Materials used for winding - field coil winding

Objectives: At the end of this lesson you shall be able to
- **classify different types of insulating materials used for winding according to their ability to withstand temperature**
- **list out the insulating materials used for winding and their applications.**

Insulating materials : In winding work, proper selection of insulating materials is an important criterion. The ageing factor of the insulation of electrical equipment and apparatus depends upon many factors, such as temperature, electrical and mechanical stress, vibration, moisture, dirt and chemical reaction.

Classification of insulating materials used for winding: The temperature encountered in electrical equipment and apparatus very often decides the ageing factor of insulating materials of the system. Certain basic thermal classifications have proved useful and have been accepted throughout the world. Hence the insulating materials used for winding are classified according to their ability to withstand a particular range of temperatures.

Each class of insulation is associated (according to BIS 1271-1985) with a particular temperature. When this temperature is not exceeded, it will ensure an economic life for the insulation of an equipment under usual conditions of service. One must also take into account other factors like vibration, dirty conditions, the presence of chemicals, etc. since these factors may cause early breakdown of an insulation material.

The recognised classes of the most commonly used insulating materials and the temperatures assigned to them are given in Table 1.

The temperature quoted in Table 1 is the actual temperature of the insulation and not the rise in temperature of the electrical equipment.

Table 1

Classification of insulations
(as per BIS:1271-1958/1985)

Sl. No.	Class	Max. safe temp.	Description of insulation material
(1)	**(2)**	**(3)**	**(4)**
1	Y	90°C	Cotton, silk, paper without impregnation,
2	A	105°C	Cotton,silk, paper immersed in oil.
3	E	120°C	Leatheroid paper, empire cloth., fibre.
4	B	130°C	Mica, glass fibre, asbestos.
5	F	155°C	The insulation of this class consists of materials of a better quality than class B insulation. Glass fibre, mica,asbestos etc.
6	H	180°C	Silicon elastomer and combinations of materials such as mica, glass fibre, asbestos etc.
7	200 220 250	200°C 220°C 250°C	This class consists of materials such as mica, porcelain, glass, quartz, etc.

Materials: The following are the common insulating materials used for winding purposes.

Insulation paper sheets: They are generally used for insulating slots and other metal parts from the live wire in a winding system.

Leatheroid paper: It is a special paper having better ageing and dielectric strength. It is available in colours of dark grey and bottle green. It is used for Class A insulation scheme.

Pressphan paper: It consists of highly glazed and pressed paper, having good dielectric strength. Normally, it is available in yellow colour. Used for Class A insulation scheme.

Triplex paper: In this a layer of polyester film is deposited on the surface/surfaces of leatheroid or pressphan paper or elephantide paper to make it non-hygroscopic. Normally one side of this paper is glazed and colours may be brown, green, grey or yellow depending upon the papers used. This paper is used for Class E insulation schemes.

Millinex paper: This is a synthetic paper, milky white in colour. It is highly non-hygroscopic and possesses good electrical and mechanical strength. Used for class E and B insulation schemes.

Micanite paper (mica folium) and micanite cloth: It consists of soft mica, bonded with paper or cloth base. This can withstand higher temperatures. Normally it is white in colour with the mica visible. Used for Class E and B insulation schemes.

Empire cloth: It is an impregnated cloth and is highly flexible. Generally it is available in black or yellow colour, depending upon the colour of the varnishes used. It is recommended for Class A insulation scheme.

Glass fibre cloth: It is a cloth made of glass wool. It has high dielectric strength and can withstand high temperature. It is highly flexible. When not impregnated, the colour is white. Impregnated fibre glass cloth is normally used in winding, and the colour will be golden yellow or black. Used for Class E and B insulation schemes.

The above insulating sheets are available in thicknesses of 2 mil, 5 mil, 7 mil, 10 mil & 15 mil, having a width of one metre. They are generally sold in kilograms.

For Classes `F' and `H', special type of insulation sheets are used. Some of the brand names are `Hypotherm and Nomex'.

TAPES**:** These are used for wrapping the conductor or groups of conductors in the winding process.

Cotton tape: Generally it is not impregnated and is available with cross and straight woven fabric. It is white in colour. Used for Class A and E insulation schemes.

Empire tape: It is an impregnated cloth tape. The colour of the tape will be the colour of the impregnating varnish used, i.e. yellow or black. Used for class A insulation scheme.

Fibre glass tape: It is available as either impregnated or non-impregnated types. It has got high dielectric strength and can withstand high temperature. It is generally used for Class E, B and F insulation schemes.

The above mentioned tapes are available in sizes 2,5, 7 and 10 mils thick, 12mm, 19mm and 25 mm wide-in rolls of 25, 50 and 100 metres.

For class `F' and `H' insulation schemes, special types of silicon based tapes are used. For example, SILICON-ELASTOMER which is a brand name.

SLEEVES : Sleeves are used to insulate winding lead connections and terminations.

Cotton sleeves: These are made of cotton fabric, generally not varnished. They are used for class A insulation scheme.

Empire sleeves: These are impregnated cotton sleeves and are used for class A insulation scheme.

Fibre glass sleeves : These are impregnated fibre glass, woven fabric sleeves. Generally, they are yellow and black in colour. Used for class E, B & F insulation schemes.

PVC sleeves: These are made up of polyvinyl chloride sheets and are available in different colours. They are highly non-hygroscopic. Due to their deterioration at rise in temperature, they are not used for winding purposes. They may be used for insulating exposed lead terminations.

The above mentioned sleeves are available in sizes 1mm, 2mm, 3mm, 4mm up to 12 mm in dia. and generally one metre long. Sometimes they may be rolled into 25, 50 and 100 metre rolls.

Other insulating materials

Fibre: Generally fabric-based fibre is used in insulation. It is used for wedges and packing purposes. It is somewhat reddish in colour and is available in sheets with a thickness of 1 mm to 12 mm, and is sold by weight in kgs. It is used for Class A,E & B insulation schemes.

Bamboo: Well seasoned bamboos are used as wedges in the winding process. Readymade cut pieces of suitable sizes are available in shops. It is used for Class A & E insulation schemes.

Hemp thread: It is used for binding the coils and overhangs. It is available in different thicknesses and in rolls. Used for Class A insulation scheme.

Terylene thread: It is made up of terylene material and is used for binding the coils and overhangs. It is available in different thicknesses and in rolls. It is suitable for Class E & B insulation schemes.

Varnish: It is a liquid insulating material which is used for increasing the insulating property of some of the materials used in the winding process. Two types of varnishes are available for winding purposes.

– Air-drying insulating varnish

– Baking insulation varnish

These varnishes are available in two colours, golden yellow and black. They are available in tins of 1 to 5 litres normally.

More particulars about varnish and varnishing processes are discussed in Ex. 3.2.130.

Winding wires

Objectives: At the end of this lesson you shall be able to
- **refer to a winding-wire table having particulars like gauge number, diameter, area of cross-section, weight per km, accommodation of turns per square cm and their current-carrying capacity etc.**
- **state the scheme of insulation of a field coil**
- **explain the method of winding field coils**
- **explain the method of connecting the field coils,and the method of testing.**

Winding wires : The annealed copper conductors, normally in round shape, are used for winding small and medium capacity electrical machines and equipments. These copper wires are provided with a variety of insulation as stated below.

- Super-enamelled copper wire (S.E.)
- Single cotton-covered copper wire (S.C.C.)
- Double cotton-covered copper wire (D.C.C.)
- Single silk-covered copper wire (S.S.C.)
- Double silk-covered copper wire (D.S.C.)
- PVC-covered copper winding wire

Generally super-enamelled copper winding wire with medium covering is used for most of the winding applications, whereas for some special applications super-enamelled copper wire with thick covering may be used.

Field coils and armature of certain DC machines might be wound with super-enamelled, DCC or DSC copper winding wires.

PVC covered copper winding wire is mainly used for submersible pumps.

The winding wires are available in different sizes and grades of insulation.

All the required particulars for SE copper wire having medium covering are given in Table 1.

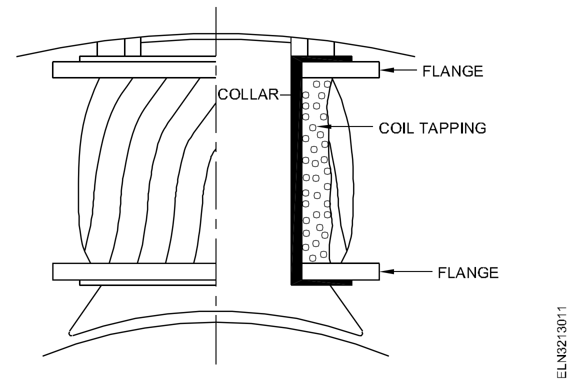
Such tables are published by all leading manufacturers of winding wires to help the winder in his task. The current-carrying capacity of the conductor shown in Table 1 is at 2.3A/ mm^2. In general usage, a rating nearly 3 to 4 times higher in value, is used depending upon the insulation and temperature grade of the machinery.

Winding of field coils: In rewinding a field coil, special attention shall be given for selection of proper winding wire - its insulation, correct size of coil and the insulation scheme involved in different stages so as to satisfy the original condition, unless otherwise warranted by necessity.

Insulation details for a field coil : The field coil shall be well insulated from the frame, field pole and pole shoes.

Collar : The insulation used around the field pole, called a collar, is shown in Fig 1.

Fig 1



Flanges: The insulation used on either side of the coil i.e. to insulate it from the frame and pole shoes is called flanges. (Fig 1)

Table 1

(Data for super - enamelled copper wire)

Size	Dia-meter inches	Dia-meter mm	Area sq. mm	Turns per square cm.	Curr-ent in am-pere	Per 1000 metre in Kg.
14	.080	2.03	3.244	22	7.5	28.18
15	.072	1.82	2.63	27	6.1	22.84
16	.064	1.62	2.1	33	4.8	18.06
17	.056	1.42	1.59	42	3.7	13.85
18	.048	1.21	1.167	58	2.7	11.05
19	.040	1.01	0.811	87	1.9	7.08
20	.036	.91	0.636	105	1.5	5.75
21	.032	.81	0.52	134	1.2	4.55
22	.028	.71	0.4	172	.92	3.58
23	.024	.60	0.29	234	.68	2.56
24	.022	.55	0.25	275	.57	2.24
25	.020	.50	0.202	329	.4	1.78
26	.018	.45	0.162	397	.38	1.45
27	.0164	.41	0.137	484	.32	1.29
28	.0148	.37	0.111	583	.26	1.01
29	.0136	.34	0.094	680	.22	0.804
30	.0124	.31	0.078	834	.18	0.712
31	.0116	.29	0.070	939	.158	0.646
32	.0108	.27	0.06	1,068	.137	0.505

Size	Dia-meter inches	Dia-meter mm	Area sq. mm	Turns per square cm.	Curr-ent in am-pere	Per 1000 metre in Kg.
33	.0100	.26	0.055	1,070	.118	0.45
34	.0092	.23	0.043	1,490	.100	0.362
35	.0084	.21	0.036	1,744	.083	0.324
36	.0076	.19	0.029	2,085	.068	0.261
37	.0068	.17	0.023	2,542	.054	0.209
38	.0060	.15	0.018	3,162	.042	0.164
39	.0052	.13	0.014	4,379	.032	0.127
40	.0048	.12	0.0117	5,030	.027	0.114
41	.0044	.11	0.0098	6,060	.028	0.09
42	.0040	.10	0.0078	7,692	.018	0.073
43	.0036	.09	0.0064	9,375	.015	0.06
44	.0032	.08	0.005	12,000	.012	0.047
45	.0028	.07	0.0039	15,384	.009	0.037
46	.0024	.06	0.0028	21,428	.006	0.026
47	.0020	.05	0.00196	30,612	.005	0.015
48	.0016	.04	0.00126	47,619	.003	0.012

*** Current carrying capacity taken as 2.3 ampere per sq. mm.**

Coil wrapping or coil taping : The insulation used around the coil is called coil wrapping or coil taping.

For example, the following are the details of insulation for a typical field coil.

- Conductor - super-enamelled copper wire with medium covering.
- Collar - 10 mils single, leatheroid.
- Flanges - 15 mils single, leatheroid.
- Coil wrapping - two layers of 7 mils, 19 mm wide cotton tape.
- Coil lead covering - empire sleeves.
- Varnish - air-dry, golden yellow, Class E. varnish.

Preparation of a field coil : Field coils are wound with insulated copper wire whose diameter and number of turns depend on the exciting voltage and machine capacity. While rewinding, it is essential to follow the same size of winding wire,coil and insulation scheme as that of the original. The wire can be wound on a wooden former that consists of a centre-piece (cut to the size of the inner dimensions of the coil) and two side pieces to hold the coil in place. The construction of the former is given in Fig 2. The centre-piece (winding frame) is slightly tapered to one side to facilitate removal of the coil from the former. Proper shape of the coil could be retained during its removal from the former after completion of the winding, if strips of tape or cord are placed on the centre-piece (winding frame) before starting the winding of the coil as shown in Fig 3. These tapes or cords can then be tied up easily after completion of winding as shown in Fig 4. The former is placed in a lathe chuck or in a coil-winding machine or in a hand winder to wind the coil, with the same size wire and the same number of turns as those of the original coil. The collar and flange insulation papers should be of the same type, grade,thickness and size as those of the original.

Fig 2

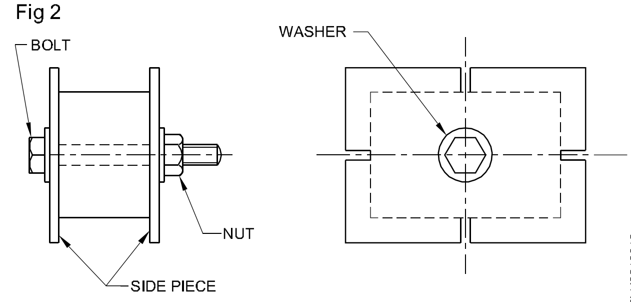


Fig 3

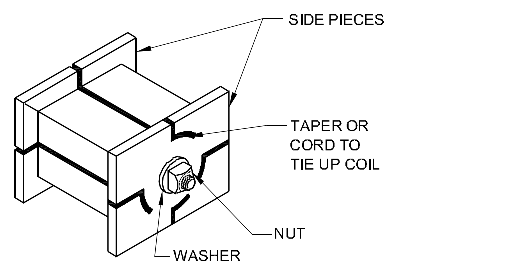
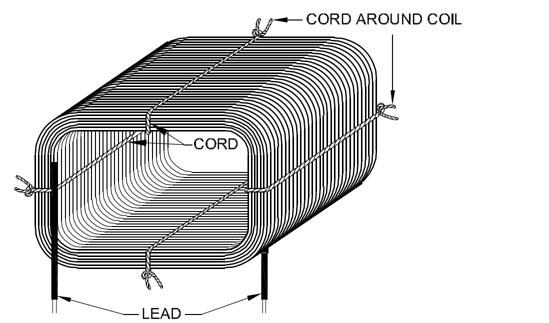
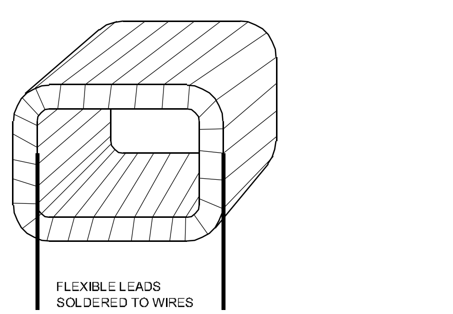


Fig 4



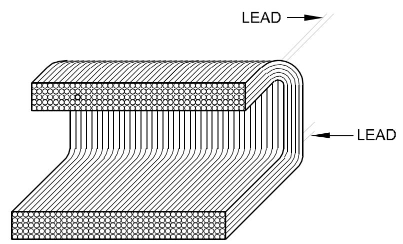
The size of the former may be obtained from the original coil or by measuring the dimensions of the field pole and allowing for the thickness of the tape. (Fig 5 shows the coil taped with cotton tape.)

Fig 5



When a field coil consists of many turns of fine wire arranged as shown in the cut-away view of shunt field winding (Fig 6), there may be thousands of turns. It is not advisable to try to rewind this type of coil by counting the number of turns. The usual method is to weigh the old coil and to wind the new coil with the same wire size having the same weight.

Fig 6



A CUTAWAY VIEW OF A SHUNT-FIELD WINDING

However, Table 1 could be used to check whether the coil, when wound, will be having the same size as that of the original so that it could be accommodated without difficulty.

Often in such trials it is found that the coil after completion is found to be larger in size and has to be modified by reducing some of the turns.

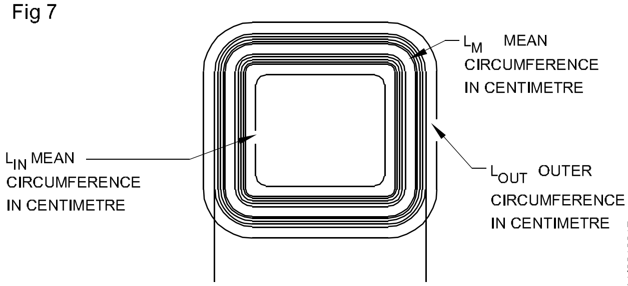
Reasons for such problems can be as follows.

- Slight change in diameter of the selected winding wire.
- Extra thick coating of insulation.
- Loose winding.
- Slight change in thickness of the insulation paper used in between the layers.

Procedure to find the size of the coil before actual winding: Weigh the coil without taped insulation and refer to the last column of Table 1 and determine the length of the winding wire in metres. From the original coil determine the average length of a turn.

Suppose, referring to Fig 7, we have

Fig 7



inner circumference of the coil = L_{IN} cm.

outer circumference of the coil = L_{OUT} cm.

mean circumference of the coil

$$L_M = \frac{L_{IN} + L_{OUT}}{2}$$

The mean circumference of the coil could be taken as length of one turn.

$$\text{No. of turns of the coil} = \frac{\text{Total length of winding wire}}{\text{Length of the turn}}$$

After determining the number of turns, refer to the column under `Turns per square cm' against the chosen winding wire.

Using the following formula, the cross-section of the proposed coil in sq cm could be found.

$$\text{Cross - section of the coil in sq.cm.} = \frac{\text{Total number of turns}}{\text{Turns per sq.cm.}}$$

Check the available space with respect to the calculated cross-section of the coil. You may multiply the cross-section of the coil by a factor of 1.25 to allow for the additional area required for insulation.

Termination of field coil leads: While winding, see that the ends of the coil are taken to the coil sides. Insulate the end leads with the proper size of cotton/empire/fibre glass sleeving and terminate the same. In the case of fine super-enamelled copper wires used for coil winding, use insulated flexible cord for lead connections. (Fig 5)

Solder the flexible cord with the enamelled copper wire. At the end, the soldered joints should be insulated properly with empire/fibre glass tapes.

Taping the field coil : When required, tape the coil with a suitable size of cotton/empire/fibre glass tape. Before starting for taping, tie down the end leads of the coil to prevent them from being cut or damaged. Tape the coil tightly and uniformly. The tape of the coil must not tear or slip off while it is being placed on the pole.

Some field coils may not be taped. But they are definitely insulated from the body and pole using insulating paper flanges and collars.

Grounding of a field coil may be caused by careless insulation work at this stage.

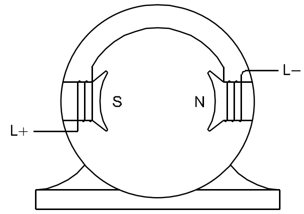
Varnishing the field coil : After preparing the field coil, preheat the coil in an oven at about 90°C for 3 to 4 hours to drive the moisture out from the field coil. Cool the coil to 60°C and dip the coil in baking varnish for 5 to 10 minutes, till the air bubbles ceases in the varnish tank. Drain the varnish and bake in the oven at 120°C for 6 to 8 hours.

After the varnishing is over, assemble the field coils on the field poles. While laying the field coils, observe the lead end position for the right connection.

Connecting field coils : In DC machines, the field coils are connected so that alternate polarity is formed in the machine.

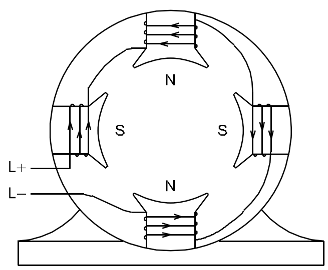
Thus, in a two-pole DC machine as shown in Fig 8, one of the poles is north and the other one is south. In a four-pole DC machine the poles must be alternately north and south as shown in Fig 9.

Fig 8



IN A TWO-POLE MOTOR, THE FILEDS ARE CONNECTED TO FORM A NORTH AND SOUTH PLOE

Fig 9



NORTH AND SOUTH POLES IN A FOUR-POLE MOTOR

The field coils are connected in series except in very large DC machines and in machines that have been reconnected from a higher to a lower voltage, in such cases they are connected in parallel with reverse polarity for alternate poles.

To form alternate polarity in the field coils, which are wound in a similar direction, the current should flow through the first pole coil - say in a clockwise direction, through the second pole coil in a counter-clockwise direction and through the third pole coil in a clockwise direction and the fourth pole coil in an anticlockwise direction and so on. It is extremely difficult to determine this direction once the field coils are taped, as the direction of the winding turns is not visible.

