Principle of induction motor

Objectives: At the end of this lesson you shall be able to
- **state the principle of a 3-phase induction motor**
- **explain briefly the method of producing a rotating magnetic field.**

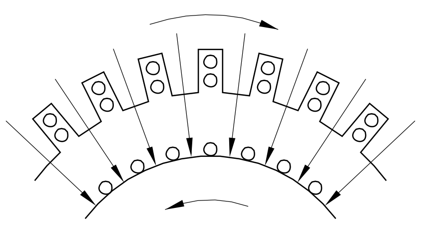
The three-phase induction motor is used more extensively than any other form of electrical motor, due to its simple construction, trouble-free operation, lower cost and a fairly good torque speed characteristic.

Principle of 3-phase induction motor: It works on the same principle as a DC motor, that is, the current-carrying conductors kept in a magnetic field will tend to create a force. However, the induction motor differs from the DC motor in fact that the rotor of the induction motor is not electrically connected to the stator, but induces a voltage/current in the rotor by the transformer action, as the stator magnetic field sweeps across the rotor. The induction motor derives its name from the fact that the current in the rotor is not drawn directly from the supply, but is induced by the relative motion of the rotor conductors and the magnetic field produced by the stator currents.

The stator of the 3-phase induction motor is similar to that of a 3-phase alternator, of revolving field type. The three-phase winding in the stator produces a rotating magnetic field in the stator core as it will be explained later. The rotor of the induction motor may have either shorted rotor conductors in the form of a squirrel cage or in the form of a 3-phase winding to facilitate the circulation of current through a closed circuit.

Let us assume that the stator field of the induction motor is rotating in a clockwise direction as shown in Fig 1. This makes for the relative motion of the rotor in an anticlockwise direction as shown in Fig 1. Applying Fleming's right hand rule, the direction of emf induced in the rotor will be towards the observer as shown in Fig 2. As the rotor conductors have a closed electric path, due to their shorting, a current will flow through them as in a short-circuited secondary of a transformer.

Fig 1



The magnetic field produced by the rotor currents will be in a counter-clockwise direction as shown in Fig 2 according to Maxwell's Corkscrew rule. The interaction between the stator magnetic field and the rotor magnetic field results in a force to move the rotor in the same direction as that of the rotating magnetic field of the stator, as shown in Fig 3. As such the rotor follows the stator field in the same direction by rotating at a speed lesser than the synchronous speed of the stator rotating magneticfield.

Fig 2

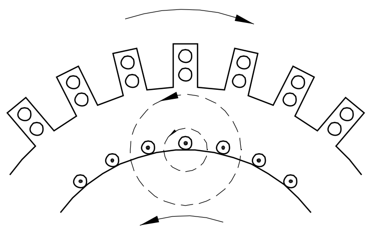
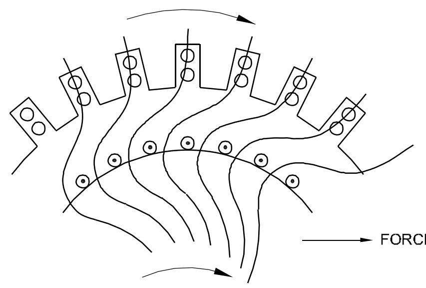


Fig 3



At higher speeds of the rotor nearing to synchronous speeds, the relative speed between the rotor and the rotating magnetic field of the stator reduces and results in a smaller induced emf in the rotor. Theoretically, if we assume that the rotor attains a speed equal to the synchronous speed of the rotating magnetic field of the stator, there will be no relative motion between the stator field and the rotor, and thereby no induced emf or current will be there in the rotor. Consequently there will not be any torque in the rotor. Hence the rotor of the induction motor cannot run at a synchronous speed at all. As the motor is loaded, the rotor speed has to fall to cope up with the mechanical force; thereby the relative speed increases, and the induced emf and current increase in the rotor resulting in an increased torque.

To reverse the direction of rotation of a rotor: The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator as well as the rotor, the phase sequence of the supply is to be changed by changing any two leads connected to the stator.

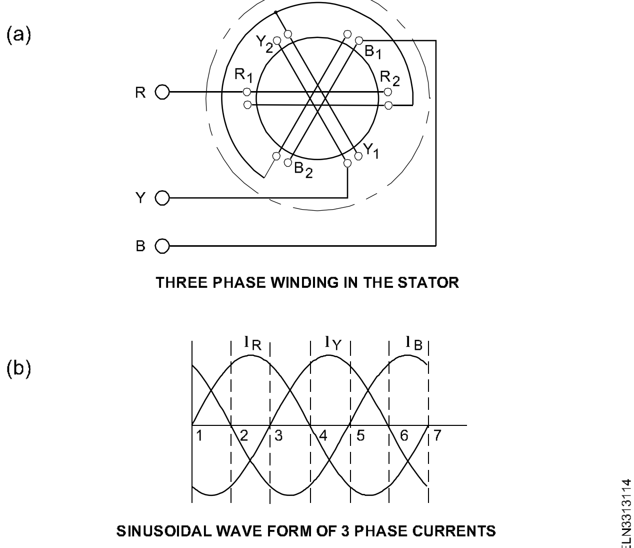
Rotating magnetic field from a three-phase stator: The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator. The stator of the induction motor contains three-phase windings placed at 120 electrical degrees apart from each other. These windings are placed on the stator core to form non-salient stator field poles. When the stator is energized from a three-phase voltage supply, in each phase winding will set up a pulsating field. However, by virtue of the spacing between the windings, and the phase difference, the magnetic fields combine to produce a field rotating at a constant speed around the inside surface of the stator core. This resultant movement of the flux is called the **`rotating magnetic field'**, and its speed is called the **`synchronous speed'**.

