for the small fans, toy motors, advertising displays, film projectors, record players, gramophones, hair dryers, photo copying machines etc.

SINGLE PHASE A.C. SERIES MOTOR

In a normal d.c. motor if direction of both field and armature current is reversed, the direction of torque remains unchanged. So when normal d.c. series motor is connected to an a.c. supply, both field and armature current get reversed and unidirectional torque gets produced in the motor hence motor can work on a.c. supply.

But performance of such motor is not satisfactory due to the following reasons :

- There are tremendous eddy current losses in the yoke and field cores, which causes overheating.
- Armature and field winding offer high reactance to a.c. due to which operating power factor is very low.
- The sparking at brushes is a major problem because of high voltage and current induced in the short circuited armature coils during the commutation period.

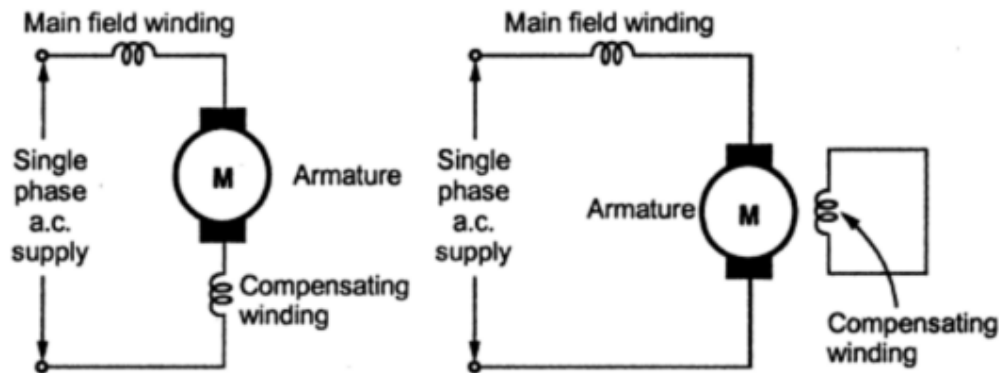
ELECTRICAL MACHINES**SINGLE PHASE INDUCTION MOTORS**

Some modifications are required to have the satisfactory performance of d.c. series motor on a.c. supply, when it is called **a.c series motor**. The modifications are :

- To reduce the eddy current losses, yoke and pole core construction is laminated.
- The power factor can be improved by reducing the magnitudes of field and armature reactances. Field reactance can be decreased by reducing the number of turns. But this reduces the field flux. But this reduction in flux ($N \propto 1/\phi$), increases the speed and reducing the torque. To keep the torque same it is necessary to increase the armature turns proportionately. This increases the armature inductance.

Now to compensate for increased armature flux which produces *severe* armature reaction, it is necessary to use **compensating winding**. The flux produced by this winding is opposite to that produced by armature and effectively neutralizes the armature reaction.

If such a compensating winding is connected in series with the armature as shown in the Fig. (a), the motor is said to be '*conductively compensated*'. For motors to be operated on a.c. and d.c. both, the compensation should be conductive. If compensating winding is short circuited on itself as shown in the Fig. (b), the motor is said to be '*inductively compensated*'.



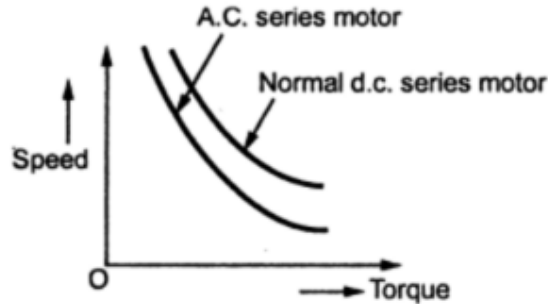
(a) **Conductively compensated motor** (b) **Inductively compensated motor**

In this compensating winding acts as a secondary of transformer and armature as its primary. The ampere turns produced by compensating winding neutralise the armature ampere turns.

To reduce the induced e.m.f. due to transformer action in the armature coils while commutation period, the following measures are taken :

- The flux per pole is reduced and number of poles are increased.
- The frequency of supply used is reduced.
- Preferably single turn armature coils are used.