Testing of field coil connections : There are two methods to test the correct field coil polarity.

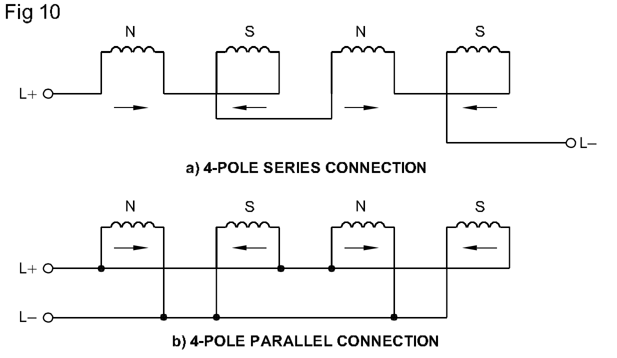
– Compass method

– Iron rod method

Compass method : The compass method may be used on any number of poles. (If it is a compound motor, test one field winding - either shunt or series at a time.) For testing the field coils of a four-pole motor, the four field coils are connected in series, as shown in Fig 9.

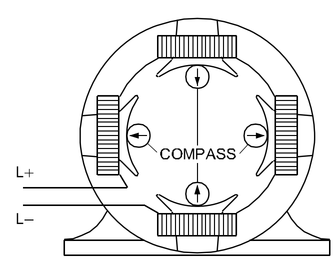
Fig.10 shows series and parallel connection of field coils to create alternate poles

Fig 10



Then a low DC voltage, say 10 to 20% of the rated voltage, is applied to the field circuit. A compass is placed near a pole either inside of the machine or alongside the field coil as shown in Fig 11. A notation is made as to the end of the needle which points to the pole. When the compass is moved to the next pole, the other end of the needle should be attracted. Thus the poles should be of alternate polarity. If not, interchange the lead connection of the particular field coil.

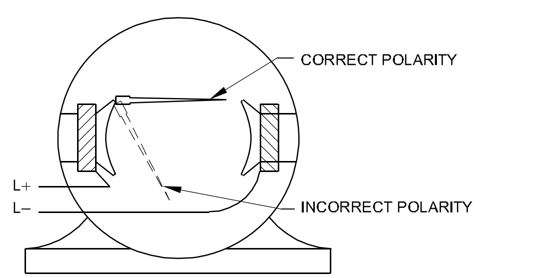
Fig 11



ON A 4-POLE MOTOR, ADJACENT POLES MUST HAVE OPPOSITE POLARITY

Iron rod method : In this method, the rated DC voltage is applied to the field circuit. The head of an iron nail is placed against one pole, as shown in Fig 12. If the polarities are correct, the other end of the nail will be attracted to the next pole; if incorrect, it will be repulsed.

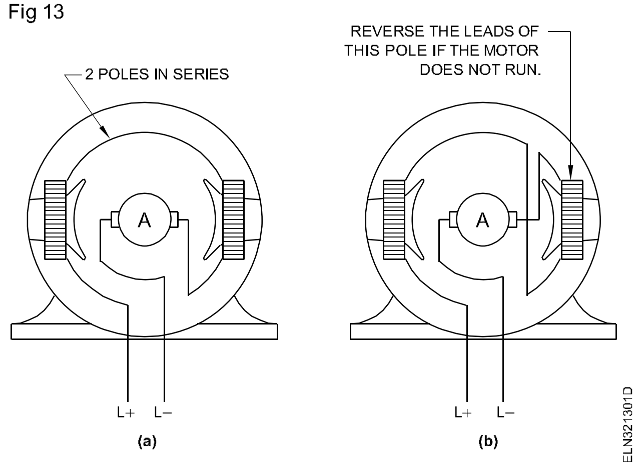
Fig 12



TESTING POLARITY OF THE FIELD COILS WITH A NAIL

In the case of a small two-pole DC motor, the trial and error method is used. Initially two field coils and armature are connected in series as shown in Fig 13a. If the motor runs, the polarities of the connected field poles are correct. If the motor does not rotate, interchange the field coil connection as in Fig 13b. If the motor runs, it is assumed the field and armature are in good condition and properly connected.

Fig 13



Armature winding - terms - types - rewinding of mixer/liquidizer

Objectives: At the end of this lesson you shall be able to
- **define the general terms used in DC armature winding**
- **explain the different types of DC armature winding.**

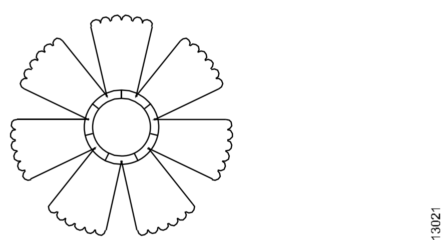
Winding : Winding is an orderly arrangement of insulated conductors in the slots of armature/stator cores with their end connection in a specified sequence.

Winding is mainly classified as:

- closed coil winding
- open coil winding.

Closed coil winding : It is also called DC armature winding. In closed coil winding, the end of the coil, after connecting through the other coils in the armature, finds itself connected to the commencement end of the starting coil as shown in Fig 1.

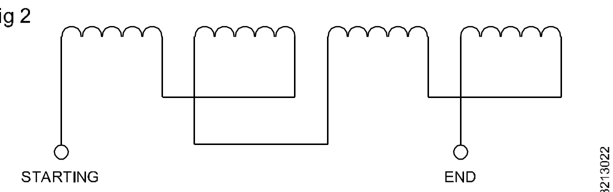
Fig 1



CLOSED COIL WINDING

Open coil winding : It is also called AC stator winding. In open coil winding, the end of the coil after connecting through other coils in the stator, is terminated as end lead, i.e. the starting end of the coil and the finishing end of the coil are kept open as shown in Fig 2.

Fig 2



OPEN COIL WINDING

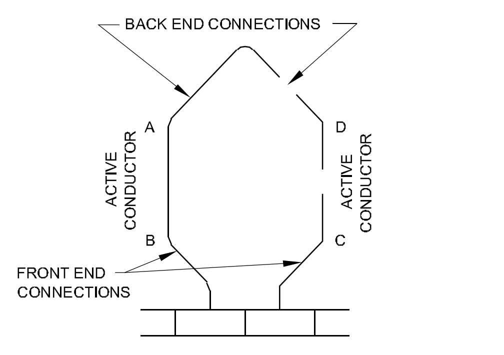
DC armature winding : It is a closed coil winding, wherein the coil ends are connected through the commutator segments to form the closed circuit.

Terms used in DC armature winding

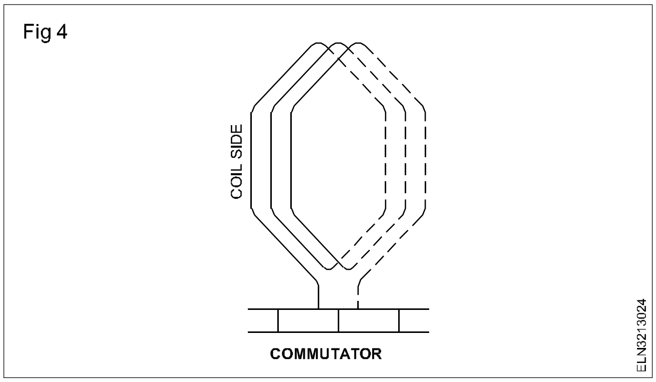
Coil or winding element : Length of a wire lying in the magnetic field and in which an emf is induced is called an active conductor.

Referring to Fig 3, we find the two active conductors AB and CD along with their end connections constitute one coil or winding element of the armature winding. The coil may consist of a single turn only as shown in Fig 3 or multi-turns as shown in Fig 4. A single-turn coil or winding element will have two conductors only. But a multi-turn coil may have many conductors per coil side. In Fig 4 for example, each coil side has 3 conductors. The group of conductors constituting a coil side of a multi-turn coil is tied together with a tape as a unit (Fig 5) and is placed in the armature slot. It may be noted that each winding element has two connecting leads and each commutator bar has two connecting leads brought from the winding. As such there are as many commutator bars as the number of winding elements.

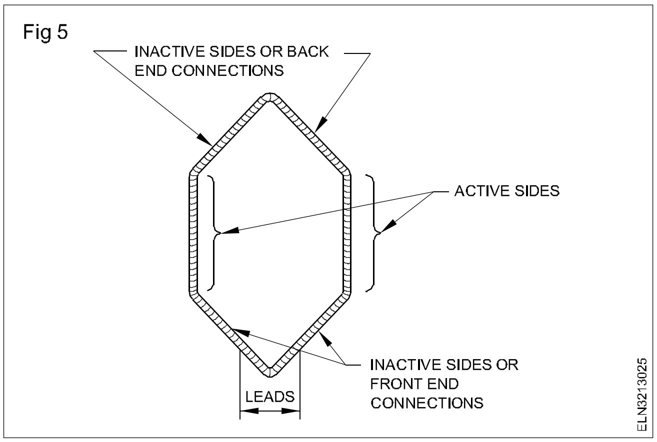
Fig 3



COMMUTATOR



Active sides : These are the sides which lie within the slots. They are also known as coil sides. The induction takes place only in the active sides of the coil while they move in the magnetic field. (Fig 5)



In winding calculation these active sides are considered as conductors. The coil has got two conductors irrespective of the number of turns.

Inactive sides : That part of a coil which does not lie in the slot is known as the inactive side of a coil. No induction takes place in the inactive sides.

Example: Back and front end connections. (Fig 5)

Leads of coil : The ends coming out from a coil are known as leads of a coil. Every coil has got two leads.

Pole-pitch(Y_p) : It may be variously defined as:

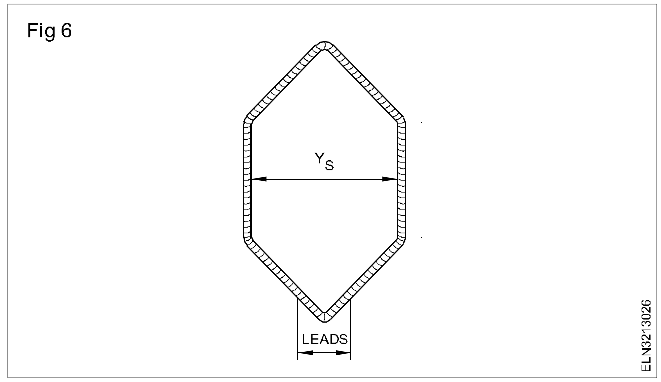
- the periphery of the armature divided by the number of poles of the machine i.e. the distance between two adjacent poles.It is denoted by Y_p.
- it is equal to the number of armature conductors (or armature slots) per pole. For example, if there are 48 conductors, 24 coils, 24 slots and 4 poles, then the pole pitch is

$$Y_P = \frac{\text{Number of slots}}{\text{Number of poles}} = \frac{24}{4} = 6 \text{ in terms of slots}$$

or

$$Y_P = \frac{\text{No. of conductors}}{\text{No. of poles}} = \frac{48}{4} = 12 \text{ in terms of conductors}$$

Coil-span or coil-pitch(Y_S) : The coil-span or coil-pitch is the distance, measured in terms of armature slots or armature conductors between two sides of a coil. It is in fact the periphery of the armature measured in terms of slots or conductors spanned by the two sides of the coil. It is denoted by Y_S as shown in Fig 6.



Coil-pitch Y_S is calculated in the same way as is done for Pole pitch.

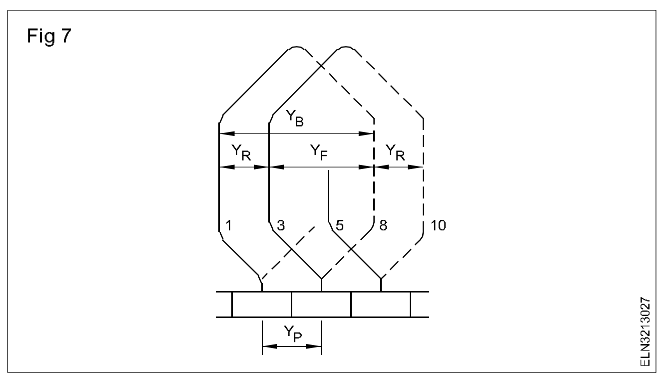
Hence the modified calculation will be

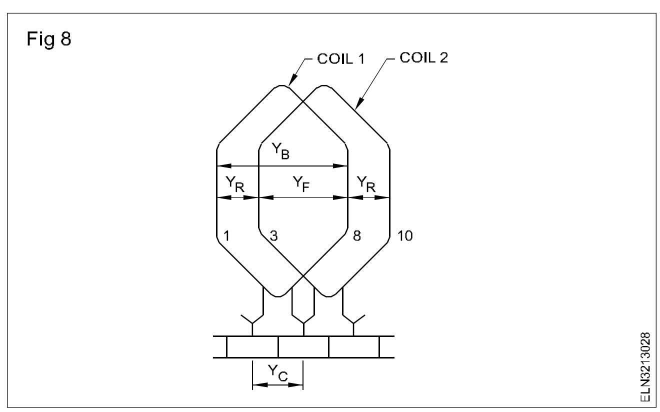
$$Y_S = \frac{\text{No. of slots}}{\text{No. of poles}} - K = \frac{S}{P} - K \text{ (in terms of slots)}$$

$$= \frac{\text{No. of conductors}}{\text{No. of poles}} - K = \frac{C}{P} - K \text{ (in terms of conductors)}$$

where K = any part of S/P or C/P that is subtracted to make Y_s an integer.

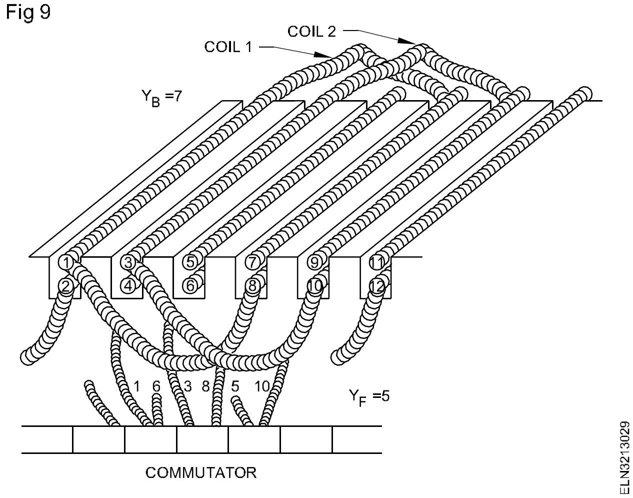
Back pitch (Y_B) : The distance measured in terms of the armature conductors which a coil advances on the back of the armature is called back pitch and is denoted by Y_B. This is illustrated in Figs 7 and 8. The back pitch is also equal to the coil-pitch.





As shown in Fig 9, coil side 1 is connected on the back of armature to coil side 8 (same coil). Hence $Y_B = 8 – 1 = 7$ conductors.

Fig 9



Front pitch(Y_F) : The number of armature conductors or elements spanned by a coil on the front (commutator end of an armature) is called the front pitch and is designated by Y_F. This is shown in Figs 7,8 and 9. Coil side 8 is connected to coil side 3 (second coil) through the commutator segment. Hence $Y_F = 8 – 3 = 5$ conductors.

Average pitch (Y_A) : The average of the front pitch Y_F and the back pitch Y_B is called average pitch. Y_A

$$\text{i.e., } Y_A = \frac{Y_B + Y_F}{2}$$

It is expressed in number of conductors.

Resultant pitch (Y_R) : In general, it may be defined as the distance between the beginning of one coil and the beginning of the next coil to which it is connected or it is the distance between the beginnings of two consecutive coil sides as shown in Figs 7 and 8 and denoted by letter Y_R. As in Fig 9, $Y_R = Y_B – Y_F$, i.e. $Y_R = 7–5 = 2$ conductors. The resultant pitch Y_R depends upon the type of winding like lap or wave, as well as simplex or multiplex.

Commutator pitch(Y_c) : It is the distance (measured in commutator bars or segments) between the segments to which the two ends of a coil are connected. It is denoted by Y_c. From the figures 7, 8 and 9, it is clear the commutator pitch $Y_c = 1$ segment.

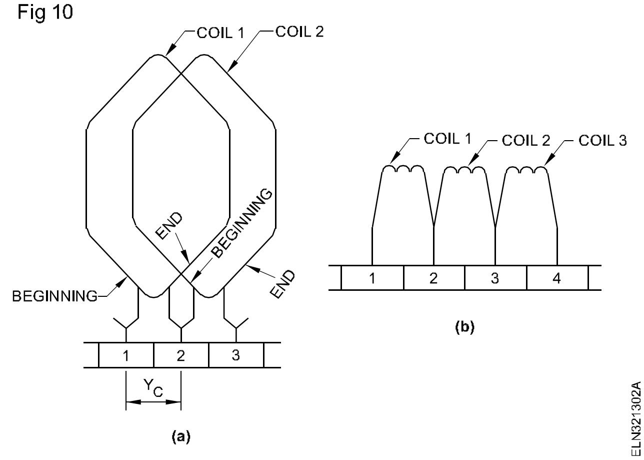
The commutator pitch Y_c varies with the type of winding, like lap or wave as well as simplex or multiplex.

Types of DC armature windings

Lap and wave winding : The DC armature windings are classified into two main groups, lap and wave windings. The difference between them is the manner in which, the leads are connected to the commutator segments.

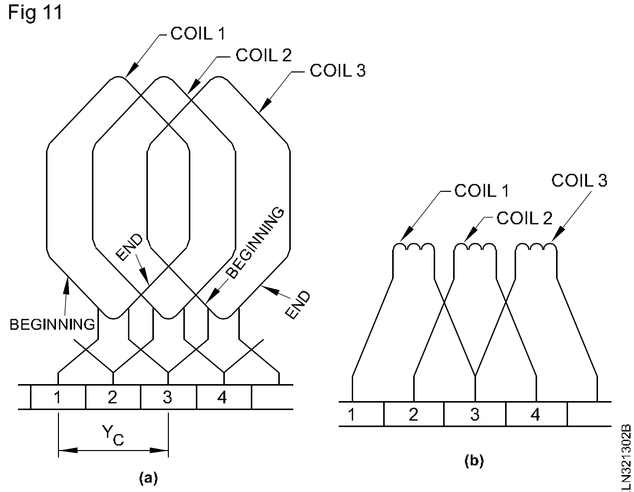
Simplex lap winding : In a simplex lap winding, the end lead of coil 1 is connected to the beginning lead of the adjacent coil(coil 2) through the commutator segments. The commutator pitch of one segment is maintained. Fig 10 shows the lead connection of a simplex lap winding.

Fig 10



Duplex lap winding : In duplex lap winding, the end lead of coil 1 is connected to the beginning lead of coil 3, through commutator segments. The commutator pitch of two segments is maintained as shown in Figs 11a and b.

Fig 11



In triplex lap and quadruplex lap windings, the end leads of coil 1 are connected to the beginning leads of coil 4 and coil 5 respectively through commutator segments. In general commutator pitches

Y_c = 1 segment for simplex lap winding

Y_c = 2 segments for duplex lap winding

Y_c = 3 segments for triplex lap winding

Y_c = 4 segments for quadruplex lap winding.

Simplex wave winding : In simplex wave winding, the end lead of the coil 1 is connected to the beginning of a coil placed at a distance equal to one pole pitch. (Fig 12)

Duplex wave winding : In duplex wave winding there is parallel combination of two simplex wave windings as shown in Fig 13.

Fig 12

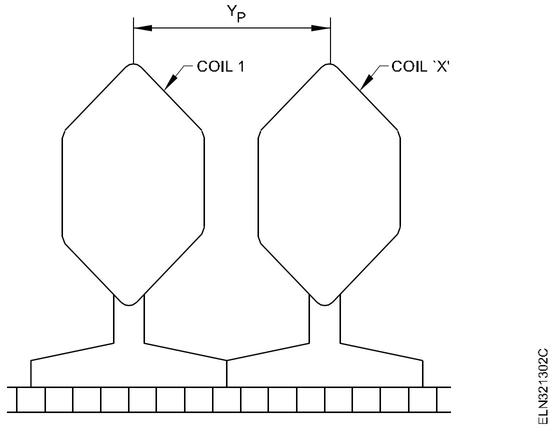
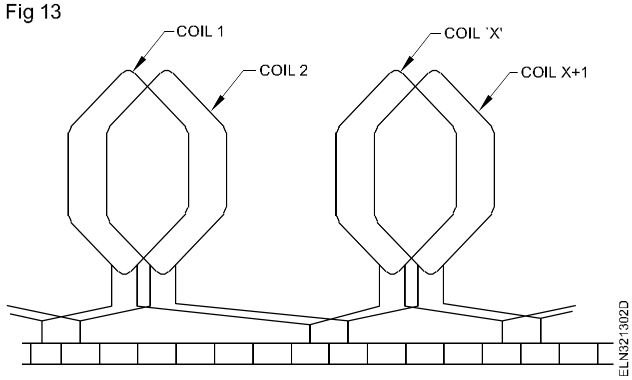


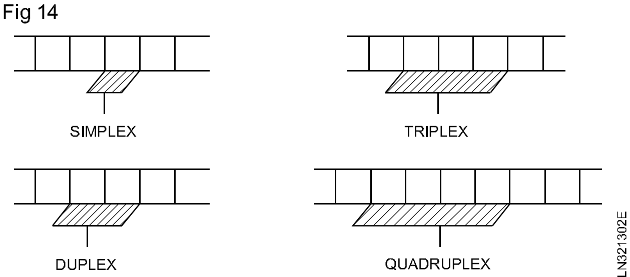
Fig 13



Triplex wave winding : Triplex wave winding will have a parallel combination of three simplex wave windings, and so on.