The manner, in which the rotating field is set up, may be described by considering the direction of the phase currents at successive instants during a cycle. Fig 4a shows a simplified star-connected, three-phase stator winding. The winding shown is for a two-pole induction motor. Fig 4b shows the phase currents for the three-phase windings. The phase currents will be 120 electrical degrees apart as shown in Fig 4b. The resultant magnetic field produced by the combined effect of the three currents is shown at increments of 60° for one cycle of the current.

At position (1) in Fig 4b, the phase current I_R is zero, and hence coil R will be producing zero flux. However, the phase current I_B is positive and I_y is negative.

Considering the instantaneous current directions of these three phase windings, as shown in Fig 4b at position 1, we can indicate the current direction in Fig 5(1).

Fig 4



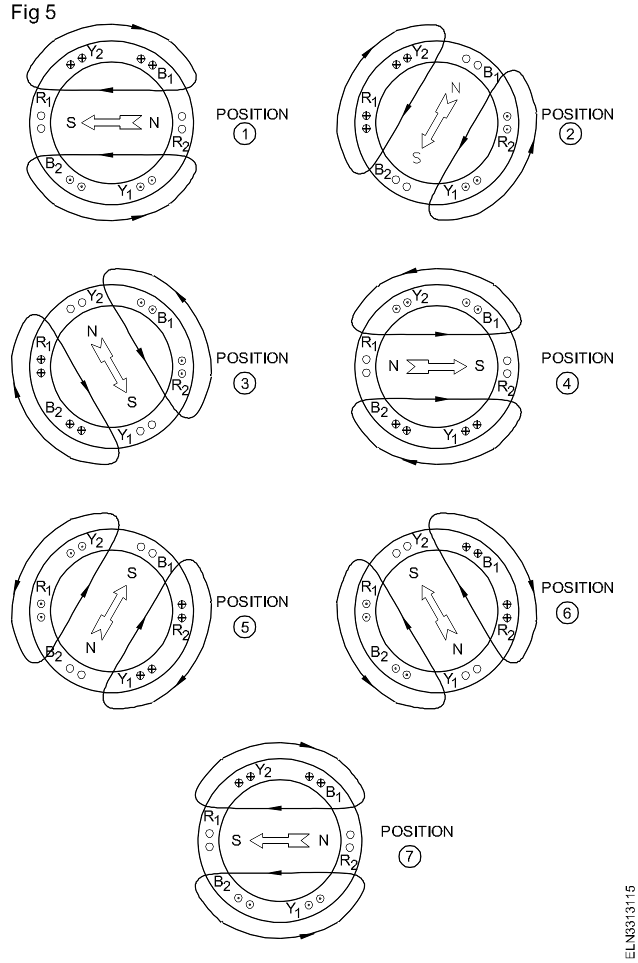
THREE PHASE WINDING IN THE STATOR

SINUSOIDAL WAVE FORM OF 3 PHASE CURRENTS

For convenience the +ve current is shown as +ve sign, and the -ve current is shown as dot (•) sign. Accordingly Y_2 and B_1 are shown as positive and Y_1 and B_2 are shown as negative. Using Maxwell's corkscrew rule, the resulting flux by these currents will produce a flux as shown in Fig 5(1). The arrow shows the direction of the magnetic field and the magnetic poles in the stator core.

At position 2, as shown by Fig 5(2), 60 electrical degrees later, the phase current I_B is zero, the current I_R is positive and the current I_Y is negative. In Fig (2) the current is now observed to be flowing into the conductors at the coil ends R_1 and Y_2, and out of the conductors at coil R_2 and Y_1. Therefore, as shown in Fig 5(2), the resultant magnetic poles are now at a new position in the stator core. In fact the poles in position 2 have also rotated 60° from position (1).

Fig 5



Using the same reasoning as above for the current wave positions 3, 4, 5, 6 and 7, it will be seen that for each successive increment of 60 electrical degrees, the resultant stator field will rotate a further 60° as shown in Fig 5. Note that from the resultant flux from position (1) to position (7), it is obvious that for each cycle of applied voltage the field of the two-pole stator will also rotate one revolution around its core.

From what is stated above it will be clear that the rotating magnetic field could be produced by a set of 3-phase stationary windings, placed at 120° electrical degrees apart, and supplied with a 3-phase voltage.

The speed at which the field rotates is called synchronous speed, and, it depends upon the frequency of supply and the number of poles for which the stator is wound.

Hence

N_s = Synchronous speed in r.p.m.

$$= \frac{120F}{P} \text{rpm}$$

where `P' is the number of poles in the stator, and `F' is the frequency of the supply.

Construction of a 3-phase squirrel cage induction motor - relation between slip, speed, rotor frequency, copper loss and torque

Objectives: At the end of this lesson you shall be able to

- **describe the construction of a 3-phase, squirrel cage induction motor**
- **describe the construction of double squirrel cage motor and its advantage**
- **explain slip, speed, rotor frequency, rotor copper loss, torque and their relationship.**

Three-phase induction motors are classified according to their rotor construction. Accordingly, we have two major types.