The characteristics of such motor are similar to that of d.c. series motor. The torque varies as square of the armature current and speed varies inversely as the armature current. The speed of such motor can be dangerously high on no load condition and hence it is always started with some load. Starting torque produced is high which is 3 to 4 times the full load torque. The speed-torque characteristics of such type of motor is as shown in following figure.



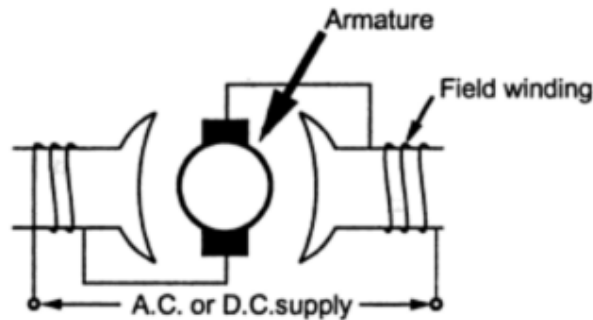
Because of high starting torque it is used in electric traction, hoists, locomotives etc.

UNIVERSAL MOTOR

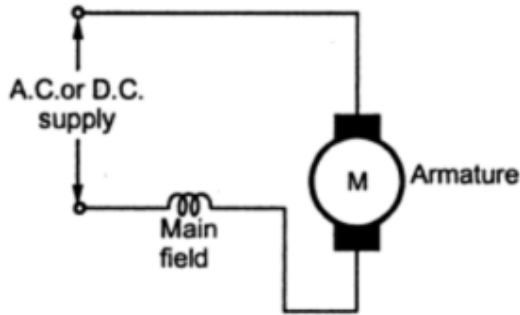
There are small capacity series motors which can be operated on d.c. supply or single phase alternating supply of same voltage with similar characteristics, called universal motors. The general construction of such motor is similar to that of a.c. series motor as discussed in last article. It is manufactured in two types.

- Non-compensated, low h.p.
- Compensated type, high h.p.

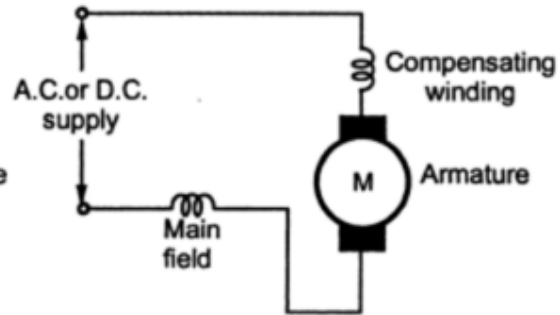
Non-compensated type pole has 2 poles, having entire magnetic path as laminated. Armature is wound type similar to the normal d.c. motor. Such non compensated construction is shown in the following figure.



While in compensated type, the motor has distributed field winding consisting of main field and compensating winding. This is somewhat similar to the stator of split phase single phase induction motor type construction. This also has a wound armature similar to the normal d.c. motor. Following figure shows the connection diagrams for both the types of universal motor.

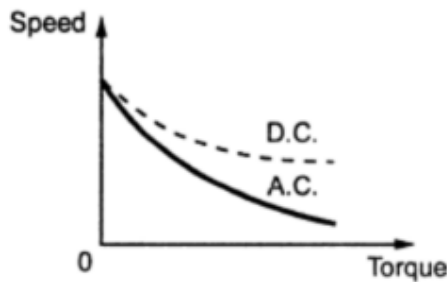


(a) Non-compensated type

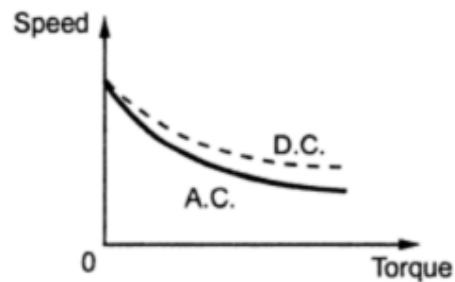


(b) Compensated type

The speed - torque characteristics for both the types of universal motor are shown in following figure.