> **The width of the brush will be such that in simplex lap or wave winding, the brush will make contact with only one segment. The brush will contact two segments in duplex, three in triplex and four in quadruplex. (Refer to Fig 14)**

Fig 14



Progressive lap or wave winding : In progressive lap or wave winding, the front pitch Y_F will be less than the back pitch Y_B, i.e. as you lay the coils clock-wise, the connections to the commutator segments will also proceed clockwise as in Figs 15a and b. In progressive winding, Y_c is referred to as +1.

Retrogressive lap or wave winding: In retrogressive lap or wave winding, the front pitch Y_F will be greater than the back pitch Y_B, i.e. as you lay the coils clockwise, the connection to the commutator segments will proceed anticlockwise as shown in Figs 16 a & b. In retrogressive winding Y_c is represented as -1.

Fig 15

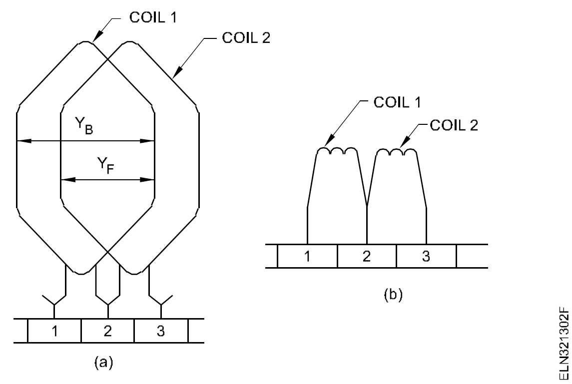
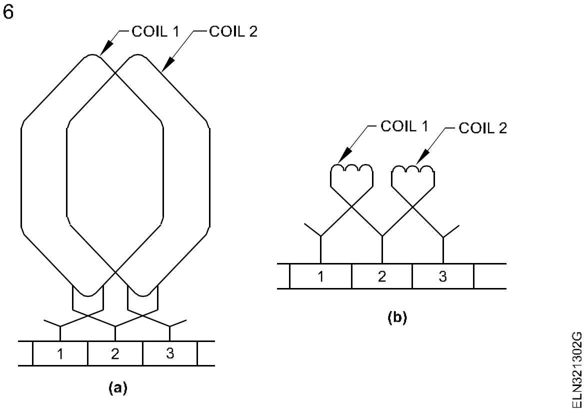
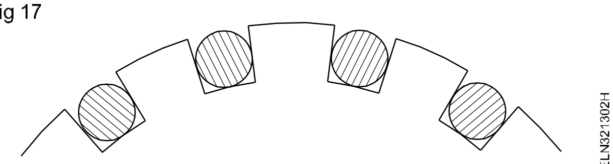


Fig 16



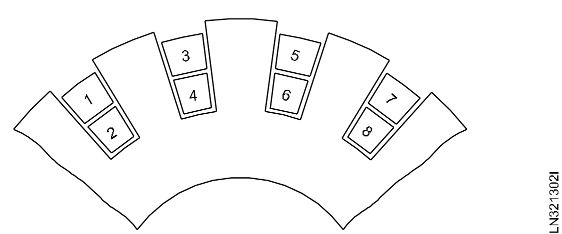
Single layer winding : A single layer winding is one in which only one coil side is placed in each armature slot, as shown in Fig 17. Such a winding is not used much.

Fig 17



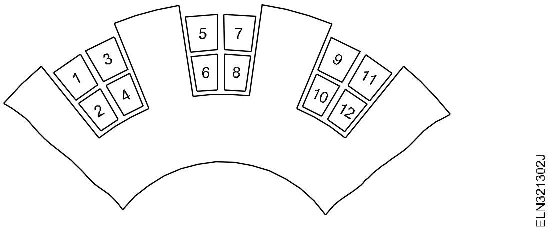
Two-layer winding : In this type of winding, there are two conductors or coil sides per slot arranged in two layers as shown in Fig 18. Usually, one side of every coil lies in the upper half of one slot and the other side of the same coil lies in the lower half of some other slot at a distance of one coil pitch away.

Fig 18



Multi-coil winding : Sometimes 4 or 6 or 8 coil sides are used in each slot in several layers because it is not practicable to have too many slots.(Fig 19) The coil sides lying at the upper half of the slots are numbered odd, i.e. 1,3,5,7 etc. while those at the lower half are numbered even, i.e. 2,4,6,8 etc.

Fig 19



Simplex lap and wave winding - developed diagram

Objectives: At the end of this lesson you shall be able to
- **state the conditions for Lap winding and wave winding**
- **calculate and draw the developed ring diagram for simplex lap and wave winding.**

Development winding diagram : To draw the development winding diagram, the winding particulars like number of conductors, number of poles, pitches, types of windings etc. are required. For any DC armature winding, there shall be as many coils as the number of commutator segments. Further, the number of coils will be the multiple of the number of slots, i.e. for a single layer, there will be double the number of slots as that of the commutator segments and for a double layer there will as many slots as the commutator segments.

Lap winding

Conditions for lap winding : For lap winding the following terms and conditions are to be fulfilled.

- The front pitch Y_F and the back pitch Y_B should be approximately equal to the pole-pitch Y_P.
- Both the front pitch Y_F and the back pitch Y_B should be an odd number.
- The back pitch Y_B and the front pitch Y_F should differ by 2 conductors, for simplex lap winding. In the case of multiplex winding, it is equal to 2 x No. of `plex'.

Ex. For duplex 2x2 = 4 conductors.

For triplex 2x3 = 6 conductors and so on.

The average pitch should be as given by the formula

Commutator pitch should be

Y_C = ± 1 for simplex

= ± 2 for duplex

= ± 3 for triplex and so on.

- The number of parallel paths `A' in the armature will be the multiple of the number of poles. A = P, in the case of simplex lap winding, i.e 2-pole armature winding will have 2 parallel paths, 4-pole armature winding will have 4 parallel paths and so on. However, the number of parallel paths for multiplex winding will be equal to A = P x No. of `plex'.
- There must be as many brushes as there are poles.
- The brushes must be wide enough to cover atleast *m* segments, where '*m*' is the 'plex' (multiplicity) of the winding.

Progressive winding

$$\text{Back pitch} Y_B = \frac{Z}{P} + 1$$

Front pitch $Y_F = Y_B - 2$ x plex

Reprogressive winding

$$\text{Front pitch} Y_F = \frac{Z}{P} + 1$$

Back pitch $Y_B = Y_F - 2$ x plex

To make the winding possible as lap-winding, Z/P must be an even number.

Considering the above points, only the armature having the designated slots can be wound for lap winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex lap winding.

Example

No. of commutator segments	6
No. of slots	6
No. of poles	2
Type of winding	simple lap.

As pointed out earlier the winding should be in double layer only.

Solution

No. of coils = No. of commutator segments = 6 coils

No. of conductors or coil sides = No. of coils x 2
= 6 x 2 = 12 conductors.

$$\text{Pole pitch} Y_P = \frac{\text{No. of slots}}{\text{No. of poles}} = 6/2 = 3 \text{ slots}$$

Also Y_P in terms of conductors $= \dfrac{\text{No. of conductors}}{\text{No. of poles}}$

$= 12/2 = 6$ conductors

No. of conductors/slot = 12/6 = 2 conductors/slots.

Hence the winding is double layer winding.

Back pitch $Y_B = \dfrac{Z}{P} + 1 = 12/2 + 1 = 6 + 1 = 7$

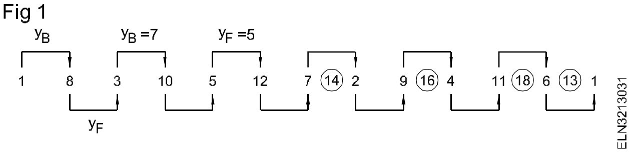
Front pitch $Y_F = Y_B - 2 \times \text{Plex} = 7 - 2 = 5$

$Y_B = 7$ and $Y_F = 5$ for progressive winding

$Y_B = 5$ and $Y_F = 7$ for retrogressive winding

The winding sequence of conductors for progressive lap winding is shown in Fig 1.

Fig 1



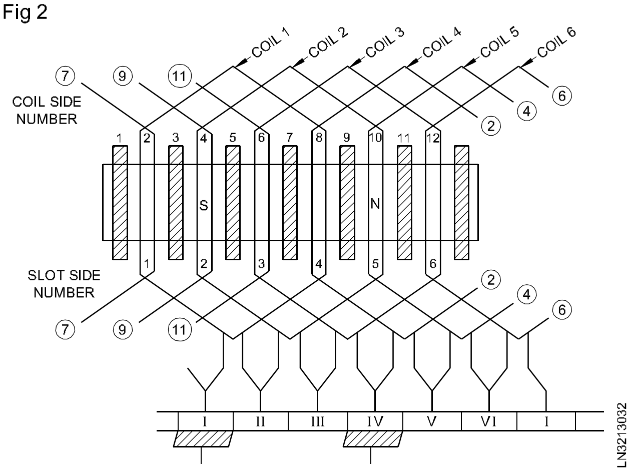
Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	II
2	3	10	2	5	II	III
3	5	12	3	6	III	IV
4	7	2	4	1	IV	V
5	9	4	5	2	V	VI
6	11	6	6	3	VI	I

Development winding diagram for 12 conductors, 2 poles, 6 slots, 6 segments, simplex double layer lap winding

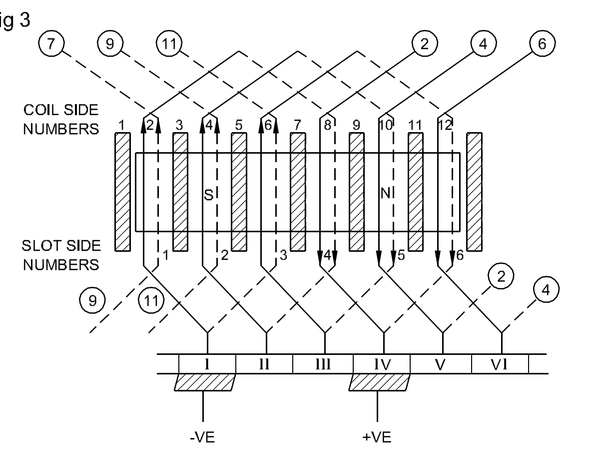
Fig 2 shows the arrangement of coils in the respective slots and the connection of the coils with the segments.

Fig 2



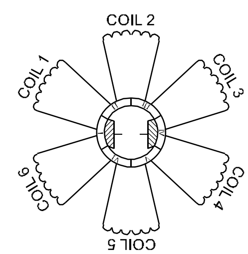
Development diagram with conductors : Fig 3 shows the arrangement of armature conductors in the slots and connections to commutator segments.

Fig 3



Ring diagram : Fig 4 shows the connection of 6 coils with the commutator segments in the form of a ring diagram.

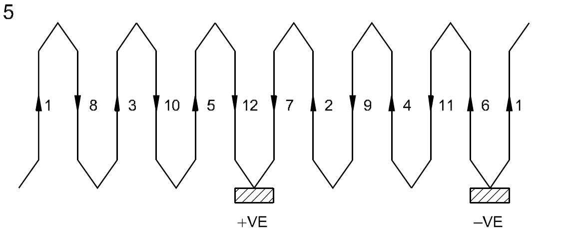
Fig 4



RING DIAGRAM

Sequence diagram : This diagram is mainly used to trace the direction of current in the coil sides (conductors). With the help of this diagram the brush position can be located. (Fig 5)

Fig 5



Wave winding

Conditions for wave winding : For wave winding, the following terms and conditions should be fulfilled.

- The front pitch Y_F and back pitch Y_B should be approximately equal to the pole pitch Y_P.
- Both the front pitch Y_F and the back pitch Y_B should be an odd number.
- The back pitch Y_B and the front pitch Y_F may be of the same value or may differ by 2 conductors, in the case of simplex, and the same or 2 or 4 conductors for multiplex wave winding, depending upon the condition

$$Y_A = \frac{Y_B + Y_F}{2} \text{ approximately}$$

- The average pitch should be as given by the formula

$$Y_A = \frac{Y_B + Y_F}{2} \quad \text{(or)}$$

$$Y_A = \frac{\text{No.of conductors} \pm 2 \text{ x plex}}{\text{No. of poles}}$$

$$Y_A = \frac{Z \pm 2}{P} \text{ for simplex wave winding}$$

$$= \frac{Z + 2}{P} \text{ for progressive simplex wave winding}$$

$$= \frac{Z - 2}{P} \text{ for retrogressive simplex wave winding}$$

$$Y_A = \frac{Z \pm 4}{P} \text{ for duplex wave winding}$$

$$Y_A = \frac{Z \pm 6}{P} \text{ for triplex wave winding and so on}$$

- $$Y_C = \frac{\text{No.of commutator segments} \pm m}{\text{Pairs of poles}} = \frac{C \pm m}{p/2}$$

where Y_c is the commutator pitch

C = total number of commutator segments

p = number of poles

m = the plex of the winding.

The commutator pitch Y_c shall be equal to the average pitch Y_A. $Y_c = Y_A$

The resultant pitch is the sum of the front and back pitches. $Y_R = Y_B + Y_F$

- The number of coil sides must satisfy the following relations.

  Z = P x Y_A ± 2 where P is the number of poles.

- In the case of simplex wave winding the number of parallel paths `A' is equal to 2 only, irrespective of the number of poles. However the number of parallel paths increases in multiples of the plex of the windings.

  Eg. A = 2 x plex.

Considering the above points, only an armature having designated slots can be wound for wave winding.

- Two brushes are necessary, but as many brushes as there are poles may be used, and they must be set so that they short-circuit only the coils cutting no flux.

- The brushes must be wide enough to cover atleast `m' segments where 'm' is the 'plex' of the winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex wave winding.

Example

Number of commutator segments	7 Nos.
Number of slots	7 Nos.
Number of poles	2 Nos.
Type of winding	Wave.

Winding table

1 The number of coils = Number of commutator segments = 7 coils.

2 The number of conductors or No. of coil sides = No. of coils x 2 = 7 x 2 = 14 conductors.

3 $$\text{Pole pitch } Y_P = \frac{\text{No.of slots}}{\text{No. of poles}} = 7/2 = 3.5 \text{ slots,}$$
say 3 slots

$$\text{Also, } Y_P = \frac{\text{No.of conductors}}{\text{No. of poles}} = 14/2 = 7 \text{ conductors}$$

4 No. of conductors/slot = 14/7 = 2 conductors/slot. Hence, the winding is double layer.

5 $$\text{Average pitch } Y_A = \frac{Z \pm 2}{P}$$

$$= \frac{14 + 2}{2} = 16/2 = 8 \text{ (for progressive winding).}$$

$$= \frac{14 - 2}{2} = 12/2 = 6 \text{ (for retrogressive winding).}$$

Hence $Y_A = Y_C = 8$ or 6.

6 Taking $Y_A = 8$ for progressive winding we have

$2Y_A = 2 \times 8 = 16 = Y_B + Y_F$

$Y_B - Y_F = 2$

$Y_B + Y_F = 16.$

Hence back pitch $Y_B = 9$ and front pitch $Y_F = 7$.

Taking $Y_A = 6$ for retrogressive winding we have

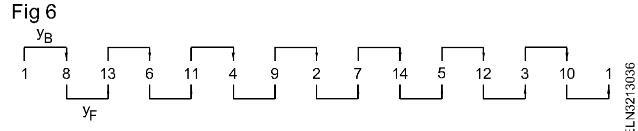
$2Y_A = 2 \times 6 = 12 = Y_B + Y_F$

$Y_B - Y_F = 12.$

Hence, back pitch $Y_B = 7$ and front pitch $Y_F = 5$ for retrogressive wave winding.

The winding sequence of conductors for retrogressive wave winding is shown in Fig 6.

Fig 6



$Y_B = 7$, $Y_F = 5$.

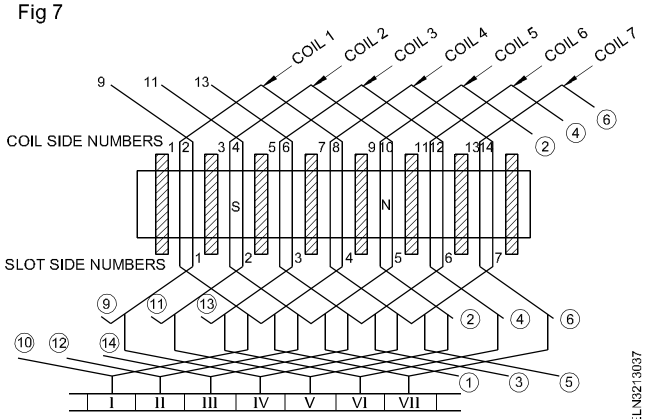
Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	VII
2	13	6	7	3	VII	VI
3	11	4	6	2	VI	V
4	9	2	5	1	V	IV
5	7	14	4	7	IV	III
6	5	12	3	6	III	II
7	3	10	2	5	II	I

Development winding diagram for 14 conductors, 2 poles, 7 slots, 7 segments, simplex, double layer wave winding

Development diagram with coil connection : Fig 7 shows the arrangement of coils in their respective slots and their connection to the segments.

Fig 7



Development diagram with conductors : Fig 8 shows the arrangement of armature conductors in the slots and the connection to commutator segments.

Ring diagram : The ring diagram of wave winding in the case of a 2-pole armature will appear similar to that of lap winding, but the coil ends will be connected as shown in Fig 9.

Fig 8

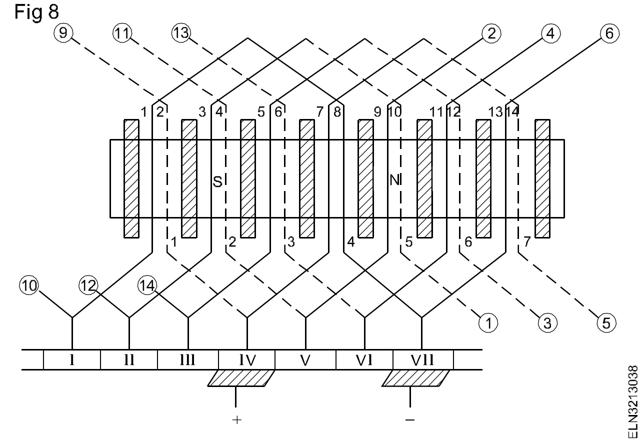
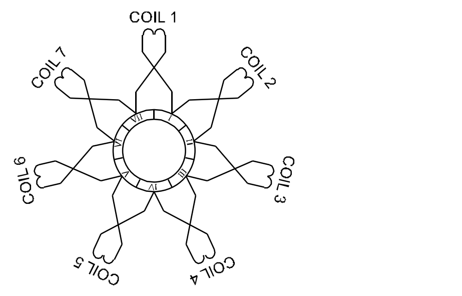
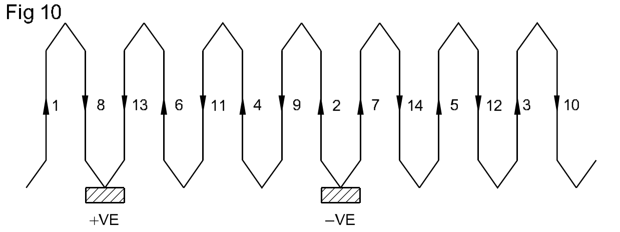


Fig 9



Sequence diagram : This diagram (Fig 10) is mainly used to trace the current direction of the coil sides (conductors) and, thereby, locate the brush position. Please note the brush is placed at a distance of 3 commutator segments i.e. less than 180° geometrical (app.155°).

Fig 10



Preparation of armature for rewinding

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

- **explain the types of slots and their relative advantages, and the place of their use**
- **state the scheme of insulation of armature**
- **state the necessity and the method of testing a commutator before rewinding.**

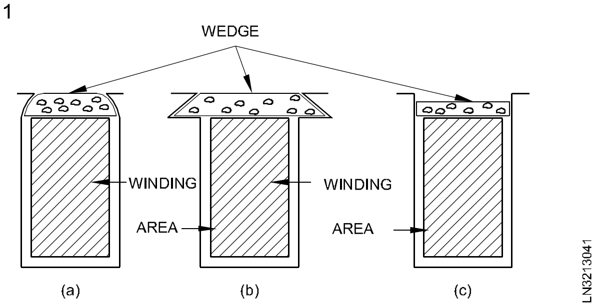
Slots : Slots are provided in the armature laminated core, to house the armature conductors in position.

Types of slots: Generally the following three types of slots are provided in armature cores.