– Squirrel cage induction motors

– Slip ring induction motors.

Squirrel cage motors have a rotor with short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotor windings of the slip ring motors are brought out through slip-rings which are in contact with stationary brushes.

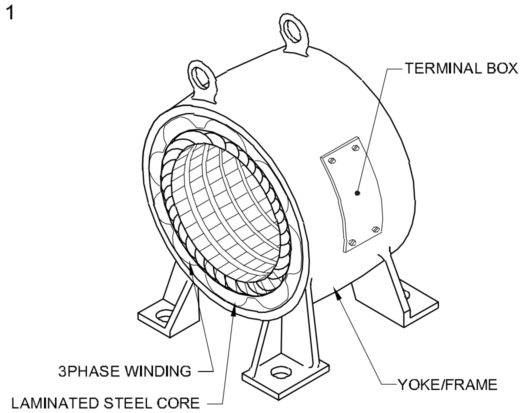
Development of these two types of induction motors is due to the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque will be low with increased losses and poor efficiency. For certain applications of loads where high starting torque and sufficient running torque are the only requirements, the rotor resistance should be high at the time of starting, and low while the motor is running. If the motor circuit is left with high resistance, the rotor copper loss will be more, resulting in low speed and poor efficiency. Hence it is advisable to have low resistance in the rotor while in operation.

Both these requirements are possible in slip-ring motors by adding external resistance at the start and cutting it off while the motor runs. As this is not possible in squirrel cage motors, the above requirements are met by developing a rotor called double squirrel cage rotor where there will be two sets of short circuited bars in the rotor.

Stator of an induction motor: There is no difference between squirrel cage and slip-ring motor stators.

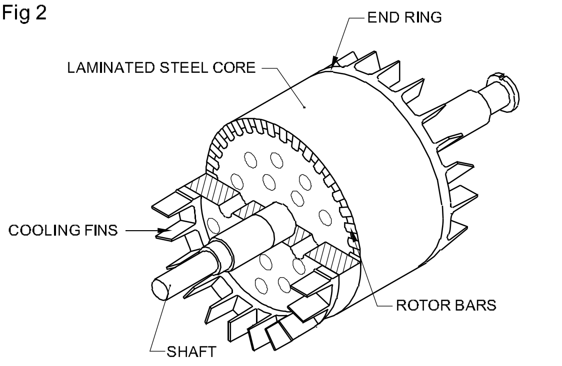
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase windings are placed 120 electrical degrees apart, and may be connected in either star or delta externally, for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Fig 1



Rotor of a squirrel cage induction motor: The rotor of the squirrel cage induction motor shown in Fig 2 contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end-ring at either end of the rotor core. On large machines, these conductor bars and the end-rings are made up of copper with the bars brazed or welded to the end rings as shown in Fig 3. On small machines the conductor bars and end-rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.

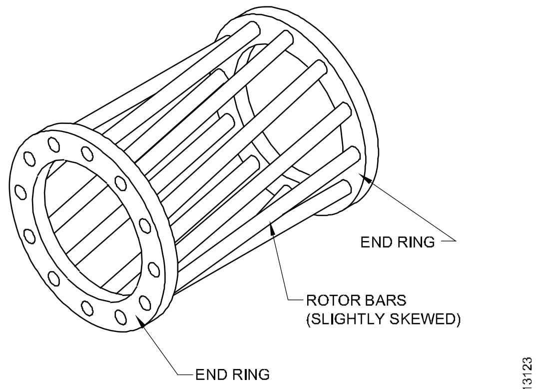
Fig 2



CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

The rotor or rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason, the stator is sometimes called the primary, and the rotor is referred to as the secondary of the motor. Since the motor operates on the principle of induction; and as the construction of the rotor, with the bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 3)

Fig 3



DETATCHED VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

The rotor bars are not insulated from the rotor core because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque; also it helps to reduce some of the internal magnetic noise when the motor is running.

End shields: The function of the two end shields which are to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

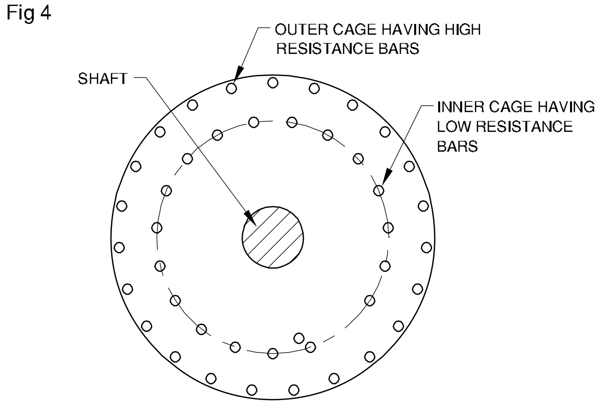
Double squirrel cage induction motor

Rotor construction and its working: This consists of two sets of conductor bars called outer and inner cages as shown in Fig 4. The outer cage consists of bars of high resistance metals like brass, and is short-circuited by the end-rings. The inner cage consists of low resistance metal bars like copper, and is short-circuited by the end-rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.