(a) Non-compensated type



(b) Compensated type

Compensated type universal motor has better speed-torque characteristics i.e. the characteristics are same for the operation of motor on a.c. or d.c. supply. The motors are generally designed for full load operating speeds ranging between 3000 to 20000 r.p.m.

Applications : Though compensated type characteristics are better, the non-compensated type are more preferred for low h.p. applications. While compensated type of universal motors are preferred for high h.p. applications. High starting torque is the important feature of universal motors.

The universal motors are used for domestic applications like vacuum cleaners, food processors and mixers, hair driers, coffee grinders, electric shavers etc. Their other applications are blowers, portable tools like drilling machines and small drives.

PHASOR DIAGRAM OF A.C. SERIES MOTOR

Consider the equivalent circuit of a.c. series motor as shown in the following figure.

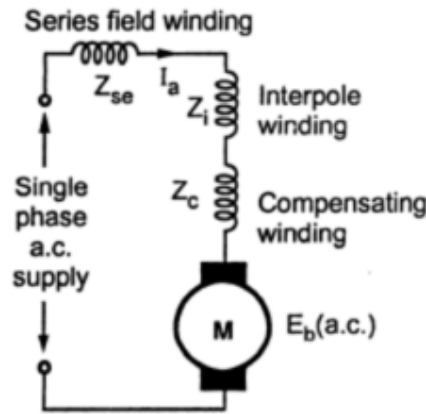
It is conductively coupled a.c. motor.

When armature current I_a flows through it, there is voltage drop across each winding impedance and induced e.m.f. E_b (a.c.), when a.c supply is given to it.

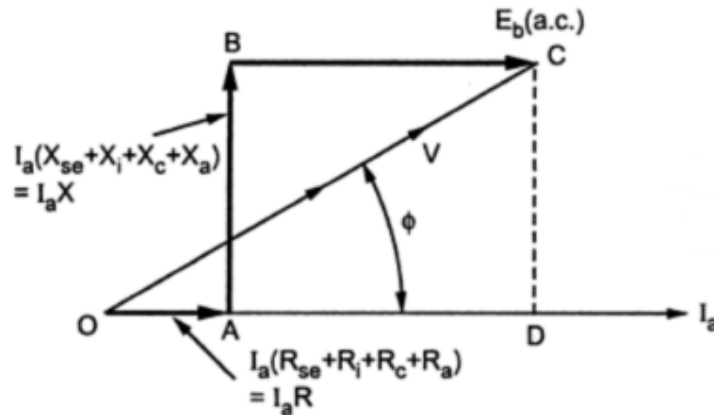
$$\bar{V} = \bar{E}_b(a.c.) + \bar{I}_a \bar{Z}_{se} + \bar{I}_a \bar{Z}_i + \bar{I}_a \bar{Z}_c + \bar{I}_a \bar{Z}_a \quad (1)$$

But $Z_{se} = R_{se} + jX_{se}, Z_i = R_i + jX_i, Z_c = R_c + jX_c, Z_a = R_a + jX_a$

$$\therefore \bar{V} = \bar{E}_b(a.c.) + \bar{I}_a R_{se} + \bar{I}_a R_i + \bar{I}_a R_c + j(\bar{I}_a X_{se} + \bar{I}_a X_i + \bar{I}_a X_c + \bar{I}_a X_a) \quad (2)$$



Thus adding the drops $I_a R$ and $I_a X$ to $E_b(a.c.)$ vectorially, the voltage V can be obtained. As $E_b(a.c.)$ is produced due to current I_a , it is proportional to I_a and in phase with it. Thus the phasor diagram with I_a as reference is shown in following figure. The angle between V and I_a is ϕ and $\cos \phi$ is the power factor of the motor.



Note that $I_a X$ drop leads $I_a R$ by 90° as inductive current lags voltage across it by 90° .