- Open type
- Semi-enclosed type
- Closed type

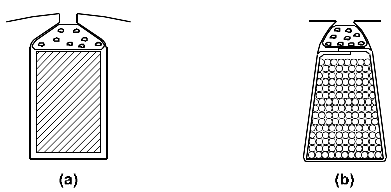
Open type slots : Open type slots are used for medium and high voltage machines. The slots are tapered a little or dovetailed on the top to receive the wedges after rewinding, as shown in Figs1 a, b & c. Former wound coils after being properly insulated are housed in the slots. To prevent the coils from coming out of the slots, banding is done with steel wire on the shallow channel over the circumference of the armature. In such types of armatures, better cooling facilities are provided by keeping ventilating ducts below the slots.

Fig 1



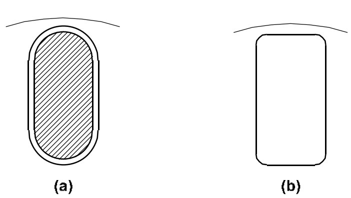
Semi-enclosed type slots : Semi-enclosed types of slots are used for low and medium voltage machines. The slots in this type of armature are tapered towards the periphery, i.e. openings towards the teeth are smaller as compared to the base, as shown in Figs 2 a & b. So reluctance is less than in open type slots. Moreover, the coils cannot come out easily because of the provision of small wedges on the teeth. The conductors are placed in the slots one by one, and not the complete coil at the same time during the winding process. In the case of bar or strip winding, they are pushed through sideways and bent to shape to form the overhangs required.

Fig 2



Closed type slots: Closed type of slots are used in rotors of AC machines and high speed alternators. The slots in this type of armature are totally closed as shown in Figs 3 a & b.

Fig 3



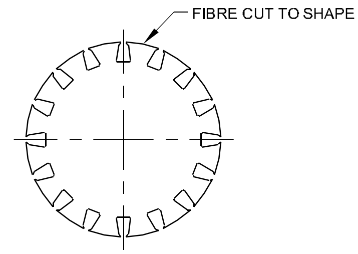
They have no opening on the periphery to receive the conductors. Therefore, conductors are pushed through the slots. The reluctance is lower than in the above two types, and so the efficiency is high.

Insulation scheme for armature

For armature winding, the following insulation schemes are required.

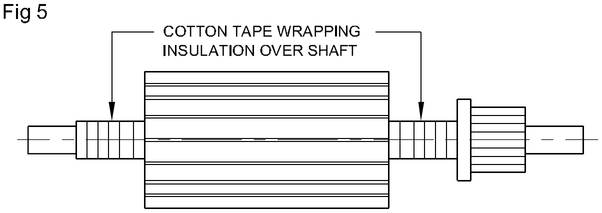
Armature core insulation : Both the sides of the armature core ends have to be insulated with fibre or insulation paper cut in the shape of the stampings. (Fig 4)

Fig 4



Shaft insulation: The exposed portion of the shaft on either side of the armature shall be insulated. Cotton or fibre glass tapes are wound on the area of the shaft where the overhangs of the winding are exposed. The number of layers of tapping depends upon the overhang projection. (Fig 5)

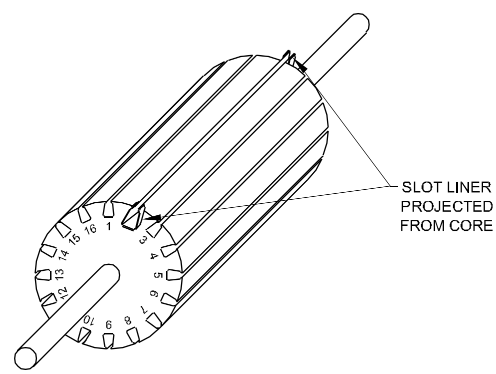
Fig 5



Slot insulation

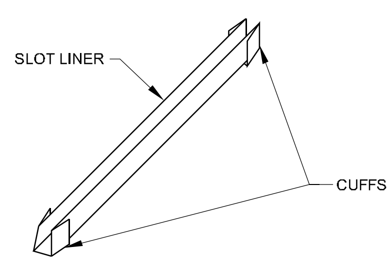
Slot liner : The slot liner is an insulation sheet cut to the inner dimensions of the slots and projected on either side of the slots. (Fig 6)

Fig 6



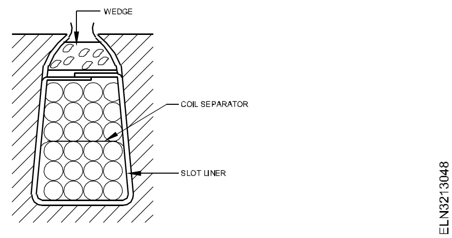
Cuffing : In some applications, the edges of the slot liner are folded on either end to prevent them from sliding in the slots. (Fig 7)

Fig 7



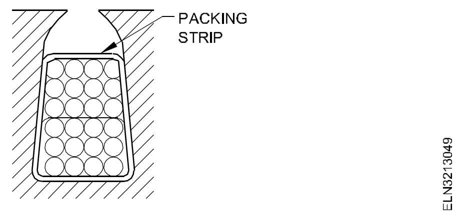
Coil separator : When multi-layer windings are used to insulate the winding layers from each other, coil separators are used. They should be extended on either side of the slot. (Fig 8)

Fig 8



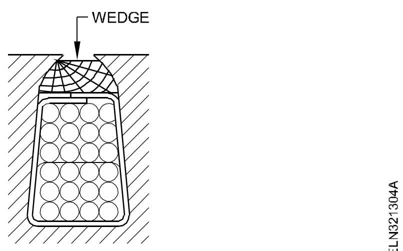
Packing strip : The thick insulation paper used in between the slot liner and wedge is called a packing strip. This should extend beyond each end of the armature core. (Fig 9)

Fig 9



Wedge : A solid insulation piece like bamboo or fibre used to prevent the conductors from coming out of slots is called a wedge. This should be tightly held in the slots. (Fig 10)

Fig 10

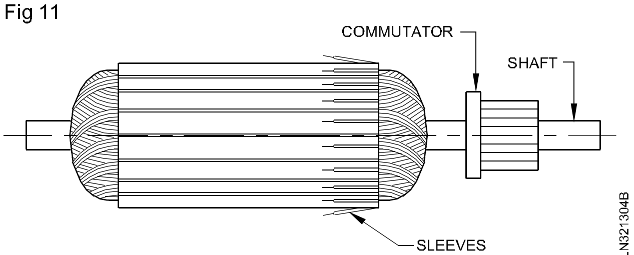


Coil insulation : In some applications, the slot portions of the coil sides are taped with cotton or fibre glass tapes. This is known as coil insulation.

Overhang insulation : The overhang portion of the winding, insulated with flexible insulation sheets like fibre glass cloth, to prevent the conductors of different groups contacting each other is known as overhang insulation.

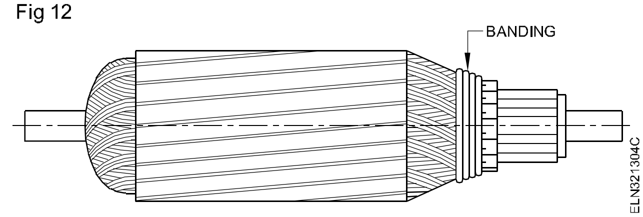
Lead insulation : Lead insulation is one where the end leads of armature conductors are insulated with sleeves, like empire or fibre glass, before soldering with the commutator segments. (Fig 11)

Fig 11



Banding insulation : In the case of small armatures, overhangs of armature are tied with hemp/terylene threads. In large DC armatures overhang is insulated with insulating sheets and tied with steel wires (banding). (Fig 12)

Fig 12

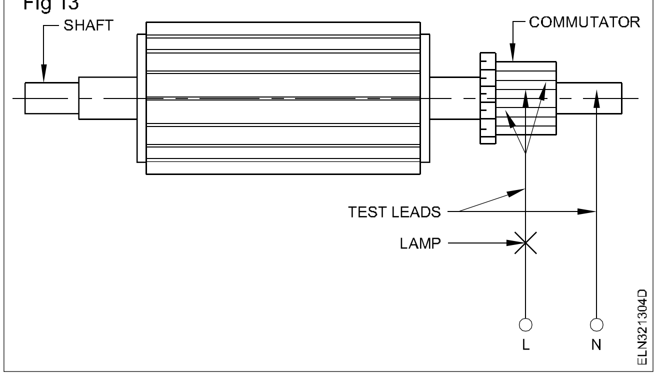


Varnishing : Baking varnish is used for impregnation of armature windings. This process is known as varnishing.

Testing of the commutator before winding : Before attempting to wind the armature, the usual procedure is to test the commutator. This is done to facilitate repairs in case the commutator is defective. The commutator is tested for grounded bars and shorted bars. If the commutator is extensively damaged and the segments have come out, the commutator has to be replaced with a new one.

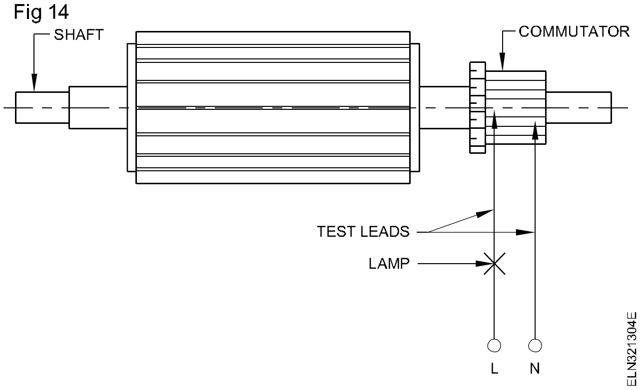
Test for grounded commutator : A commutator is grounded when one or more bars contact the iron core of the commutator or shaft. This can be tested by a test lamp as shown in Fig 13. Touch one lead of the test lamp permanently to the shaft of the armature. Touch the other lead of the test lamp on the commutator bar. If the commutator is not grounded the lamp should not glow; there should be no sparking or arcing between the bar and the ground. Place the test lead on the next commutator bar and test in the same manner. Similarly test all the bars individually. If the lamp lights when a bar is touched that bar is grounded.

Fig 13



Test for shorted commutator : The test which is illustrated in Fig 14 is made to reveal defects in the mica between the bars. Place one test lead on a commutator bar and the other test lead on an adjacent bar. No light should be visible in the test lamp. If a light is observed, a short exists between the bars contacted by the test leads. Move each lead over one bar at a time and test as before. Continue in this manner until all the bars have been tested.

Fig 14



Rewinding of mixer/liquidizer

Objectives: At the end of this lesson you shall be able to
- **explain the type of winding used in mixer/liquidizer**
- **explain the connections of coils, with and without loops**
- **explain the data to be collected for rewinding an armature**
- **explain the term 'lead swing'**
- **explain the method of winding the armature**
- **explain the method of balancing the armature.**

Almost all the domestic mixers/liquidizers use universal motors for their high speed and high torque requirements. Though the basic design remains the same, there will be variation in capacity, number of slots, segments, size of winding wire, brush grade and time rating etc.

When rewinding the mixer/liquidizer, great care needs to be exercised in taking data so as to strictly follow the pattern of winding as in the original. Even a slight change in the diameter of the winding wire or change of number of turns will result in bad performance of the rewound mixer. In general, care should be taken while selecting the winding wire, insulation paper, solder and the soldering iron. As the armature winding requires high skill, most of the beginners may not be successful in their first attempt. As it has high potential for self-employment with good financial gains, go ahead with a number of attempts till you reach perfection. But at each time of failure of winding, investigate the fault and do not repeat that mistake.

Before collecting the necessary data for rewinding it is essential that the trainee is familiar with the type of windings used in mixer/liquidizers and the variations thereof. Types of armature winding is discussed in the earlier portion of this information sheet. Normally simplex lap winding with loops is used in mixers/liquidizers. Winding may further be progressive or retrogressive as shown in Figs 1 (a) and (b).

Lap winding with loops : A lap winding with two coils per each slot which is commonly found in mixers/ liquidizers is shown in Fig 2. A 12 slot armature in this case has 24 coils and 24 segments. There must be twice as many commutator segments as slots. As shown in Fig 2 one loop is made short and the next one long, so that the leads may be soldered to the segments in proper sequence.

Fig 1

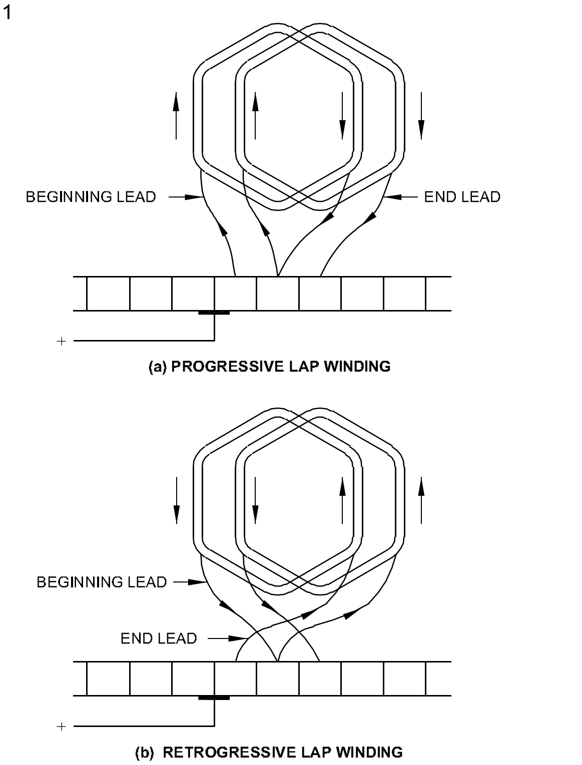
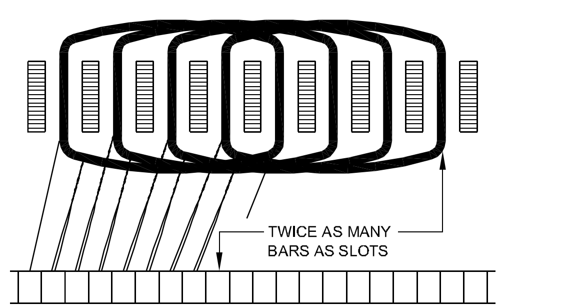


Fig 2



Lap winding may also have three coils for each slot. Then it is necessary to have three times as many commutator segments as slots.

Lap winding without loops : In lap winding each coil can be wound independently and the two ends of the coil brought out. Then the end leads may be connected to the segments in proper sequence.

Collection of data for rewinding a mixer : When rewinding the armature and field of a universal motor, sufficient information must be gathered on the process of stripping to enable the trainee to rewind it exactly as it was wound originally. Initially we should take the name-plate details and a sample is given in Table 1.

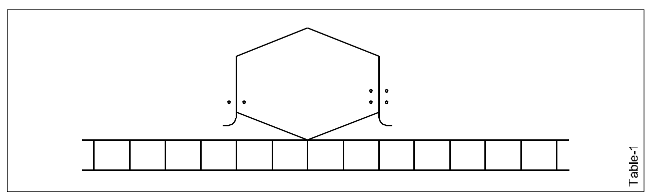
After taking the name plate details, dismantle the mixer and strip the winding carefully. During this process collect the information as detailed in the data sheet shown in Table 2.

Table 1

Name-plate details

Make	:________________	Type	:____________	Code No	:____________
KW	:________________	Volts	:____________	Amps	:____________
No. of poles	:________________	Hertz	:____________	r.p.m	:____________
Frame	:________________	Model	:____________		

Table 2

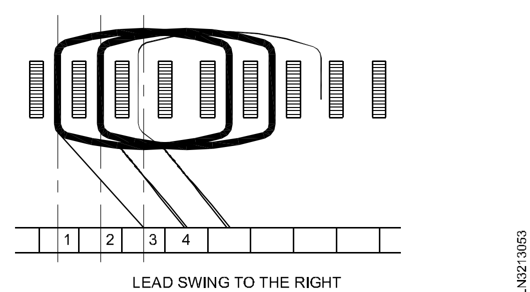
	Size of wire	Turns	Insulation	Connection
STATOR				
	Size of wire	No.of turns	Coil pitch	Coils/Slots
ROTOR				
	No.of slots	Bars	Draw the end connection and show the lead swing. 	
Details of lead swing Centre of slots to	Centre of bars Centre of mica			
Lap	Commutator pitch	Wave		

Lead swing : As the machines are desinged to have a particular position of the brushes in the periphery of the commutator, the coil end connections to the commutator segments are fixed at certain positions which should not be changed while rewinding to have trouble free operation. The positioning of the coil leads to the particular segment is called lead swing.

One of the most important operations in the winding of an armature is placing the coil leads in the proper commutator bars. Leads may be placed in the bars in any one of three different positions, depending on the original location. If a slot in the armature is viewed from the commutator end, the leads to the commutator may swing to the right of the slot as shown in Fig 3 or to the left, as shown in Fig 4 or they may be aligned with it as shown in Fig 5. The following method is used in determining the position of the leads in the commutator.

Stretch a piece of cord or string through the centre of a slot. Note whether it is aligned with a commutator bar or with the mica between bars. If the data calls for a lead swing of three bars to the right, place the lead of the first coil three bars to the right, counting the bar that lines up with the slot as No.1. All the other leads follow in succession, as shown in the figure 3. If the centre of the slot is in line with the mica, consider the bar to the right of the mica as bar No.1.

Fig 3



Method of winding single or double coil per slot

Armature with one coil per slot : The procedure for winding and connecting an armature having one coil per slot is as follows:

Fig 4

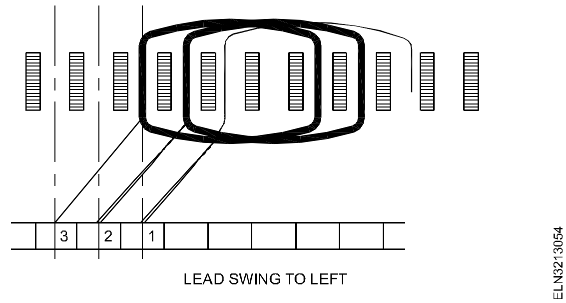
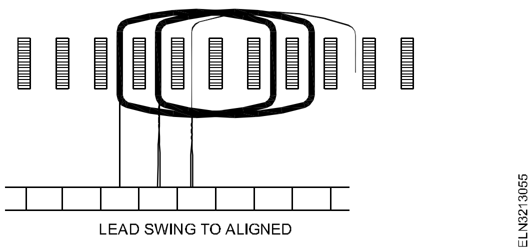
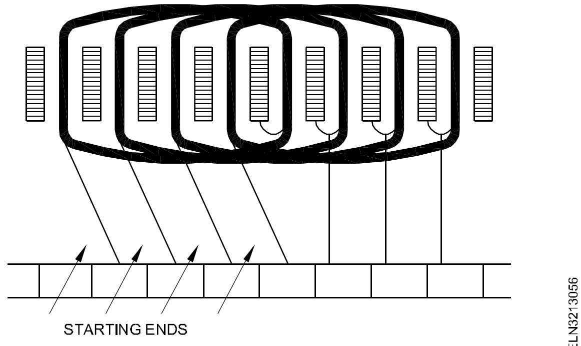


Fig 5



Start in any slot and wind one complete coil in the slots of proper pitch. Place the beginning of coil 1 into the proper commutator according to the lead swing bar and leave the end lead free for connections after the armature is wound as shown in Fig 6.

Fig 6



Wind the entire armature in this manner, leaving all the end leads disconnected. After all the coils are wound, start connecting all the top or end lead to the commutator bar adjacent to the bottom lead of the same coil to produce a simplex lap winding like that given in the Fig 7.

Armature with two coils per slot : Simplex lap-wound armatures having two coils per slot are more common than those having one coil per slot. The procedure for winding this type of armature is as follows:

Start winding with two wires and place the beginning leads in the commutator bars according to the data taken. Cut the wires when the proper number of turns have been wound into the slots and leave the end leads free. Start the next coil, one slot to the left of the first coil as viewed from the commutator end. (When the coils proceed to the left, the winding is called left- handed and to the right, right-handed.) Follow this procedure until all coils have been wound. (Fig 8). Then place the top or end, leads in the commutator bars in the proper succession. This is shown in Fig 9.