At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables to produce a high starting torque.

Fig 4

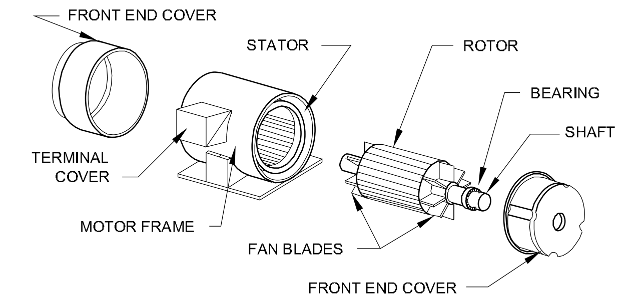


ROTOR OF THE DOUBLE SQUIRREL CAGE MOTOR

As the speed increases, the rotor frequency is reduced. At low frequency, the total resistance offered for the current flow in the inner cage reduces due to reduction of reactance ($X_L = 2\pi f_r L$), and the major part of the rotor current will be in the inner cage rather than in the highly resistant outer cage.

As such, the low resistance of the inner cage becomes responsible for producing a torque just sufficient to maintain the speed. Fig 5 shows the exploded view of 3 phase squirrel cage induction motor

Fig 5



PARTS OF 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Slip and rotor speed: We have already found that the rotor of an induction motor must rotate in the same direction as the rotating magnetic field, but it cannot rotate at the same speed as that of the magnetic field. Only when the rotor runs at a lesser speed than the stator magnetic field, the rotor conductors could cut the stator magnetic field for an emf to be induced. The rotor current could then flow and the rotor magnetic field will set up to produce a torque.

The speed at which the rotor rotates is called the rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the `slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed, it is called a fractional slip.

Therefore, fractional slip S

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

Then percentage slip (% slip)

$$= \frac{N_s - N_r}{N_s} \times 100$$

where N_s = synchronous speed of the stator magnetic field

N_r = Actual rotating speed of the rotor in r.p.m.

Most squirrel cage induction motors will have a percentage slip of 2 to 5 percent of the rated load.

Example

Calculate the percentage slip of an induction motor having 6 poles fed with 50 cycles supply rotating with an actual speed of 960 r.p.m.

Given:

Poles = 6

N_r = Rotor speed = 960 r.p.m.

F = frequency of supply = 50 Hz

N_s = Synchronous speed

$$= 120\frac{f}{P}$$

$$= \frac{120 \times 50}{6} = 1000 \text{r.p.m.}$$

$$\% \text{ slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$= \frac{1000 - 960}{1000} \times 100 = 4\%$$

Generated voltage in the rotor and its frequency: As the rotor cuts the stator flux, it induces voltage in rotor conductors and it is called the rotor voltage. The frequency of this rotor voltage is equal to the product of the slip and stator (supply) frequency (f_s).

Frequency of the rotor voltage

f_r = Fractional slip x stator frequency

$$= \frac{N_s - N_r}{N_s} \times f \text{ (or)}$$

From the above, we find that, at the time of starting, the rotor is at rest, and the slip will be equal to one and the rotor frequency will be the same as the stator frequency. When the motor is running at high speed, the slip will be low and the frequency of the rotor will also be low.

Example 1

A 3-phase induction motor is wound for 4 poles, and is supplied from a 50 Hz supply. Calculate a) the synchronous speed, b) the speed of the rotor when the slip is 4 percent, and c) the rotor frequency.

a Synchronous speed $= N_s = \frac{120f}{P}$

$$= \frac{120 \times 50}{4} = 1500 \text{ r.p.m.}$$

b Actual speed of the rotor = N_r

$$\text{Percentage slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$N_s - N_r = \frac{N_s \times \text{Percentage slip}}{100}$$

$$N_r = N_s - \frac{N_s \times \%\text{slip}}{100}$$

$$= 1500 - \frac{1500 \times 4}{100}$$

= 1440 r.p.m.

c Rotor frequency f_r = Slip x Stator frequency

$$= \frac{N_s - N_r}{N_s} \times f$$

$$= \frac{1500 - 1440 \times 50}{1500}$$

$$= \frac{60 \times 50}{1500} = 2 \text{ Hz.}$$

Example 2

A 12-pole, 3-phase alternator driven at a speed of 500 r.p.m. supplies power to a 8-pole, 3-phase induction motor. If the slip of the motor at full load is 3%, calculate the full load speed of the motor.

Let N_r = actual speed of motor

Supply frequency = frequency of alternator

$$= \frac{12 \times 500}{120} = 50 \text{ Hz.}$$

Synchronous speed N_s of the induction motor

$$= \frac{120 \times 50}{8} = 750 \text{r.p.m.}$$

$$\% \text{ slip } S = \frac{N_s - N_r}{N_s} \times 100 = 3$$

$$= \frac{750 - N_r}{750} \times 100 = 3$$

$$750 - N_r = \frac{3 \times 750}{100} = 22.5$$

N_r = 727.5 r.p.m.

Example 3

A 400V, 3-phase, eight-pole 50 Hz squirrel cage motor has a rated full load speed of 720 r.p.m. Determine

a the synchronous speed

b the rotor slip at rated load

b the percentage slip at rated load

d the percentage slip at the instant of start up

e the rotor frequency at the rated load

f the rotor frequency at the instant of start up.