Consider ΔOCD

$$V^2 = [I_a R + E_b(a.c.)]^2 + (I_a X)^2 \quad (3)$$

and
$$\cos \phi = \frac{I_a R + E_b(a.c.)}{V} \quad (4)$$

Example

In a 4-pole, 50 Hz single-phase Induction motor, the power absorbed by the forward and backward field rotor equivalent resistances are 200 W and 21W respectively at a motor speed of 1440 rpm. The mechanical losses totals 20W. Compute the shaft torque at the above speed.

$$N_s = \frac{120f_s}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$S = \frac{N_s - N_r}{N_s} = 0.04$$

$$T_d = T_{df} - T_{db} = 200 - 21 = 179 \text{ W}$$

$$P_d = T_d(1 - S) = 179(1 - 0.04) = 171.84 \text{ W}$$

$$P_0 = P_d - W_m = 171.84 - 20 = 151.84 \text{ W}$$

$$P_0 = \frac{2\pi N_r T}{60}$$

$$\therefore T = \frac{60 \times 151.84}{2\pi \times 1440} = 1.007 \text{ Nm}$$

Example (AMIE W11, 12 marks)

A 220 V single-phase induction motor gave the following test results : Blocked-rotor test; 120 V, 9.6 A, 460 W. No-load-test : 220 V, 4.6 A, 125 W. The stator winding resistance is 1.5 Ω, and during the block rotor test, the starting winding is open. Determine the equivalent circuit parameters. Also, find core, friction, and windage loss of the motor.

Solution

Equivalent impedance of motor windings

$$Z_{eq} = \text{voltage applied/current drawn} = 120/9.6 = 12.5 \Omega$$

Equivalent resistance of motor winding

$$R_{eq} = P/I^2 = 460/(9.6)^2 = 5 \Omega$$

Rotor winding resistance referred to stator

$$R_2' = R_{eq} - R_1 = 5 - 1.5 = 3.5 \Omega$$

Equivalent reactance of motor windings

$$X_{eq} = \sqrt{(Z_{eq}^2 - R_{eq}^2)} = \sqrt{(12.5)^2 - 5^2} = 11.45 \Omega$$

∴ Rotor winding reactance referred to stator

$$X_2' = \text{standard winding reactance}$$

$$X_1 = X_{eq}/2 = 11.45/2 = 5.72 \Omega$$

Assuming that magnetizing reactance is the same in both the cross and main axes

$$X_m = (2 \times \text{No load voltage})/\text{No load current} = 2 \times 220/4.6 = 95.6 \Omega$$

$$\text{Stator copper losses} = 460 - (9.6)^2 \times 50 = 222 \text{ W}$$

A 220 V 50 Hz single-phase induction motor gave the following test results:

Blocked rotor test: 110 V, 10 A, 400 W.

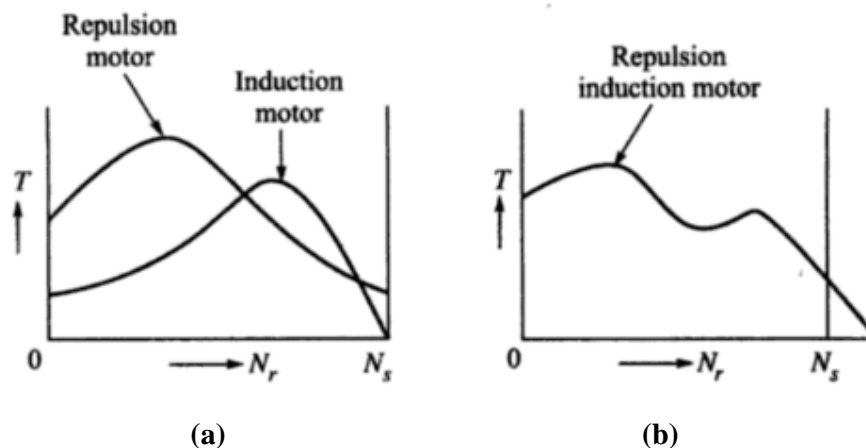
No load test: 220 V, 4 A, 100 W.

Find (a) the parameters of equivalent circuit (b) the iron friction and winding losses.