Fig 7

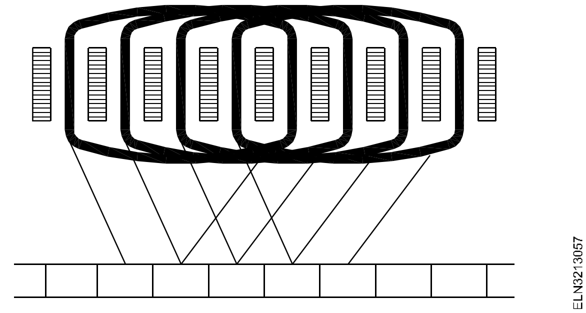


Fig 8

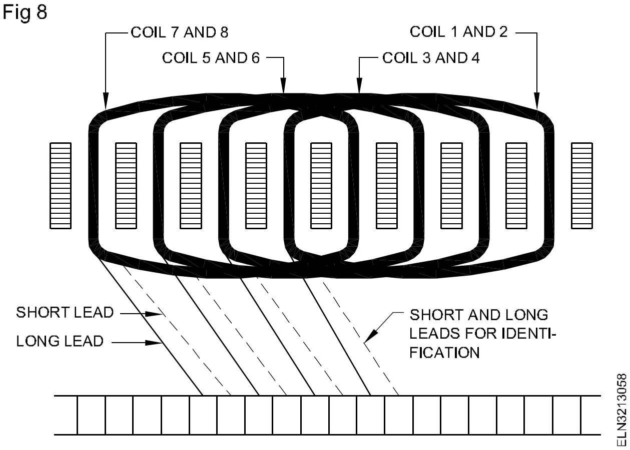
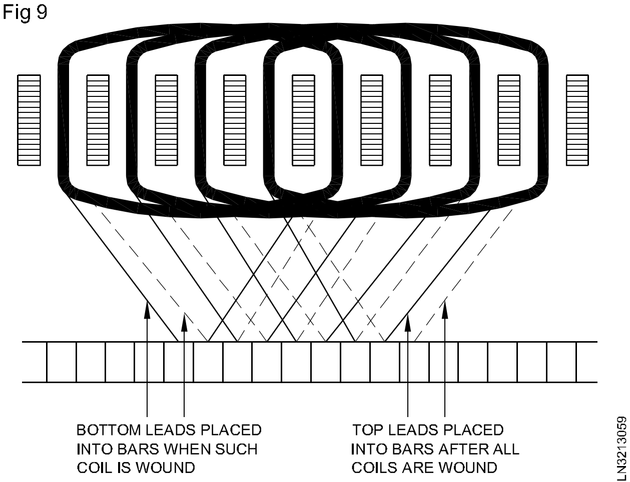


Fig 9



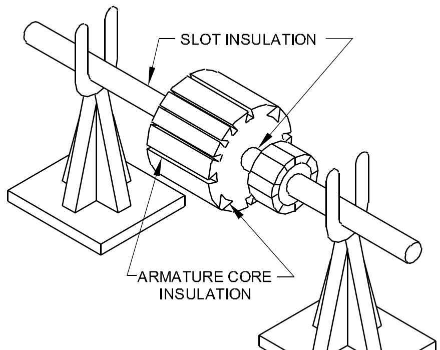
Sleeving of different colours is used for identification of the leads. One colour is used for the beginning and end of the first coil and another colour for the second coil in the same slot, the third coil uses the same colour as the first and so on. It will be necessary to test the first top lead and the colours to identify all the others. Using short and long leads for the two coils in the same slot is another method of identifying the leads so that they can be connected properly.

Method of rewinding and balancing the armature

Objectives: At the end of this lesson you shall be able to
- **explain the method of rewinding a DC armature**
- **explain the methods of soldering/brazing/hot stacking of the winding ends to the commutator raisers**
- **explain the necessity of banding and the method of banding**
- **state the necessity of balancing and the method of balancing the armature.**

Method of winding the armature : To start the armature winding, the armature is mounted on the winding stand as in Fig 1; then the shaft, armature core and slots are insulated as per the insulation scheme taken from the data.

Fig 1



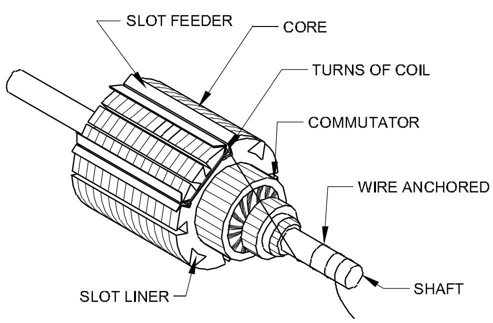
Winding methods : There are two methods of winding the armature.

Hand winding

Formed coil winding

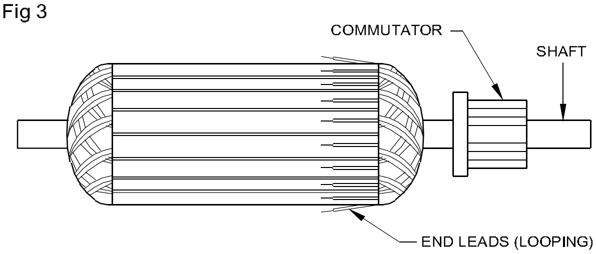
Hand winding : For hand winding, four numbers of slot feeders are placed in the two designated slots at a distance from the coil pitch. The required number of turns are wound into the slots, say slots Nos.1 and 4 as in Fig 2. Enough tension is applied on the wire to make a tight winding without breaking the wire. A loop is made at the end of the first coil and the beginning of the second coil. The second coil is started in the designated slot and the coil is wound with the same number of turns as in coil 1. The span of coil 2, has to be equal to that of coil 1.

Fig 2



When the second coil is finished, a loop is made again and then the third coil is started. In this manner the winding is continued, until all the coils have been wound. The end lead of the last coil is connected to the beginning lead of the first coil. After the entire armature is wound, there will be two coil sides in each slot, in double layer winding. It has to be ensured that all the coils have the same pitch and turns. The loops made at the end of the coils will look as shown in Fig 3, and have to be connected to the commutator raisers. The procedure of making loops while winding, explained here, is for simplex lap winding. This method is usually adopted for small armatures. For wave winding and multiplex windings, connection for raisers shall be taken from the coil ends according to the winding pattern.

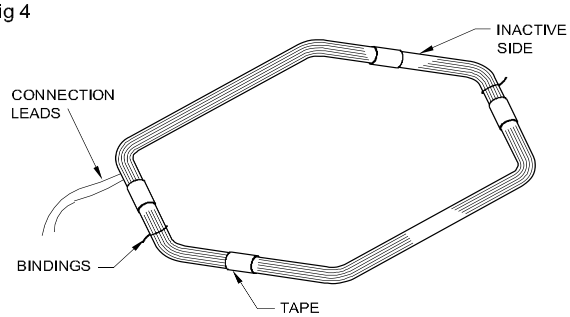
Fig 3



Formed coil winding : For this method, wooden formers are made to the dimensions of the armature coils, similar to those of the field coils as explained in Exercise 1. The total number of coils required for the armature are wound and kept ready.

The inactive side of the coils is bound with tape and tied with cotton strings as shown in Fig 4.

Fig 4



The active side of the coil is spread as in Fig 5 and the coil sides are inserted in the respective armature slots, conductor by conductor as shown in Fig 6. Similarly all the coils of the armature are placed in the respective slots and the coil ends are looped and soldered to the respective commutator segments.

Fig 5

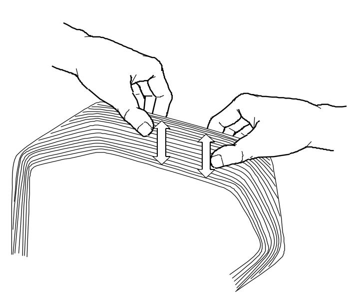
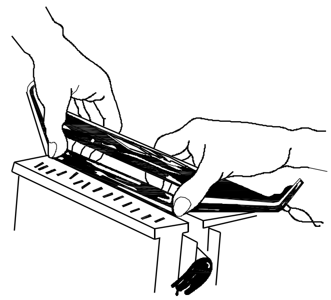


Fig 6

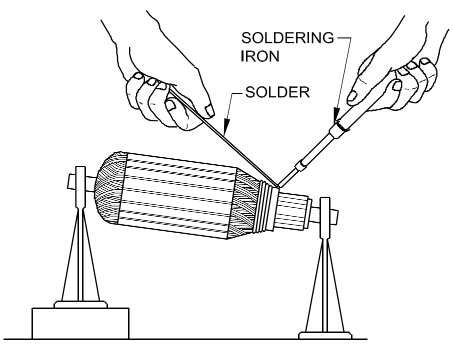


Connection of winding ends with the commutator segments : After winding the armature, the end leads of the armature conductors are placed in the slits of the commutator raisers. (Raiser slits should be properly cleaned and well prepared to receive the conductors.) For secure and good electrical contact, these conductors are well cleaned to remove insulation and dirt. Then the conductor ends are placed in the respective raiser slits and soldered/brazed or hot-stacked.

Soldering : For soldering, electric irons are generally used on small armatures and gas irons on the larger ones. The size of the iron used depends on the size of the commutator. Leads are soldered to the commutator by means of soldering iron or torch.

The procedure of soldering is as follows. First the soldering flux is applied over the wires to be soldered and also the identified commutator raiser. The wires are then placed in the respective raisers. Then the tip of the soldering iron is kept on the commutator raiser as shown in Fig 7 for some time until the heat from the iron is transferred to the area of the commutator raiser. This heat transfer could be identified by the bubbling of the flux.

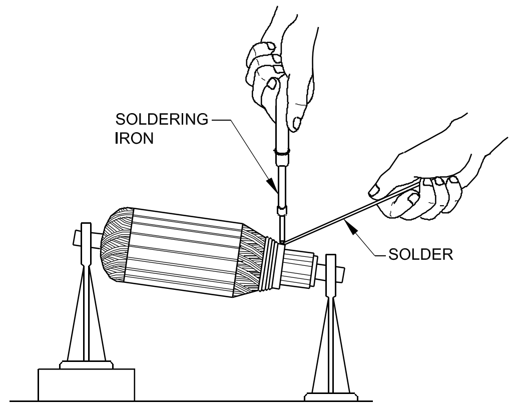
Fig 7



When the commutator raiser is sufficiently hot, the solder is placed on the commutator raiser, and the iron is kept over it and the solder melted. The solder is allowed to flow entirely around the leads. To prevent the solder from flowing down the back of the commutator and thereby causing short circuits, raise one end of the armature. To prevent the solder from flowing from one bar to another, the iron is held as shown in Fig 8. Excess flux is wiped out after the soldering is completed.

Brazing : In the case of large armature windings, the armature winding lead ends are brazed with the respective commutator raiser slits by means of a gas torch. Close inspection and care should be exercised in the control of the flame.

Fig 8



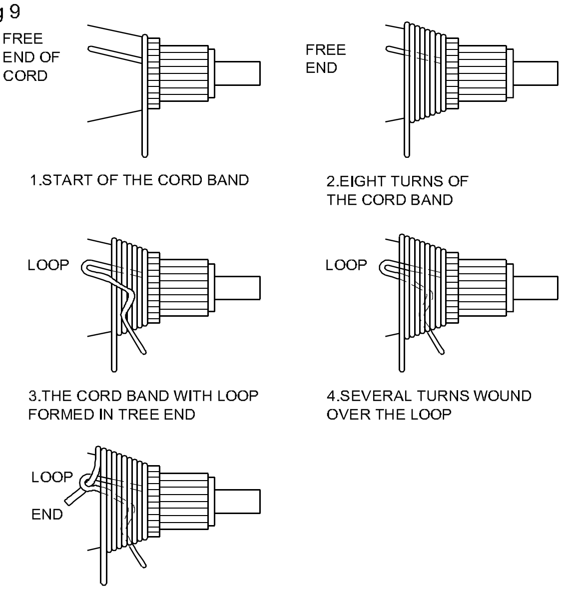
Hot stacking : In the case of small DC armatures, the armature conductors are kept in the commutator raiser slits and spot-welded. This is called hot stacking. A specially designed hot-stacking machine is available for this purpose.

Banding the armature : A temporary banding is sometimes applied on the armature before the permanent banding is done, to keep the coils in position and to facilitate shaping of the overhang.

Permanent bands are used on armatures to hold the armature end leads in position. A cord band is used on small armatures to prevent the leads from flying out of the slots, while the armature is rotating. Large armatures have steel bands for the same purpose. For large armatures having open-type slots, steel or tape bands are used to prevent the coil from flying out of the slots.

Cord bands : The procedure for making a cord band on an armature is shown in Fig 9, and the following directions should be observed.

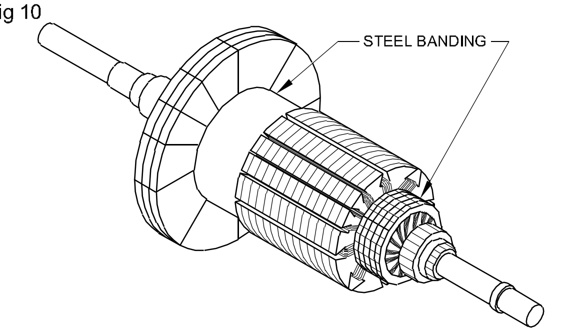
Fig 9



Use a proper size of banding cord - heavy for larger armatures, light for smaller armatures. Start at the end nearest the commutator and wind several turns in layers, allowing about 150mm long cord at the beginning to be free. Bend the cord in the form of a loop as shown in Fig 9. After winding several turns over the loop, insert the last end of the cord band through the loop, and then pull the free end of the loop. This will pull the end under the core band and secure it there. Then the pulled end of the cord can be cut off. Use enough pressure in winding so that the band will be tight.

Steel bands : Steel bands are placed on the front and back ends of the coils. These bands are put on the armature in a different manner than in the cord bands. The procedure is illustrated in Fig 10, and is as follows. Place the armature in a lathe and place mica or paper insulation in the band slot around the entire armature to insulate the band from the coil sides. Hold the insulation in place by tying a turn of cord around it.

Fig 10



Place small strips of tin or copper under the cord, equidistant around the armature, in order to secure the band after it is wound. Use the same gauge steel band wire as is found in the original band.

Steel bands must be put on the armature with much more pressure than is needed for cord bands. It is, therefore, necessary to utilize a device called a wire clamp to provide the required pressure. This device consists of two pieces of fibre fastened together by means of two screws and two wing nuts. The steel band wire is fed through this clamp to the armature. The clamp has to be secured to a bench so that it can be held stationary while slowly turning the armature while banding. Take care not to put too much pressure on the wire; otherwise it will break. After the band is placed on the coil, copper or tin strips are turned over and the entire band is soldered. One by one each band is completed in this manner.

Testing the new winding : After the rewinding and connections are completed, it is important that both the winding and the connections are tested for shorts, grounds, open circuits and correctness of connections. This must be done before varnishing the winding so that any defect that is found may be corrected more readily.

Baking and varnishing : After the armature has been wound, soldered, banded and tested, the next operation is varnishing. This process makes it moisture-proof and also prevents vibration of the coils of wire in the slots. Vibration has a tendency to impair the insulation on the wires and cause shorts. Moisture will also cause the insulation on the wires to deteriorate. Before varnishing the armature, it must be preheated to drive out the moisture on it.

Armatures may be varnished by either baking varnish or air-drying varnish. Air-drying varnish is applied to the armature when baking is undesirable or inconvenient. Baking varnish is more effective because the moisture can be eliminated fully only by baking.

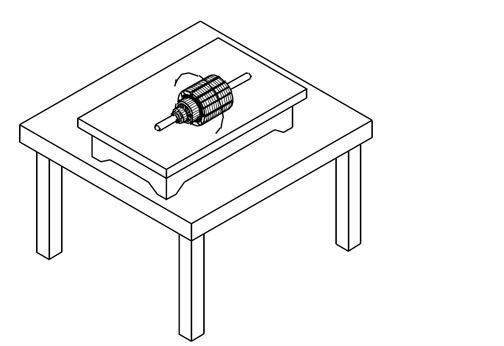
Importance of balancing the armature : The armature used in mixers/liquidizers runs at 3000 to 6000 r.p.m. depending on the load. As such these armatures should have equal weight in all directions. The causes of unbalance in weight are given below :

- Unequal turns in coils.
- Unequal core assembly.
- Unequal weight of wedges.
- Unequal slot liner insulations.

In case of unbalance, the centrifugal force which is produced due to high speed of the armature may shake loose its core and commutator in a very short space of time. In extreme cases the armature will damage the bearings and fly out. In mild cases of unbalance, there will be vibration and noise while the motor is running. Most of the manufacturers use a dynamic balancing machine to balance the armature. To balance higher weight of one side, the opposite side is plugged with lead weights. In certain cases the heavier side is balanced by drilling suitable sized holes in the periphery of the armature to reduce the weight.

Static balancing - method 1 : In small sized winding shops, the rewound armature is rolled on the surface of a horizontally positioned surface plate as shown in Fig 11. For every rolling, if the armature stops at different positions of its periphery, then it is regarded as balanced. On the other hand for each rolling the armature stops at the same position of the periphery then the armature is regarded as unbalanced. Where the armature stops at the same place and the portion of the armature touches the surface plate is regarded to have higher weight than the opposite portion.

Fig 11



In such cases, the wedges in the lighter portion have to be removed and replaced with heavier wedges made of brass or lead. However, this rolling test should be carried out a number of times till the electrician is completely satisfied that the armature is perfectly balanced.

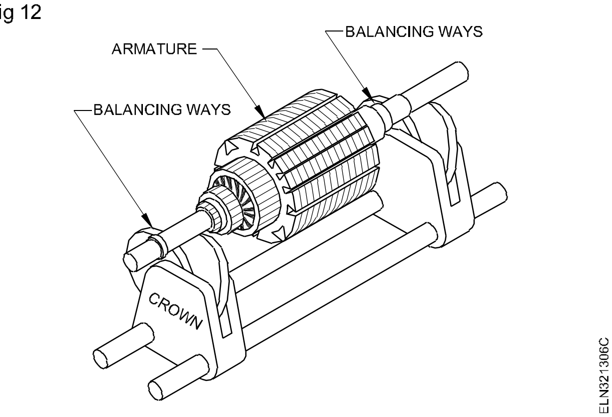
To avoid such unbalanced condition, the armature winder should see to it the causes of unbalancing are removed at the time of winding itself.

Static balancing - method 2: A balancer, similar to the balancing grinding wheel in machine shops, may be used. These balancers are built in various sizes. The method of balancing an armature using this type is as follows.

Place the armature on the balancing ways, (Fig 12) and roll the armature gently. When the armature comes to a stop, the heavier portion of the armature will be at the bottom. Mark this point (portion) with a chalk piece. With such successive rolling, if the armature stops at different positions, the armature is balanced, and if it stops in a particular position, it is necessary to counterbalance it with weights diagonally opposite to the heavy portion.

This is accomplished by placing a lead or a small metal piece on the banding of the armature. In small armatures, this weight may be placed in the place of the wedge, under the banding. Experience will determine the amount of metal necessary to balance the armature. This method of balancing is called 'static balancing'.

Fig 12



Dynamic balancing : Dynamic balancing machines are available to balance the armature or rotating the parts of electrical machines. The armatures are fixed on those machines and rotated at the rated speed. A pointer or an indicator shows the position on the armature and the weight to be added. The balancing machines available are either with the mechanical balancing or with the stroboscopic balancing.

Testing of armature winding

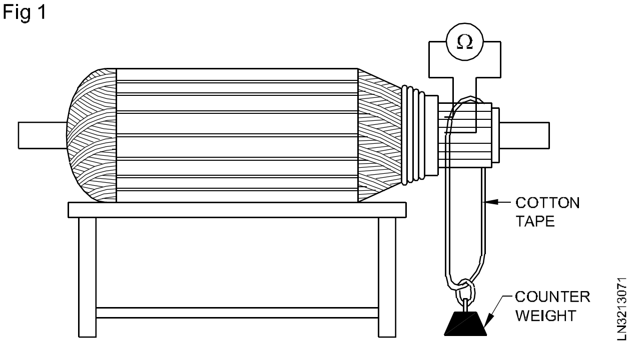
Objectives: At the end of this lesson you shall be able to
- **describe the methods of testing armature, such as the**
  - **winding resistance test**
  - **insulation resistance test**
  - **growler test**
  - **voltage drop test.**

Testing the winding : After an armature is wound and the leads are connected to the commutator, a test should be conducted. From this test, defects may be revealed, which might have occurred during winding. The common defects in armature windings are grounding, shorts in the coils, open in the coil and reversal in the coil connection. These defects can be located by different test procedures.

Armature winding resistance test : Resistance of the armature coil is measured by using a low range ohmmeter and preferably with the Kelvin bridge. Resistance between consecutive segments in the case of simplex lap winding (for wave and multiplex windings at a distance of commutator pitch Y_c) is measured. Fig 1 shows a simple arrangement to measure the resistance between the successive commutator segments.

As shown in Fig 1, a cotton tape with a counterweight is passed around the commutator to hold the connecting leads to the segments. Measurement of resistance is done in all the coils by changing the position of the connecting leads to successive commutator segments. The resistance measured should be the same in all coils. Lower resistance shows short in turns, while a higher resistance shows higher numbers of turns or open in the coil.

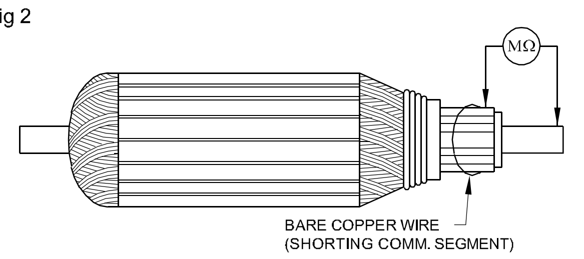
Fig 1



Insulation resistance test : With a bare copper wire short all the commutator segments. (Fig 2) Test the insulation resistance between the body and the commutator segments by a 500V Megger, for armatures rated up to 250 volts. The IR so measured shall be greater than 1 megohm. If the value is less than 1 megohm, moisture in the winding or a weak insulation is to be suspected.

This test is sometimes conducted by a series test lamp and is called the 'ground test'. It will only indicate if any coil is grounded, and not the insulation resistance.