Solution

a Synchronous speed $N_s = \frac{120 \times f}{p}$

$$= \frac{120 \times 50}{8} = 750 \text{r.p.m.}$$

b Slip at rated load = 750 - 720 = 30 r.p.m.

c Percent slip at rated load= $\frac{30 \times 100}{750} = 4\%$

d At the instant of start up the rotor speed is zero, and hence the percentage slip will be 100 percent.

e Rotor frequency at rated load f_r

$$= \frac{(f \times \text{percentage slip})}{100}$$

$$= \frac{50 \times 4}{100} = 2 \text{ Hz.}$$

f At the instant of starting the slip is 100 percent. Therefore, at this instant the rotor frequency will be equal to the stator frequency f_r (at starting) = f = 50 Hz.

Rotor copper loss: Rotor copper loss is the loss of power taking place in the rotor due to its resistance and the rotor current. Though the resistance of the rotor for a squirrel cage motor remains constant, the current in the rotor depends upon the slip, transformation ratio between the stator and rotor voltages and the inductive reactance of the rotor circuit.

Let T = torque developed by the motor

P_R = power developed in the rotor

P_m = power converted in the rotor as mechanical power

n_S = the synchronous speed in r.p.m.

n_r = the rotor speed in r.p.m.

Then $P_R = 2\pi n_s T$ watts

$P_m = 2\pi n_r T$ watts.

The difference between $P_R - P_m$ is the rotor copper loss.

$P_R - P_m$ = Rotor copper loss

Rotor copper loss $= 2\pi T(n_s - n_r)$

$$\frac{\text{Rotor copper loss}}{2\pi T} = (n_s - n_r)$$

$$\frac{\text{Rotor copper loss}}{2\pi n_s T} = \frac{(n_s - n_r)}{n_s}$$

= Fractional slip

Rotor copper loss = Fractional slip x Input power to the rotor

$= S \times 2\pi n_s T$.

Torque : The torque production in an induction motor is more or less the same as in the DC motor. In the DC motor the torque is proportional to the product of the flux per pole and the armature current. Similarly in the induction motor the torque is proportional to the flux per stator pole, the rotor current and also the rotor power factor.

Thus we have,

Torque is proportionally = Stator flux x rotor current x rotor power factor.

Let E_1 be the applied voltage

Ø be the stator flux which is proportional to E_1

S be the fractional slip

R_2 be the rotor resistance

X_2 be the rotor inductive reactance at standstill

SX_2 be the rotor inductive reactance at fractional slip S

K be the transformation ratio between stator and rotor voltages

E_2 be the rotor induced emf and equal to SKE_1

I_2 be the rotor current,

Cosθ be the rotor power factor.

Z_2 be the rotor impendence.

We can conclude mathematically the following final results.

$$T \alpha \, Ø \, I_2 \cos\theta$$

This can be deduced in to a formula

$$T \alpha \frac{SKE_1{}^2R_2}{R_2{}^2 + S^2X_2{}^2}$$

$$T \alpha \frac{\text{Rotor copper loss}}{\text{Fractional slip}}$$

$$\text{Starting torque } \alpha \frac{R_2}{R_2{}^2 + X_2{}^2} \quad \text{as fractional slip S = 1}$$

$$\text{Maximum torque } \alpha \frac{1}{X_2}$$

where X_2 in inductive reactance of the rotor at standstill and is constant.

Motor torque calculation: Since the stator flux and induced rotor current for an induction motor are not easily measured, the torque equation $T = K Ø_s I_R \cos \theta_R$ is not the most practical equation to be used for determining a motor torque. Instead the Prony Brake torque equation described earlier may be used, provided the motor's output power and Rev/min are known.

$$\text{Output power in watts} = \frac{2\pi \text{ x torque x Rev/min}}{60}$$

$$\text{Torque (newton metres)} = \frac{(60 \text{ x output watts})}{(2\pi \text{ x Rev/min})}$$

$$= \frac{(9.55 \text{ x output watts})}{(\text{Rev/min})}$$

A motor's power may also be stated in British horsepower (hp). In this case the output power in watts will be equal to the output horsepower multiplied by 746 (1 hp = 746w).

In case the motor power is given in metric horsepower, the output power in watts will be equal to the metric horsepower, multiplied by 735.6 (1 metric horsepower = 735.6 watts).

Example

Determine the torque in Newton metres produced by a 5 hp squirrel cage motors rotating at 1440 r.p.m.

Assuming it is metric horsepower, output power in watts

= hp x 735.5

= 5 x 735.5 = 3677.5 Watts.

$$\text{Torque (Newton metres)} = \frac{(60 \text{ x } 3677.5)}{(2 \text{ x } 3.14 \text{ x } 1440)}$$

= 24.4 Newton metres.

Classification of squirrel cage motors

Objectives: At the end of this lesson you shall be able to
- **state the squirrel cage bar arrangement for different classes of induction motors say class A, B, C, D, E & F**
- **compare the starting torque, starting current and slip for different types of squirrel-cage motors.**

The three-phase squirrel cage motors have been standardised according to their electric characteristics into six types designated as design A, B, C, D, E and F. Standard squirrel cage induction motors which were of shallow, slot types are designated as class A. For this reason class A motors are used as a reference and are referred to as 'normal starting-torque', normal starting current, normal slip motors.