Answer: $r_1 = r_2' = 2\Omega$; $x_1 = x_2' = 5.125\ \Omega$; $X_\phi = 88.9\ \Omega$; 60 W

REPULSION-INDUCTION MOTOR

The construction of the stator of this type of motor is similar to that of a repulsion motor, i.e., the main stator winding of a single-phase induction motor. In the rotor there are two *separate* windings. One winding is similar to the rotor winding of a repulsion motor. The other winding is of squirrel-cage type, placed below the repulsion-motor type winding. The behaviour of the repulsion induction motor is therefore the combination of the behaviour of repulsion motor and an induction motor. Under starting condition very little current will flow through the inner squirrel-cage winding since the reactance of the squirrel-cage winding which is placed deep into the rotor slot is very high. As the rotor picks up speed, the frequency of the rotor induced emf and hence the rotor reactance will decrease. More current will flow in the rotor squirrel-cage winding. The motor will work as a combination of repulsion and induction motor. The torque-speed characteristics will be as shown in following figure.



As shown in Fig. (b), the single-phase repulsion-induction motor has the advantages of high starting torque and good speed regulation. It has the ability to continue to develop torque under sudden heavy applied loads. It is also manufactured in integral kilowatt rating and is used to drive reciprocating pumps and compressors, where only single-phase power is available. Single-phase repulsion induction motors are also used in stokers, conveyors, and deep-well pumps.

ASSIGNMENT

- Q.1. (AMIE S11, 12, W15, 5 marks):** Why does a single-phase induction motor not-possess any starting torque?
- Q.2. (AMIE S11, 12, W15, 10 marks):** A 4-pole, 230V, 50Hz, single phase induction motor runs at 1425 rpm. The power absorbed by the forward and backward fields are 245 W and 35 W, respectively. The no load rotational losses is 45 W. Determine the developed torque and shaft torque.
- Q.3. (AMIE W11, 8 marks):** Using double-revolving field theory, explain the operation of a single-phase induction motor. Also, describe the torque-slip characteristics of the motor based on constant forward and backward flux waves.
- Q.4. (AMIE W11, 10 marks):** Explain the principle of operation of a linear induction motor. Draw its characteristics. Also, list its important applications.
- Q.5. (AMIE W12, 4 marks):** If the emf in the stator of an 8-pole induction motor has a frequency of 50 c/s, and that in the rotor 1.5 c/s, at what speed is the motor running and what is the slip?
- Q.6. (AMIE W12, 10 marks):** Develop the equivalent circuit of a pure single-phase induction motor using double revolving field theory.
- Q.7. (AMIE W12, 10 marks):** Give the construction and working of an a.c. series motor. Draw its circuit model and the phasor diagram for a.c. operation.
- Q.8. (AMIE W13, 8 marks):** Describe how from a pulsating magnetic field in a single-phase motor, a rotating magnetic field is created with the help of an auxiliary winding.
- Q.9. (AMIE W13, 4 marks):** Show how an armature winding connected with a series field can develop a non-zero average torque, even if the supply is a.c.
- Q.10. (AMIE W13, 8 marks):** Sketch the torque-speed characteristic of a single-phase induction motor showing the forward, backward and net torque in the speed range of $N_s \leq n \leq N_s'$
- Q.11. (AMIE W14, 7 marks):** Explain why a single phase induction motor is not self-starting and hence show how by splitting of phase a rotating field can be created.
- Q.12. (AMIE W14, 8 marks):** Explain, with necessary assumptions, how the parameters of the equivalent circuit of a single phase induction motor are to be estimated. Show the equivalent circuit for the performance calculation.
- Q.13. (AMIE W14, 5 marks):** Where are a.c. series motors used? What are the disadvantages of these motors as compared to d.c. series motors?
- Q.14. (AMIE S15, 4 marks):** List different methods for starting of a single-phase induction motor.
- Q.15. (AMIE S15, 8 marks):** What is a repulsion motor? Explain its working.
- Q.16. (AMIE S15, 8 marks):** Show the characteristics of a single-phase series motor.
- Q.17. (AMIE S13, 6 marks):** What are various types of single phase induction motors? Discuss their applications.
- Q.18. (AMIE S13, 14 marks):** Explain in detail about the working principle and operation of split phase induction motor.
- Q.19. (AMIE S15, 5 marks):** Write short note on “Universal Motors.”

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