Fig 2

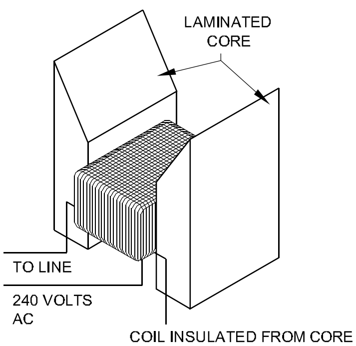


Growler test : A simple and most common method to test armature winding for short and open coils is by a growler.

Growler : There are two types of growlers - 1) internal and 2) external growlers. An external growler is used for testing small armatures and an internal growler for large DC armatures and AC motor stator windings.

External growler : An external growler, shown in Fig 3, is an electromagnetic device that is used to detect and locate grounded, shorted and open coils in an armature.

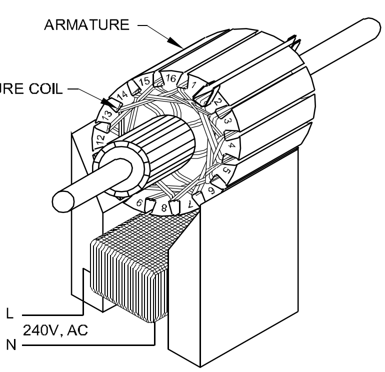
Fig 3



EXTERNAL GROWLER

This growler consists of a coil wound around an iron core and is connected to a 240 volt AC line. The core is generally H shaped and cut out on top so that the armature will fit on it, as shown in Fig 4.

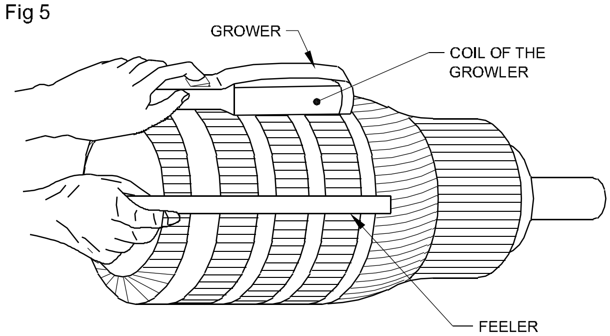
Fig 4



When an alternating current is applied to the growler coil, the voltage will be induced in the armature coils by transformer action.

Internal growler : An internal growler, such as the one used for stators, may be used for armatures as well. These are made with or without built-in feelers. The growler with a built-in feeler has a flexible blade attached to the growler so that a hacksaw blade or similar instrument is not necessary. This type is especially desirable in smaller stators that have no room for a separate feeler. Fig 5 shows an internal growler with a separate feeler, used for large armatures.

Fig 5

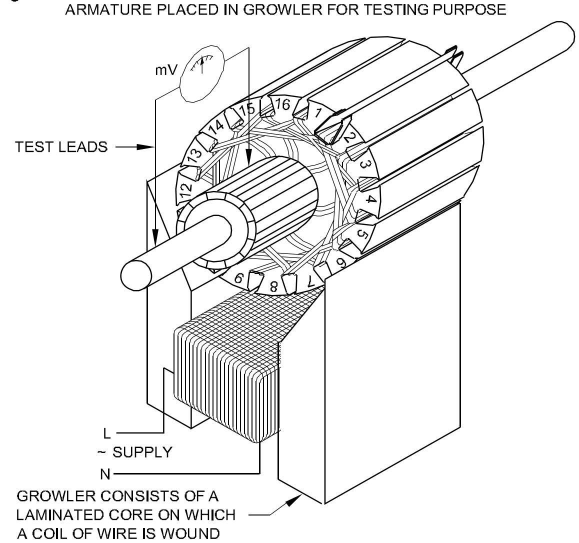


INTERNAL GROWLER

Growler test for grounded coil : The armature to be tested is placed on the growler and then the growler is switched 'ON'. Place one lead of an AC milli-voltmeter on the top commutator bar and the other meter lead on the shaft, as shown in Fig 6.

Fig 6

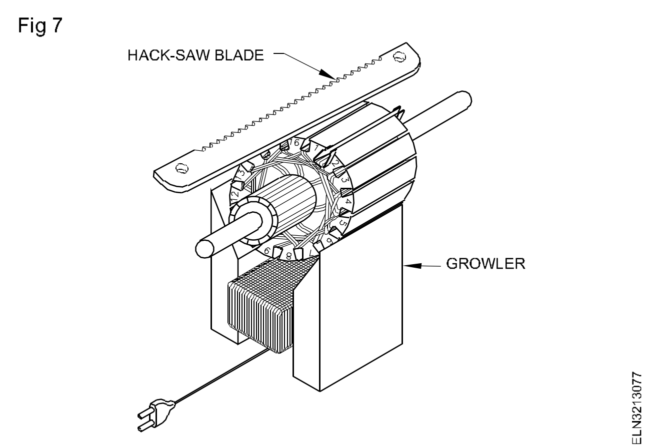
ARMATURE PLACED IN GROWLER FOR TESTING PURPOSE



If a reading is noticed on the meter, turn the armature so that the next commutator bar is in the same position as the earlier one, and test as before. Continue in this manner until all the bars are tested. Where the meter gives no deflection, it is an indication that the grounded coil is connected to this particular bar.

Growler test for shorted coil : The procedure to test for short circuits in an armature is as follows.

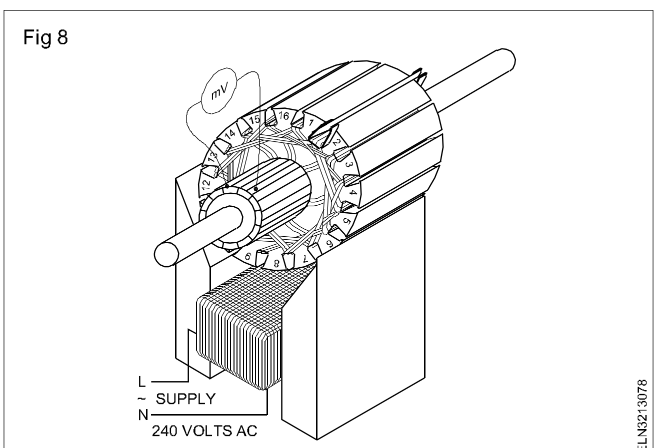
The armature to be tested is placed on the growler and then the growler is switched on. A thin piece of metal, such as a hacksaw blade, is held over the top slot of the armature as shown in Fig 7. In case of short in the winding, the blade will vibrate rapidly and create a growling noise. If the blade remains stationary, it is an indication that no short exists in the coil under test. After several top slots have been given the hacksaw blade test, turn the armature so that the next few slots are on top. Test as before and continue this procedure for the entire armature.



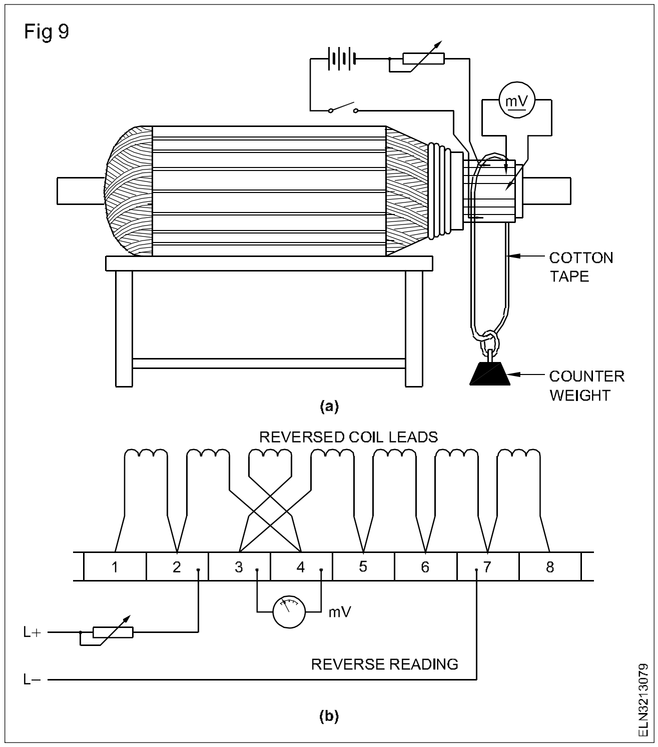
An armature having cross connections or equalizers cannot be given the hacksaw blade test. This type of armature will cause the blade to vibrate at every slot, which would seem to indicate that possibly every coil is shorted.

Test for open coil : Growlers are also provided with meters (milli-volt or ammeter) on the panel with variable resistance. In this case an open in the armature coil can be found out as follows.

Growler test for an open coil : To locate an open coil with a growler, set up the armature on the growler in the usual manner. Test the top two adjacent bars with an AC milli-voltmeter as shown in Fig 8. Rotate the armature and continue testing the adjacent bars. When the milli-voltmeter bridges the two bars connected to the open coil, the meter pointer will not deflect. All the other bars will give a deflection. This test for an open coil can be made without the meter by shorting the two top bars with a piece of wire. Absence of a spark indicates that the coil is open. The open may be either at the commutator bar or in the coil itself. The procedure may be used to determine the location of the leads of a shorted coil. However, the hacksaw blade test is the most satisfactory method of determining a shorted coil.



Drop test : The most accurate method of testing the armature for correct resistance, number of turns, short and open and reversed coil connection is by the drop test. Connect a low voltage DC supply across the commutator segments at a distance of pole pitch. Insert a variable resistance in series with the circuit. Switch 'ON' the DC supply and connect a milli-voltmeter to the adjacent segments as in Fig 9a and b.



Adjust the readings to a specified value, by using a variable rheostat. Record the milli-voltmeter readings on the consequent commutator segments by rotating the armature in one direction. The position of the segments and the connection should be the same as in the first set up. The result could be concluded as enumerated below.

- If all the readings are the same, the winding is correct.
- If the milli-voltmeter reads zero or low voltage, the coil connected to the segment is short.
- If the milli-voltmeter reads high voltage, the coil connected to the segment is open.
- If the milli-voltmeter deflects in the reverse direction as shown in Fig 9b, the coil connected with the segment is reversed.

Generally armatures are tested as a routine for insulation resistance and for shorted coils. Only when a fault in the armature winding is suspected, a drop test is conducted.

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.**

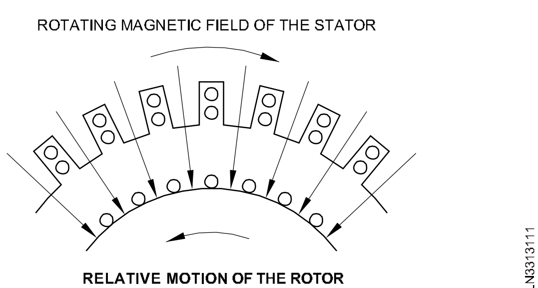
The three-phase induction motor is used more extensively than any other form of electrical motor, due to its simple construction, trouble-free operation, lower cost and a fairly good torque speed characteristic.

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

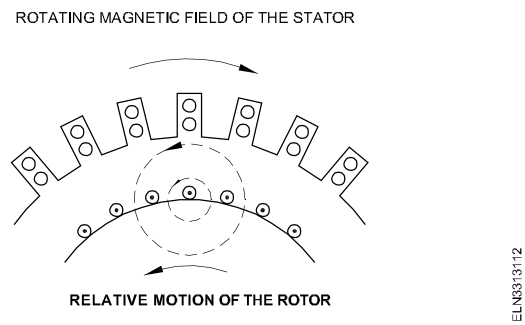
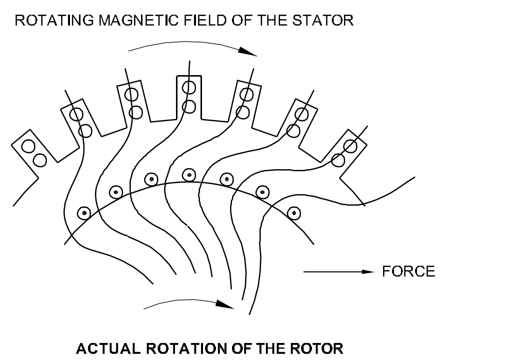


Fig 3



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.

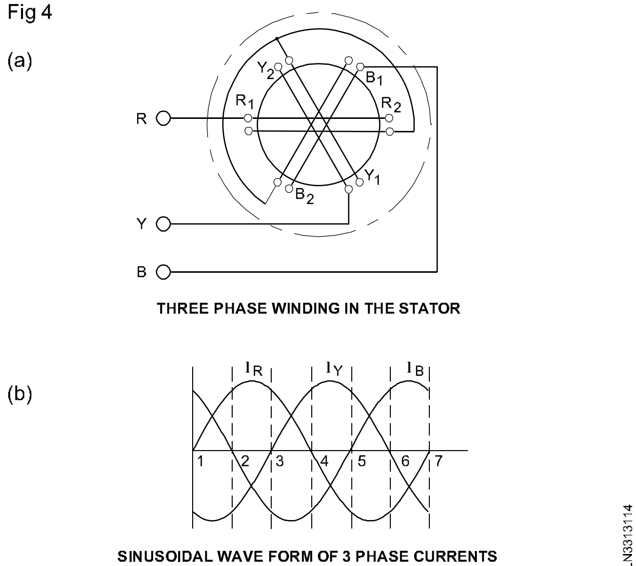
Rotating magnetic field from a three-phase stator: The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator. The stator of the induction motor contains three-phase windings placed at 120 electrical degrees apart from each other. These windings are placed 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).

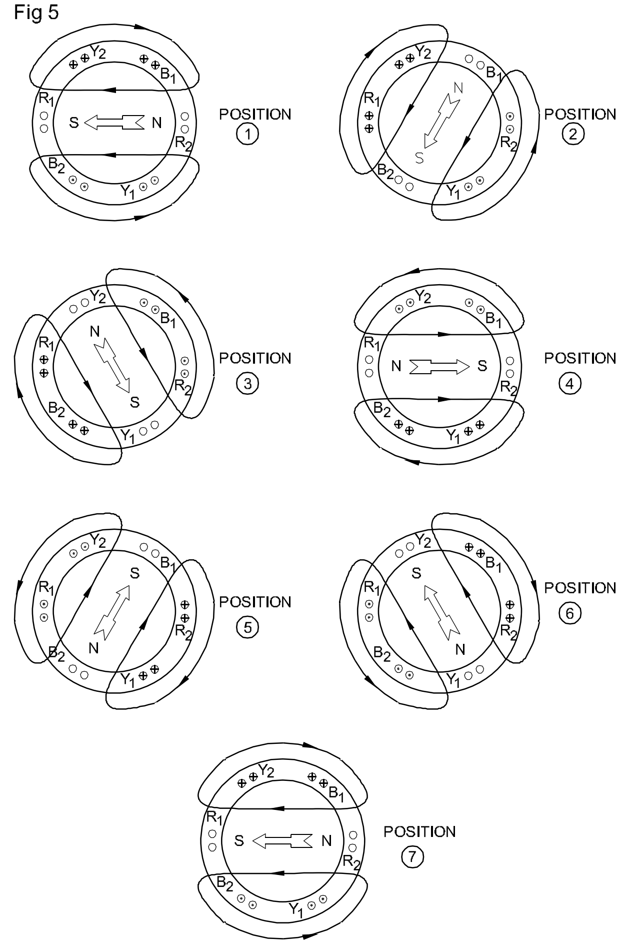
Fig 4



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.

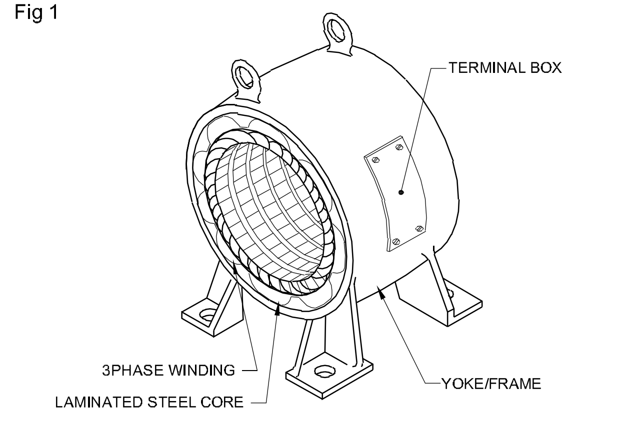
Development of these two types of induction motors is due to the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque will be low with increased losses and poor efficiency. For certain applications 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.

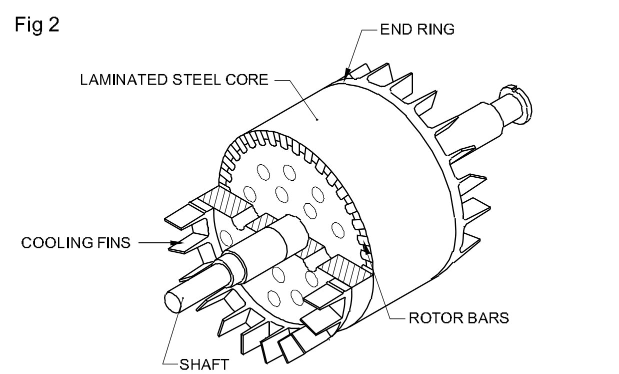
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase 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.

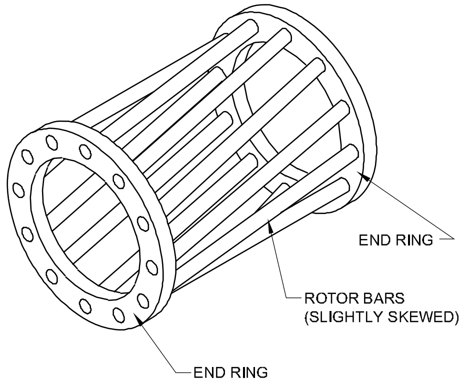
Fig 2



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.

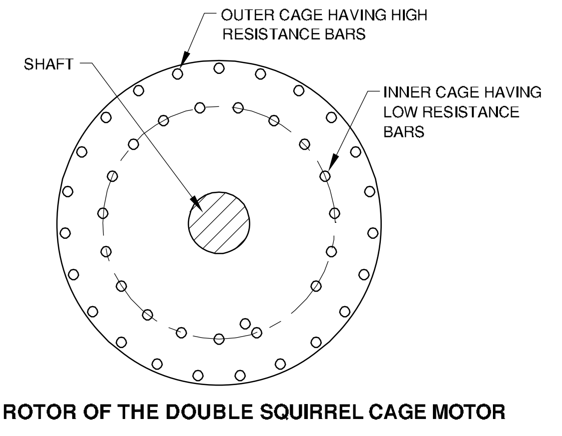
Double squirrel cage induction motor

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

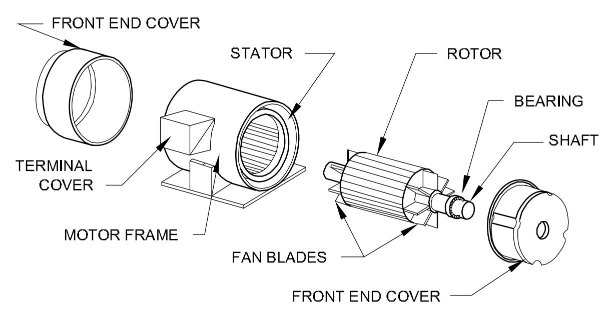


ROTOR OF THE DOUBLE SQUIRREL CAGE MOTOR

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

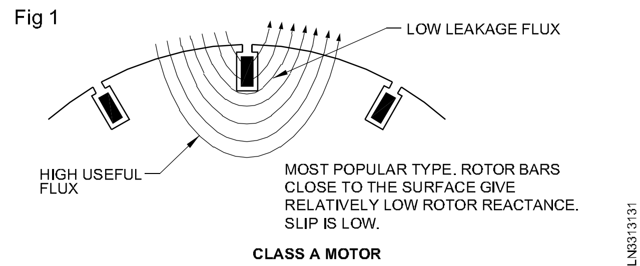
(According to starting characteristics)

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.