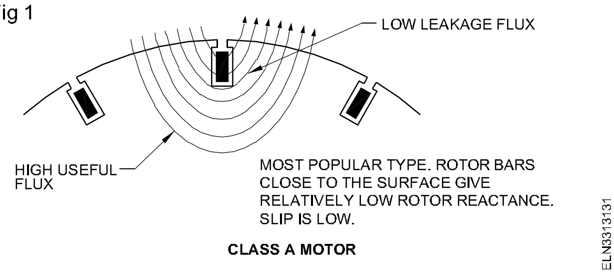
Classes of squirrel-cage motors
(According to starting characteristics)

Class	Starting torque	Starting	Current Slip
A	Normal	Normal	Normal
B	Normal	Low	Normal
C	High	Low	Normal
D	High	Low	High
E	Low	Normal	Low
F	Low	Low	Normal

Out of these six, four specific designs A through D are common squirrel cage motors. These four classes, however, cover nearly all practical applications of induction machines.

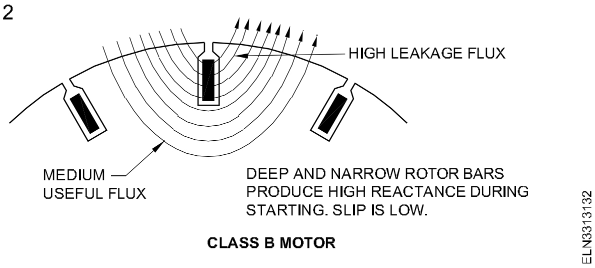
Class A motors: These motors are characterised by having a low rotor-circuit resistance and reactance. Its locked rotor current with full voltage is generally more than 6 times the full load current. Because of their low resistance, starting currents are very high. They operate at very small slips (s < 0.01) under full load. Machines in this class are suitable only in situations where very small starting torques are required. The rotor bar construction of such motor is shown in Fig 1.

Fig 1



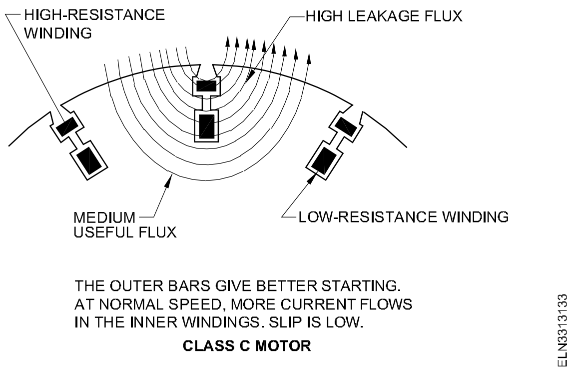
Class B motors: These are general purpose motors of normal starting torque and starting current. The speed regulation at full load is low (usually under 5%) and the starting torque is in the order of 15% of the rated speed being lower for the lower speed and larger motors. It should be realised that although the starting current is low, it generally is 600% of full load value (Fig 2).

Fig 2



Class C motors: Compared to class B motors, class C motors have higher starting torque, normal starting current and run at slips of less than 0.05 at full load. The starting torque is about 200% of the rated speed and the motors are generally designed to start at full-load. Typical application of this class motor is driving conveyors, reciprocating pumps, and compressors (Fig 3).

Fig 3



Class D motors: These are high slip motors with high starting torque and relatively low starting current. As a result of the high full load slip, their efficiency is generally lower than that of the other motor classes. The peak of the torque speed curve, resulting in a starting torque of about 300%, is identical to the starting torque. (Fig 4)

Class E motor: The Fig 5 shows the class 'E' motor having Low starting torque and low current slip

Class F motor: The Fig 6 shows the class 'F' motor having low starting torque and normal current slip

Fig 4

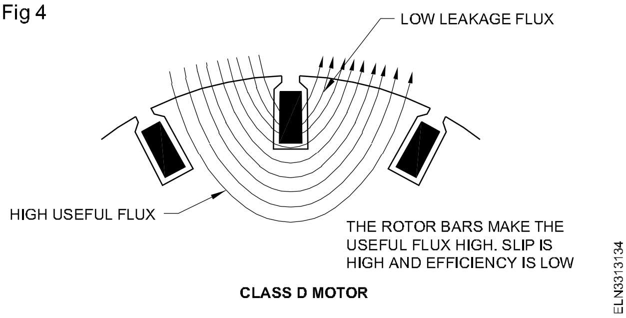


Fig 5

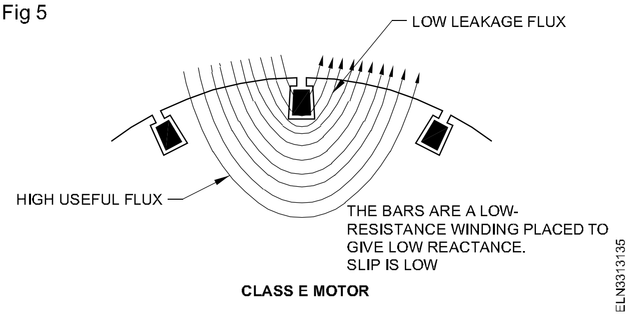
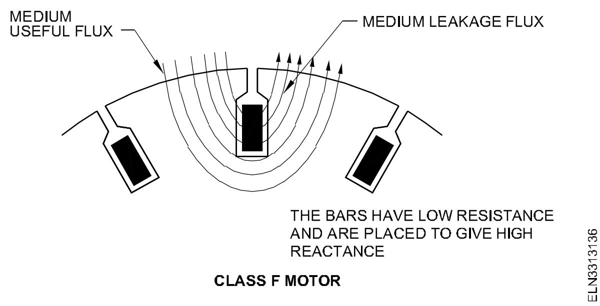


Fig 6



Now when the motor is stationary, the frequency of the rotor current is the same as the supply frequency. But when the rotor starts revolving, then the frequency depends upon the relative speed or on slip speed. Let at any slip speed, the frequency of the rotor current be f', then

$$N_s - N = \frac{120f'}{p}$$

also, $N_s = \dfrac{120f}{p}$

Dividing one by the other, we get

$$\frac{f'}{f} = \frac{N_s - N}{N_s} = s \quad f' = sf$$

Insulation test on 3 phase induction motors

Objectives: At the end of this lesson you shall be able to

- **state the necessity for and the method of testing continuity and insulation resistance in a 3-phase induction motor**
- **state the necessity of continuity test before insulation test**
- **state the N.E. code and B.I.S. recommendations pertaining to insulation tests and earthing of a 3-phase induction motor.**

It is often said that electricity is a good servant but a bad master. This is because electricity is so useful but can cause accidents, and even death if one is careless. A large number of accidents, which occur in electrical motors, is due to leakage of current from the conducting part of the motor to the non-conducting part. The main reason is the weak insulation caused by the damaged insulation materials of the motor.

Insulation materials used on winding wires or in between winding wires and the slots of the laminated core, or the insulated sleeves of lead cables may get damaged due to the following reasons.

- Moisture content in the atmosphere (*Ex.* Electrical motors in harbours)
- Chemicals and their fumes in the surroundings (Ex. Electrical machines in chemical plants)
- High temperature of the surrounding (Ex. Electrical machines in steel rolling mill)
- High temperature emanating from the machine itself while working. (Ex. Electrical machines at hill tops where the cooling ability of the thin air is poor.)
- Dust, dirt, oil particles deposited on the windings and cables. (Ex. Electrical machines in cement plants, oil mills, chemical plants etc.)
- Aging of the machine.

When the insulation deteriorates, the insulation resistance value is reduced, and the current may leak to the frame of the electrical machine. If the machine is not properly earthed, the leakage currents may develop a dangerous potential on the frame. If somebody comes in contact with the frame, he may get even fatal shocks. These leakage currents also produce erroneous readings in the measuring equipment, and also affect the working of the other electrical equipments. As such the National Electrical Code has stipulated certain minimum standards for the insulation resistance value.

Method of testing insulation resistance of the electrical motor and the recommended value of the resistance as per National Electrical Code: Before putting into operation, the electrical motor must be tested for its insulation resistance. This is to make sure that there is no leakage between the current carrying parts of the motor and the non-current carrying metal parts of the motor. As insulation resistance may fail during the course of operation due to the reasons mentioned above, it is most necessary to check the insulation resistance at intervals, say once in a month, for any motor which is in operation, as a preventive maintenance check. These values of insulation resistance must be recorded in the maintenance card and whenever the value goes below the accepted value, the motor winding has to be dried and varnished to improve the conditions.

Condition and acceptable test results: According to NE code, the insulation resistance of each phase winding against the frame and between the windings shall be measured. A megohm-meter of 500V or 1000V rating shall be used. Star points should be disconnected while testing.

To avoid accidents due to weak insulations, first the insulation resistance value between any conducting part of the machine and the frame of the machine should be tested, and the measured value should not be lesser than one megohm as a thumb rule, or more precisely should not be less than a value based on the voltage and rated power of the motor as given in the National Electrical Code.

$$\text{Insulation resistance } R_i = \frac{20 \times E}{1000 + 2P}$$

where

R_1 is the insulation resistance in megohms at 25°C

E_n related phase-to-phase voltage and

P rated power in KW.

If the resistance is measured at a temperature different from 25°C, the value shall be corrected to 25°C.

General instruction for the measurement of insulation resistance: Insulation resistance of an electric motor may be in the range of 10 to 100 megohms but as it varies greatly in accordance with the temperature and humidity of the electric motor, it would be difficult to give a definite value. When the temperature of such a motor is raised, the insulation resistance will initially drop considerably, even below the acceptable minimum. If any suspicion exists on this score, the motor winding shall be dried out. The equation given above is used to calculate the insulation resistance as a standard value. However it should not be less than 1 megohm as an acceptable value.

Secondly, in the case of accidental leakage of currents from any current carrying part to non-current carrying metal part, there should be a ground system which should provide a minimum impedence path for the faulty (leakage) current to flow. Thereby protective devices like fuses or circuit-breakers or earth leakage circuit-breakers or earth fault relays would function and disconnect the supply to the defective motor circuit.

However, this will not be possible unless and until the ground (earth) system has minimum impedance. This could be achieved by the following means.

– Using low resistance earth continuity conductors between the frame of the motor and the earth electrode.

– Providing rust-proof metal parts like bolts, nuts and lugs for connecting the earth continuity conductor (ECC) with the frame as well as the main electrodes. (Galvanised nuts and bolts are to be used.)