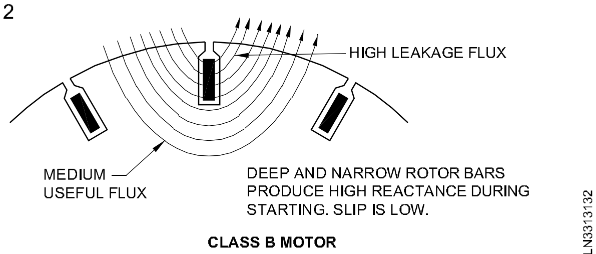
Class A motors: These motors are characterised by having a low rotor-circuit resistance and reactance. Its locked rotor current with full voltage is generally more than 6 times the full load current. Because of their low resistance, starting currents are very high. They operate at very small slips (s < 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



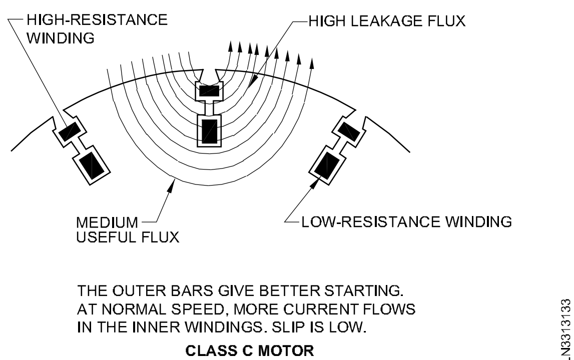
Class B motors: These are general purpose motors of normal starting torque and starting current. The speed regulation at full load is low (usually under 5%) and the starting torque is in the order of 15% of the rated speed being lower for the lower speed and larger motors. It should be realised that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

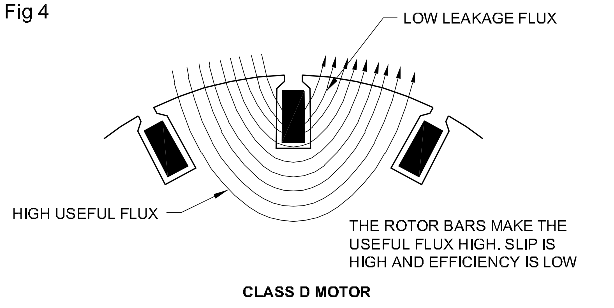


Fig 5

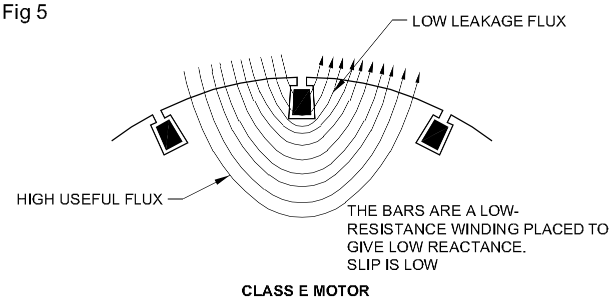
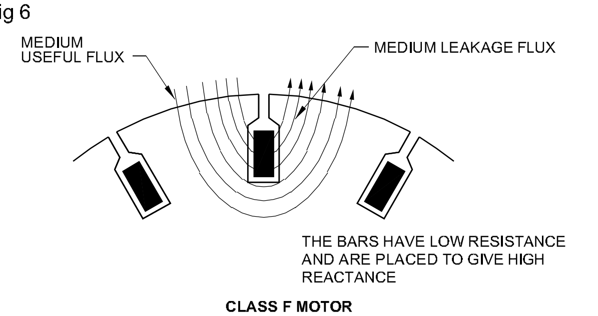


Fig 6



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

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

$$\text{also, } N_s = \frac{120f}{p}$$

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.)

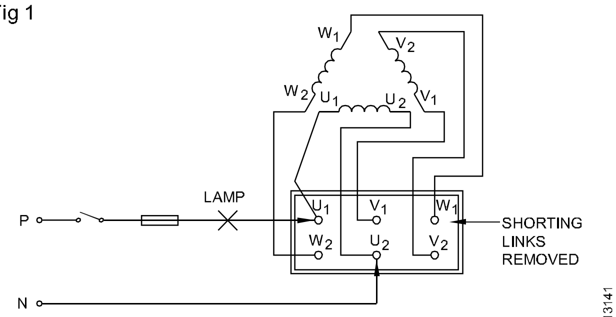
– Keeping the earth electrode resistance value as low as possible such that in case of leakage, any one unit of the protective system will operate to isolate the motor from the supply.

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

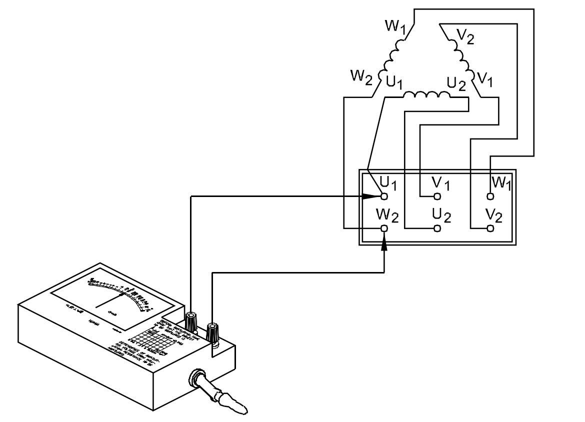


CONTINUITY TEST CIRCUIT

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).

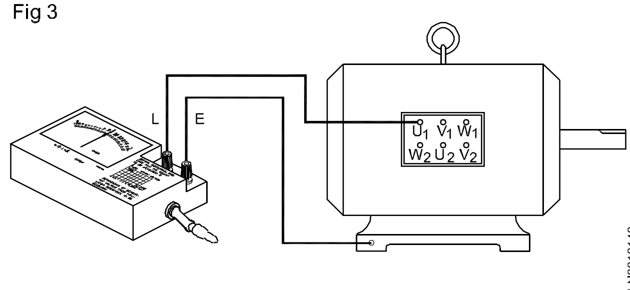
Fig 2



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.

Starter for 3-phase induction motor - power control circuits - D.O.L starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starters for a 3-phase induction motor and name the types of starters**
- **explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of the overload relay, different types of overload relays**
- **state the function of a no-volt coil, its rated voltage, position of operation, its common troubles, their causes and remedies.**

Necessity of starter: A squirrel cage induction motor just before starting is similar to a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

- Direct on-line starter
- Star-delta starter
- Step-down transformer starter
- Auto-transformer starter

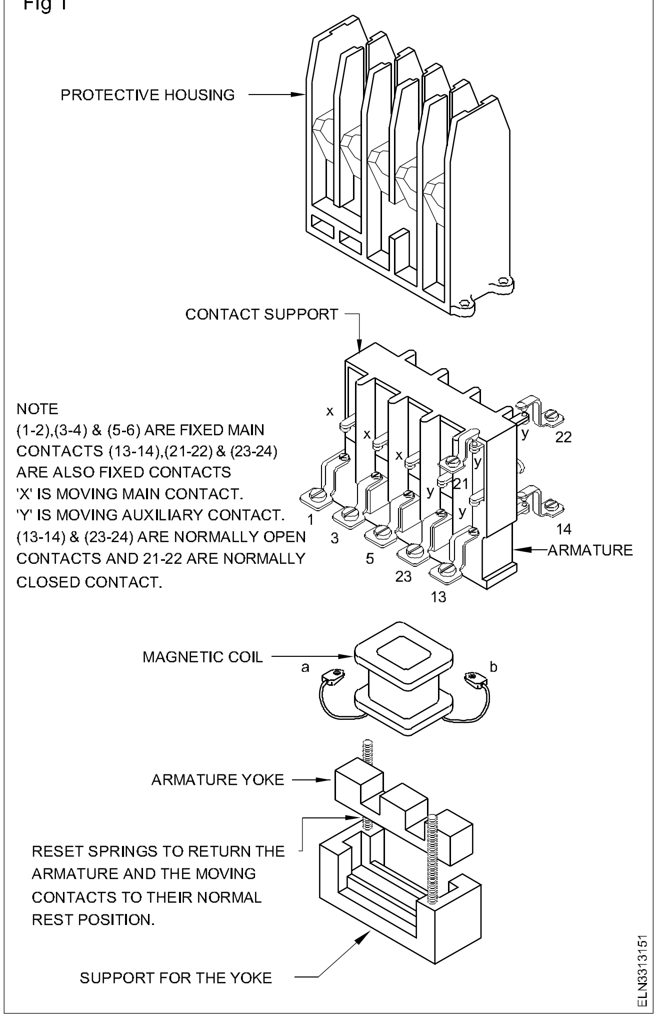
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

Fig 1

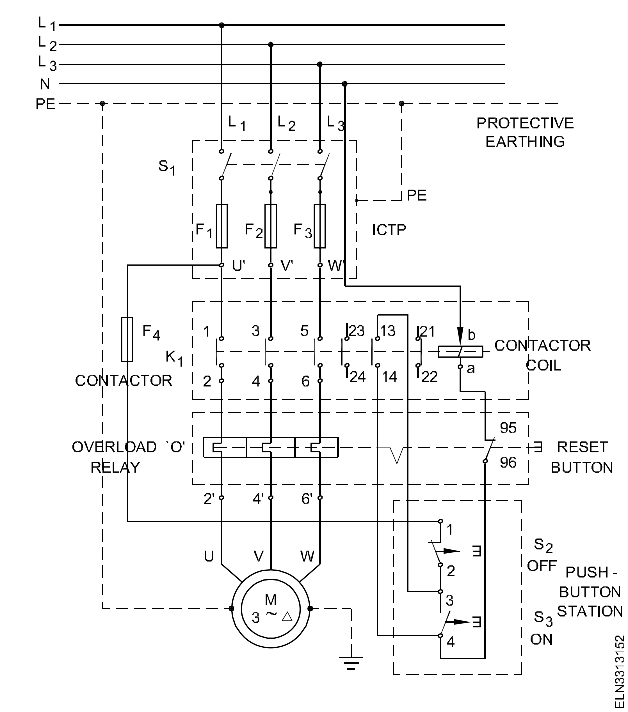


The main parts of a magnetic contactor are shown in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

Functional description

Power circuit: As shown in Fig 2, when the main ICTP switch is closed and the contactor K_1 is operated, all the three windings U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 2

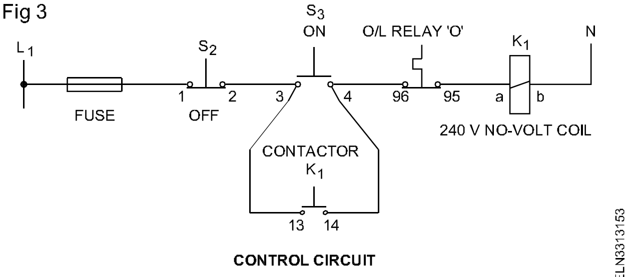


The overload current relay (bimetallic relay) protects the motor from overload (`motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also actuated together with the main contacts of K_1. If this normally open contact is connected in parallel with S_3, it is called a self-holding auxiliary contact.

Fig 3



After S_3 is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally closed contact 95 and 96 of overload relay `O' opens, and switches off the control circuit. Thereby $K_1$ switches `OFF' the motor circuit. (Fig 3)

Once the contact between 95 and 96, is opened due to the activation of the overload relay `O', the contacts stay open and the motor cannot be started again by pushing the `ON' button S_3. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the `OFF' button which is in line with the overload relay `O'.

Push-button actuation from two operating locations: If it is desired to switch a contactor off and on from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, as shown in the complete diagram Fig 4 and the control diagram Fig 5.

Fig 4

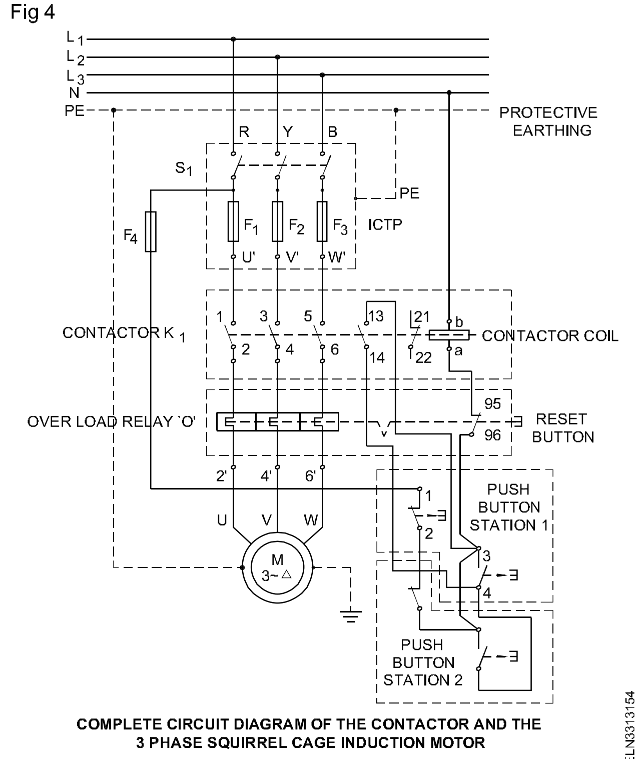
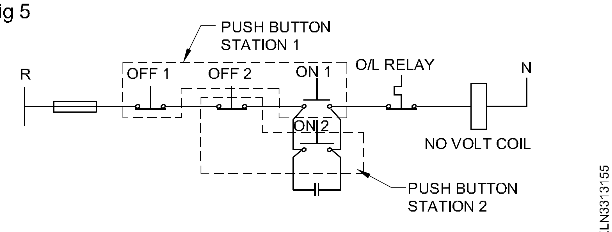


Fig 5



If either of the two ON push-buttons is actuated, K_1 is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor K_1. If either of the two OFF push -buttons is actuated, the contactor opens.

Purpose of overload relays: The overload relays protect the motor against repeated, excessive momentary surges or normal overloads existing for long periods, or high currents caused in two phases by the single-phasing effect. These relays have characteristics which help the relay to open the contactor in 10 seconds if the motor current is 500 percent of the full load current, or in 4 minutes if the current is 150 percent of the full load current.

Types of overload relay

There are two types of overload relays. They are :

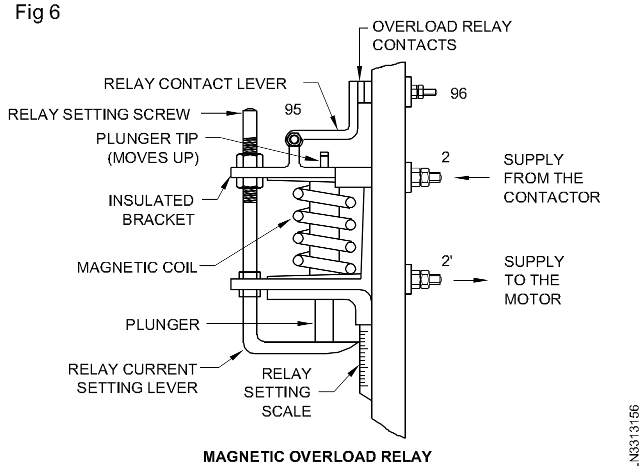
- magnetic overload relay
- thermal (bimetallic) overload relay.

Normally there are 3 coils in a magnetic relay and 3 sets of heater coils in a bimetallic relay so that two coils will operate in case of single phasing which help in avoiding the burning out of the motor.

Magnetic overload relay: The magnetic overload relay coil is connected in series with the motor circuits as shown in Fig 2. The coil of the magnetic relay must be wound with a wire, large enough in size to pass the motor current. As these overload relays operate by current intensity and not by heat, they are faster than bimetal relays.

As shown in Fig 6, the magnetic coil carries the motor current through terminals 2 and 2' which is in series with the power circuit. The relay contacts, 95 and 96, are in series with the control circuit. When a current more than a certain stipulated value, as set by the relay set scale, passes through the power circuit, the magnetic flux produced by the coil will lift the plunger in an upward direction. This upward movement makes the plunger tip to push the relay contact lever, and the contact between terminals 95 and 96 opens. This breaks the no volt coil circuit and the contactor opens the power circuit to the motor. The relay contacts between terminals 95 and 96 stay open till the rest-button (not shown in the figure) is pressed.

Fig 6



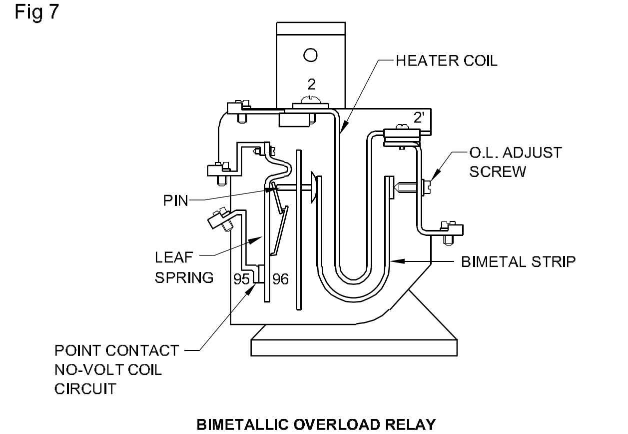
MAGNETIC OVERLOAD RELAY

Bimetallic overload relays: Most bimetallic relays can be adjusted to trip within a range of 85 to 115 per cent of the nominal trip rating of the heater unit. This feature is useful when the recommended heater size may result in unnecessary tripping, while the next larger size will not give adequate protection. Ambient temperatures affect thermally-operated overload relays.

The tripping of the control circuit in the bimetallic relay results from the difference of expansion of two dissimilar metals fused together. Movement occurs if one of the metal expands more than the other when subjected to heat. A U-shaped bimetallic strip is used in the relay as shown in Fig 7. The U-shaped strip and a heater element inserted in the centre of the U compartments for avoiding possible uneven heating due to variations in the mounting location of the heater element.

As shown in Fig 7, under normal conditions, the bimetallic strip pushes the pin against the leaf-spring tension, and the point contacts 95 and 96 are in a closed position, and hence the no-volt coil circuit is completed while the motor is running. When a higher current passes through the heater coil connected to terminals 2 and 2', the heat generated in the coil heats up the bimetal strip which bends inward. Hence the pin retracts in the right hand direction and the leaf-spring opens the contact between 95 and 96 to open the contactor. The relay cannot be reset immediately as the heat in the bimetallic strips require some time for cooling.

Fig 7



BIMETALLIC OVERLOAD RELAY

Relay setting: The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of a relay for a starter depends upon the motor type, rating and duty.

For all direct on-line starters, relays should be set to the actual load current of the motor. This value should be equal to or lower than the full load current indicated on the name-plate of the motor. Described here is a simple procedure for setting the relay to the actual load current.

Set the relay to about 80% of the full load current. If it trips, increase the setting to 85% or more till the relay holds. The relay should never be set at more than the actual current drawn by the motor. (The actual current drawn by a motor will be less than the full load current in most cases, as motors may not be loaded to capacity.)

Tripping of starters: A starter may trip due to the following reasons.

- Low voltage or failure of power supply
- Persistent overload on the motor

In the first instance, the tripping occurs through the coil which opens the contacts when the voltage falls below a certain level. The starter can be restarted as soon as the supply is back to normal.

The relay trips the starter when there is an overload. It can be restarted only after the relay is reset and the load becomes normal.

No-volt coil: A no-volt coil consists of generally more number of turns of thin gauge of wire.

Coil voltages: Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24V, 40V, 110V, 220 V (or) 230/250 V, 380V (or) 400/ 440V AC or DC are available as standard for contactors and starters.

Troubleshooting in contactor: Table 1 gives the common symptoms their causes and remedies.

Table 1

Symptoms	Causes	Remedies
Motor does not start when the 'start' button is pressed. However on pressing the armature of the contactor manually, motor starts and runs.	Open in no-volt coil circuit.	Check the main voltage for lower than acceptable value. Rectify the main voltage. Check the control circuit wiring for loose connection. Check the resistance of the no-volt coil winding. If found incorrect replace the coil.
Motor starts when `ON' button is pressed. It however stops immediately when `ON' button is released.	Auxiliary contact in parallel with the start-button is not closing.	Check the parallel connection from `ON' button terminals to the auxiliary contact of the contactor. Rectify the defect. Check the auxiliary contact points of the contactor for erosion and pittings. Replace, if found defective.
Motor does start when the start-button is pressed. However, a humming or chattering noise comes from the starter.	Movable armature and fixed limb of electromagnet are not stably attracted.	Dust or dirt or grit between the mating surfaces of the electromagnetic core. Clean them. Low voltage supply. Find the cause and rectify the defect. Break in the shading ring in the case of AC magnet.
Failure of contactor due to too much heating of the `No' volt coil.	Higher incoming supply rating. No-volt coil rating is not high.	Higher supply voltage than normal. Reduce the incoming voltage. Voltage rating of the no-volt coil is less. Replace with standard rating, according to the main supply.
Motor does not restart immediately after tripping of OL relay even though OL relay was reset.	It takes a little time for the thermal bimetal to cool and reset.	Wait for 2 to 4 minutes before re-starting.
Coil does not get energised even though supply voltage is found across the no-volt coil terminals.	Open-circuited NVC. NVC burnt out.	Check the nylon strip on relay. Check the nylon button below the start button Replace, if necessary.
Relay coil has been changed. However motor does not start when the start-button is pressed.	Control circuit of relay open.	Check the control circuit for open. Clean the control station contacts. Overload relay not reset.

Symptoms	Causes	Remedies
Humming or chattering noise.	Low voltage. Magnetic face between yoke and armature is not clean. Shading ring on iron core missing.	Feed the rated voltage. Clean the surfaces of yoke and armature. Provide shading ring in the iron core

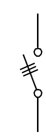
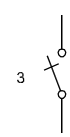
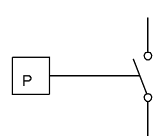
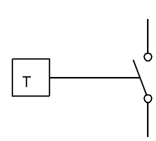
B.I.S. symbols pertaining to contactor and machines

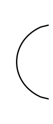
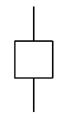
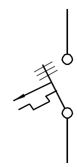
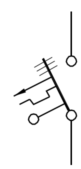
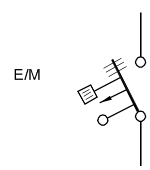
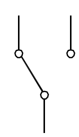
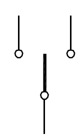
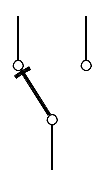
Objective: At the end of this lesson you shall be able to

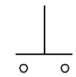
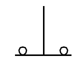
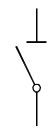
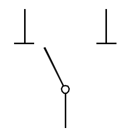
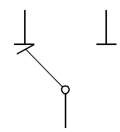
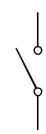
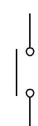
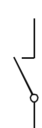
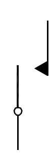
- **identify B.I.S. symbols pertaining to rotating machines and transformers (BIS 2032 Part IV), contactors, switch, gear and mechanical controls (BIS 2032 Part VII, 2032 Part XXV and XXVII).**

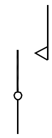
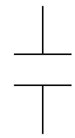
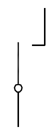
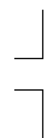
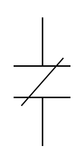
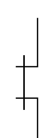
The table given below contains most of the important symbols used by an electrician. However, you are advised to refer to the quoted B.I.S. standards for further additional information.