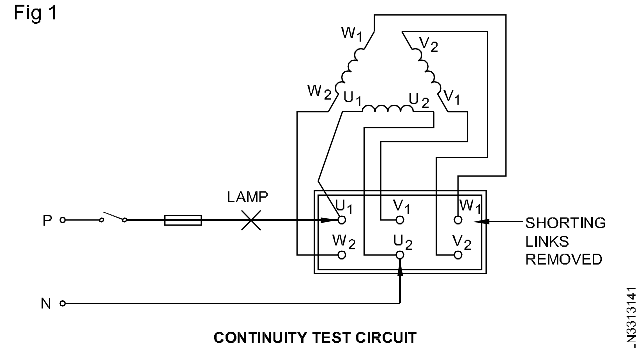
– Keeping the earth electrode resistance value as low as possible such that in case of leakage, any one unit of the protective system will operate to isolate the motor from the supply.

Necessity of continuity test before insulation test: While testing the insulation resistance between the winding and the frame, it is the usual practice to connect one prod of the Megger to the frame and the other prod to any one of the terminals of the winding. Likewise, when testing insulation resistance between windings, it is the usual practice to connect the two prods of the Megger to any two ends of a different winding. In all the cases it is assumed that the windings are in sound condition and the two ends of the same winding will be having continuity. However, it is possible the winding may have a break, and part of the winding may have a higher insulation resistance and the other part might have been grounded. Hence, to increase the reliability of the insulation resistance test, it is recommended that continuity test may be conducted in the motor before the insulation test, to be sure, that the winding is sound and the insulation resistance includes the entire winding.

Continuity test: The continuity of the winding is checked by using a test lamp in the following method as shown in Fig 1. First the links between the terminals should be removed.

The test lamp is connected in series with a fuse and a switch to the phase wire and the other end is connected to one of the terminals (say U_1 in Fig 1). The neutral of the supply wire is touched to the other terminals one by one. The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say U_2 in Fig 1). The pairs are to be found in a similar manner. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminals shows short between the windings.

Fig 1

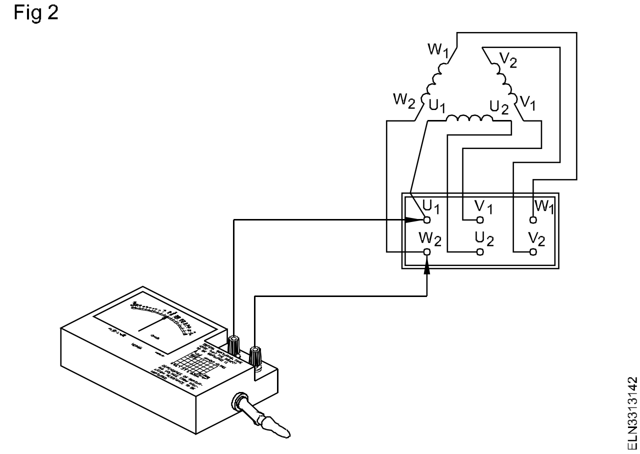


CONTINUITY TEST CIRCUIT

Limitations of lamp continuity test: However, this test only shows the continuity but will not indicate any short between the turns of the same winding. A better test would be to use an ohmmeter having an accurate low resistance range to measure the resistance of the individual windings. In a 3-phase induction motor, the resistance of the three windings should be the same, or more or less equal. If the reading is less in one winding, it shows that the winding is shorted.

Insulation test between windings: As shown in Fig 2, one of the Megger terminals is connected to one terminal of any one winding (say U_1 in Fig 2) and the other terminal of the Megger is connected to one terminal of the other windings (say W_2 in Fig 2).

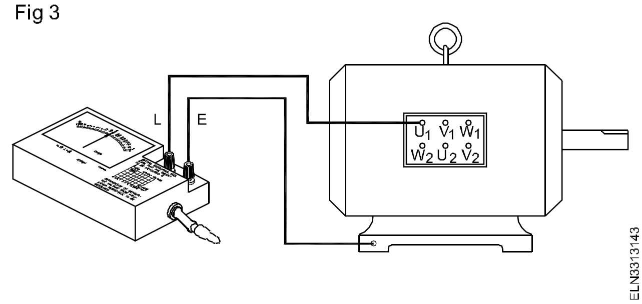
Fig 2



When the Megger handle is rotated at its rated speed, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings, and needs to be improved. Likewise the insulation resistance between the other windings is tested.

Insulation resistance between windings and frame: As shown in Fig 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger handle is rotated at the rated speed, the reading obtained should be more than one megohm. A lower reading than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.

Fig 3



Likewise the other windings are tested.

Necessity of frame earthing: The frame of the electrical equipment/machine needs to be earthed because :

- the earthing system provides safety for persons and apparatus against earth faults.
- the object of an earthing frame is to provide as nearly as possible a surface under and around the motor which shall be of uniform potential, and as near zero or absolute earth potential, as possible.

According to I.E.rules, for reasons of safety, the frame of the motor has to be connected by two distinct earth connections to two earth electrodes with the help of properly sized earth continuity conductors. Further the earth system resistance (earth electrode 5 ohms and earth continuity conductor one ohm, if not specified) should be sufficiently low such that the protective devices in the motor circuit will operate and isolate the circuit in case of earth faults.