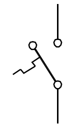
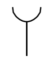
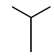
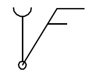
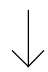
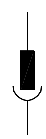
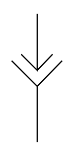
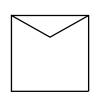
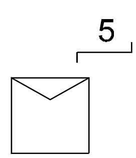
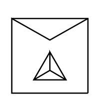
Table

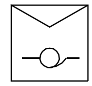
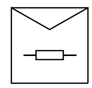
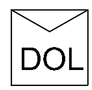
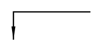
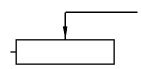
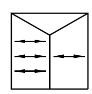
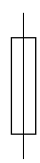
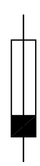
S.No.	BIS Code No.	Description	Symbol	Remarks
	BIS 2032 (Part XXV)-1980			
	9	**Switch gear, accessories**		
1	9.1	Switch, general symbol		
2	9.1.1	Alternate symbol for switch.		
3	9.2	Three-pole switch, single line representation.		
4	9.2.1	Alternate symbol for three-pole switch, single line representation.		
5	9.3	Pressure switch		
6	9.4	Thermostat		
7	9.5	Circuit-breaker		

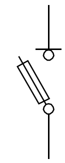
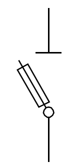
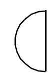
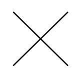
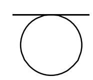
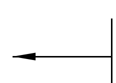
S.No.	BIS Code No.	Description	Symbol	Remarks
8	9.5.1	Alternate symbol of circuit-breaker. **Note : The rectangle of symbol 9.5 should contain some indication that a circuit-breaker is connected.**		
9	9.5.2	Alternate symbol for circuit breaker.		
10	9.5.3	Circuit-breaker with short circuit under voltage and thermal overload releases.		
11	9.5.4	Hand-operated circuit-breaker with short circuit, thermal overload protection and no-volt tripping.		
12	9.5.5	Motor - solenoid operated air circuit-breaker with short circuit and no-volt tripping (triple pole).		
13	9.6	Change over contact, break before make. NOTE : The fixed contacts may be placed at any angle except at 60°. In order to facilitate the work of the draughtsman, the contacts may be arranged differently.		
14	9.7	Two-way contact with neutral position		
15	9.8	Make-before-break contact.		
16	9.9	Contactor, normally open.		
17	9.9.1	Contactor, normally closed.		

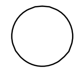
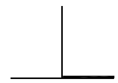
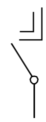
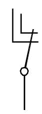
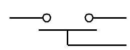
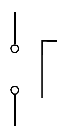
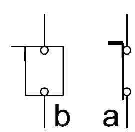
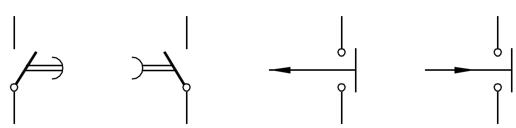
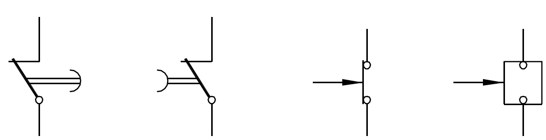
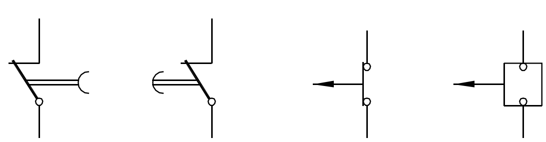
S.No.	BIS Code No.	Description	Symbol	Remarks
18	9.10	Push-button with normally open contact.		
19	9.10.1	Push-button with normally closed contact.		
20	9.11	Isolator.		
21	9.12	Two-way isolator with interruption of circuit.		
22	9.13	Two-way isolator without interruption of circuit.		
23	9.14	Make contact, general symbol.		
24	9.14.1	Alternate symbol for make contact, general symbol.		
25	9.14.2	Alternate symbol for make-contact.		
26	9.14.3	Alternate symbol for make-contact.		
27	9.14.4	Alternate symbol for make-contact.		
28	9.14.5	Alternate symbol for make-contact.		

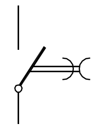
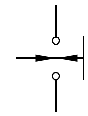
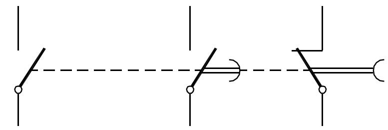
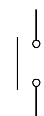
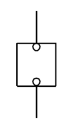
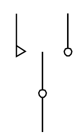
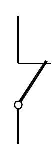
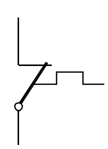
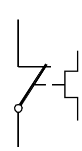
S.No.	BIS Code No.	Description	Symbol	Remarks
29	9.14.6	Alternate symbol for make-contact.		
30	9.14.7	Alternate symbol for make-contact.		
31	9.14.8	Alternate symbol for make-contact.		
32	9.14.9	Alternate symbol for make-contact.		
33	9.15	Break-contact, general symbol.		
34	9.15.1	Alternate symbol for break-contact.		
35	9.15.2	Alternate symbol for break-contact.		
36	9.15.3	Alternate symbol for break-contact.		
37	9.15.4	Alternate symbol for break-contact.		
38	9.15.5	Alternate symbol for break-contact.		

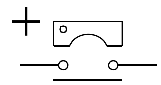
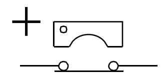
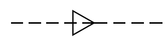
S.No.	BIS Code No.	Description	Symbol	Remarks
39	9.16	Thermal overload contact.		
40	9.17	Socket (female).		
41	9.17.1	Alternate symbol for socket (female).		
42	9.17.2	Socket with switch.		
43	9.18	Plug (male).		
44	9.18.1	Alternate symbol for plug (male).		
45	9.19	Plug and socket (male and female).		
46	9.19.1	Alternate symbol for plug and socket (male and female).		
47	9.20	Starter, general symbol.		
48	9.21	Starter by steps (Example: 5 steps).		
49	9.22	Star-delta starter.		

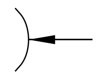
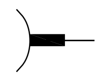
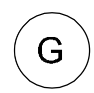
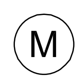
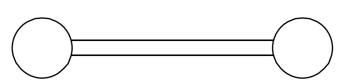
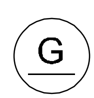
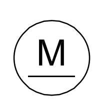
S.No.	BIS Code No.	Description	Symbol	Remarks
50	9.23	Auto-transformer starter.		
51	9.24	Pole-changing starter (Example, 8/4 poles).		
52	9.25	Rheostatic starter.		
53	9.26	Direct on-line starter.		
54	9.27	Sliding contact, general symbol.		
55	9.27.1	Resistor with moving contact, general symbol.		
56	9.28	Combined control panel for two motors (multiple speed and reversible).		
57	9.29	Fuse.		
58	9.29.1	Alternate symbol for fuse.		
59	9.29.2	Alternate symbol for fuse where supply side is indicated by a thick line.		
60	9.29.3	Alternate symbol for fuse where supply side is indicated by a thick line.		

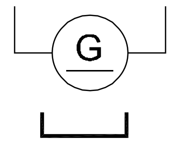
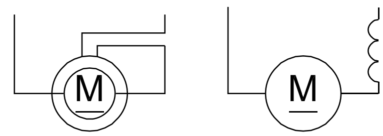
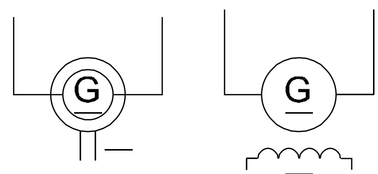
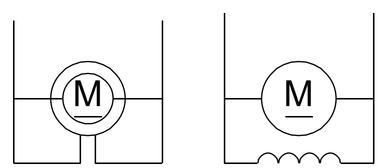
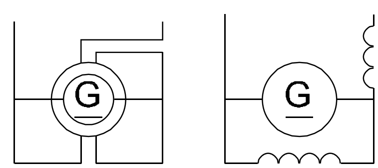
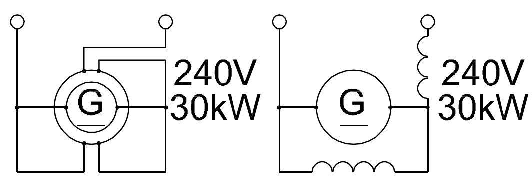
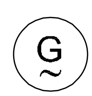
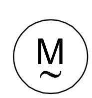
S.No.	BIS Code No.	Description	Symbol	Remarks
61	9.30	Isolating fuse-switch, switching on load.		
62	9.31	Isolating fuse-switch.		
	BIS 2032 Part(XXV11) 1932	**Contactors**		
	3.2	**Qualifying symbols**		
63	3.2.1	Contactor function.		
64	3.2.2	Circuit-breaker function.		
65	3.2.3	Disconnector (isolator) function.		
66	3.2.4	Switch-disconnector (isolator switch) function.		
67	3.2.5	Automatic release function.		
68	3.2.6	Delayed action. Convention - delayed action in direction of movement from the arc towards its centre. **Note: This symbol must be linked by a double line to the symbol of the device, the action of which is delayed.**	 	
69	3.2.6.1	Delayed action convention - delayed action in the direction of movement of the arrow mark.		

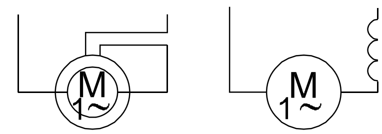
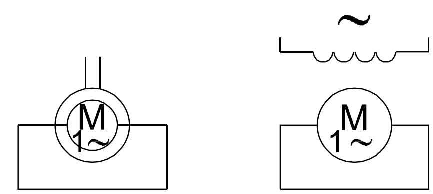
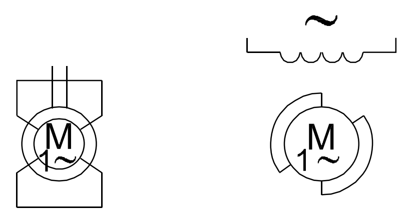
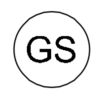
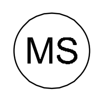
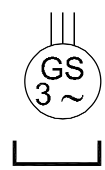
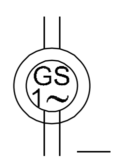
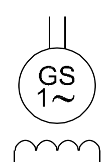
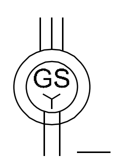
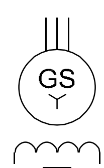
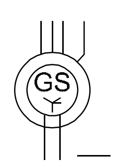
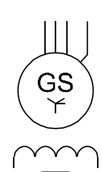
S.No.	BIS Code No.	Description	Symbol	Remarks
70	3.2.7	Non-spring return (stay put) function. NOTE : The symbols shown above may be used to indicate spring-return and stay-put contacts. When this convention is invoked, its use should be appropriately referenced. These symbols should not be used together with the qualifying symbols Nos. 3.1 to 3.4.		
71	3.2.8	Hand reset.		
72	3.3.7	Contact with two makes.		
73	3.3.8	Contact with two breaks.		
74	3.3.9	Three-point contact.		
75	3.3.10	Make contact-hand reset.		IR
76	3.3.11	Break contact-hand reset.		IR
77	3.3.19	Make-contact delayed when operating.		
78	3.3.20	Break-contact delayed when operating.		
79	3.3.21	Break-contact delayed when releasing.		

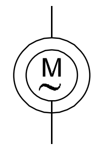
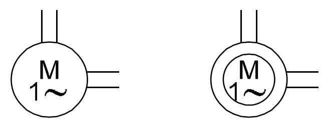
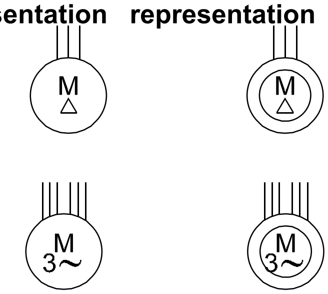
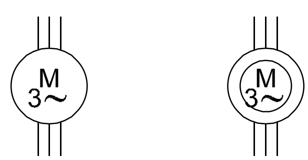
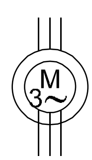
S.No.	BIS Code No.	Description	Symbol	Remarks
80	3.3.22	Make-contact delayed when operating and releasing.		
81	3.3.23	Contact assembly with one make-contact not delayed. One make contact delayed when operating and one break-contact delayed when releasing.		
82	3.3.24	Make-contact with spring return.		
83	3.3.25	Make-contact without spring return (stay-put)		 SR
84	3.3.26	Break-contact with spring return.		 SR
85	3.3.27	Two-way contact with centre off position with spring. Return from the left-hand position but not from the right hand one (stay-put).		
86	3.3.28	Temperature-sensitive make-contact. **Note: May be replaced by the value of the operating temperature conditions.**		
87	3.3.29	Temperature sensitive break-contact. NOTE : may be replaced by the value of the operating temperature conditons.		
88	3.3.30	Self-operating thermal-break contact. NOTE : It is important to distinguish between a contact as shown and a contact of a thermal relay, which in detached representation is shown in the example below.		
		Example: Break contact of a thermal relay.		

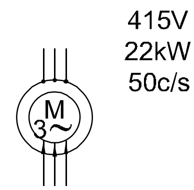
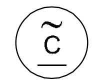
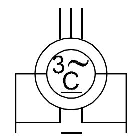
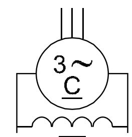
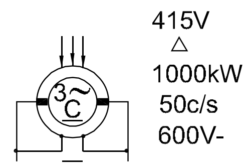
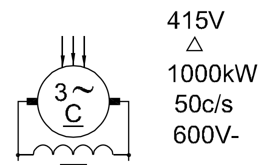
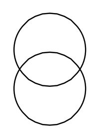
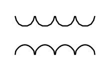
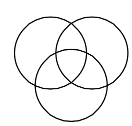
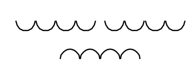
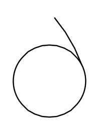
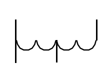
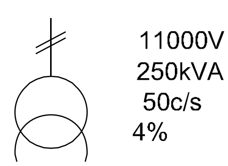
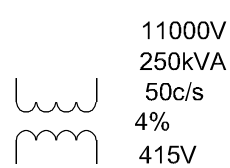
S.No.	BIS Code No.	Description	Symbol	Remarks
89	3.3.32	Blow-out magnetic make-contact.		
90	3.3.33	Blow-out magnetic break-contact.		
	BIS:2032 (PART VII) 1974	**Mechanical controls**		
91	8.4	**Mechanical interlock**		
92	8.5	Reset a Automatic reset b Non-automatic reset **Note : These symbols should be used only if it is essential to indicate the type of reset.**	 	
	BIS:2032 (Part IV) 1964	**Classification**		
		In this standard, more than one symbol have been used to designate the same type of rotating machine or transformer depending on the type and class of drawing involved. For the same type of rotating machines, in simplified as well as in the complete, multi-line symbols have been specified. In the case of transformers, symbols for single line and multi-line representation have been given separately. Wherever single line representation is required for rotating machines, reference may be made to IS:2032(Part II)-1962. Elements of symbols		
93	3.14	Winding Note: The number of half circles is not fixed, but if desired a distinction might be made for the different windings of a machine as specified in 3.2,3.3 and 3.4.		
94	3.24	Commutating or compensating winding.		
95	3.34	Series winding.		

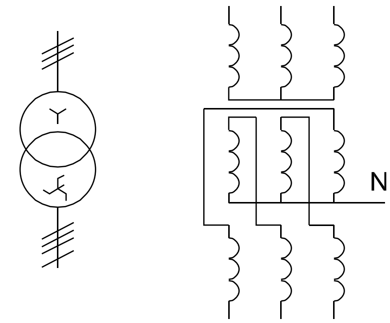
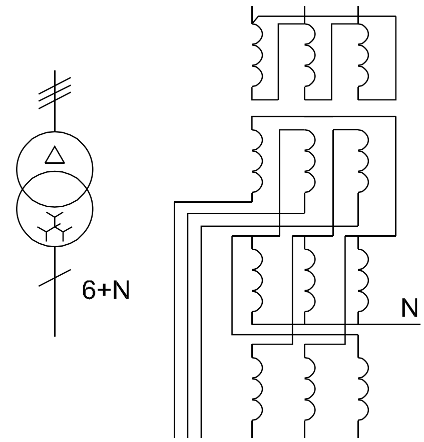
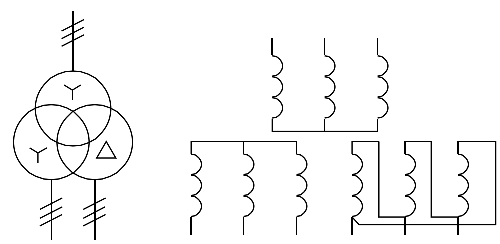
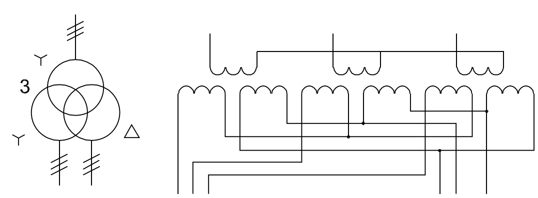
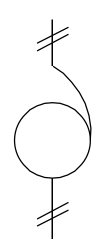
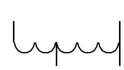
S.No.	BIS Code No.	Description	Symbol	Remarks
96	3.44	Shunt winding or separate winding.		
97	3.54	Brush or slip-ring.		
98	3.64	Brush on commutator.		
99	3.74	**Supplementary indications, numerical data.** **Supplementary indications (method of connecting windings, letter M, G or C and numerical data) are shown only on one symbol for each class of machine, as an example.**		
	4	**Rotating machines**		
	4.1	**General symbols**		
100	4.1.14	Generator		
101	4.1.2	Motor		
102	4.1.3	Machine capable of use as generator or motor.		
103	4.1.4	Mechanically coupled machines. **Note: Other special types of coupling, that is, monobloc construction, shall be suitably indicated wherever necessary.**		
	4.2	**Direct current machine**		
104	4.2.1	Direct current generator, general symbol.		
105	4.2.2	Direct current motor, general symbol.		

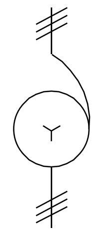
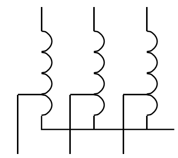
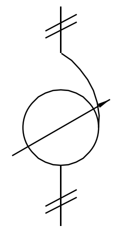
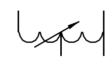
S.No.	BIS Code No.	Description	Symbol	Remarks
106	4.2.3	DC 2-wire permanent magnet generator(G) or motor (M).		
			Simplified multiline representation **Complete multiline representation**	
107	4.2.4	DC 2-wire series generator (G) or motor (M).		
108	4.2.5	DC 2-wire generator (G) or motor (M) separately excited.		
109	4.2.6	DC 2-wire shunt generator (G) or motor (M).		
110	4.2.7	DC 2-wire generator (G) or motor (M), compound-excited, short shunt.		
111	4.2.8	Symbol showing terminals, brushes and numerical data. *Example* : DC 2-wire generator compound excited short shunt, 240 V, 30 KW.		
	4.3	**Alternating current machines**		
112	4.3.1	AC generator, general symbol.		
113	4.3.2	AC motor, general symbol.		
	4.4	**Alternating current Commutator machines.**	**Simplified multiline representation** **Complete multiline representation**	

S.No.	BIS Code No.	Description	Symbol	Remarks
114	4.4.1	AC series motor, single phase.		
115	4.4.2	Repulsion motor, single phase.		
116	4.4.3	AC series motor, single phase, Deri type.		
	4.5	**Synchronous machines**		
117	4.5.1	Synchronous generator, general symbol.		
118	4.5.2	Synchronous motor - general symbol.		
119	4.5.3	Permanent magnet synchronous generator (GS) or synchronous motor (MS), three-phase.		
			Simplified multiline representation	**Complete multiline representation**
120	4.5.4	Synchronous generator (GS) or synchronous motor (MS) single-phase.		
121	4.5.5	Synchronous generator (GS) or synchronous motor (MS) three-phase, star-connected, neutral not brought out.		
122	4.5.6	Synchronous generator (GS) or synchronous motor (MS) three-phase star-connected with neutral brought out.		

S.No.	BIS Code No.	Description	Symbol	Remarks
	4.6	**Induction Machines** **Note : In symbols 4.6.1 to 4.6.9 groups of conductors may be placed in another manner than generally shown below. For example, symbol 4.6.6.**		
123	4.6.1	Induction motor, with short-circuited rotor, general symbol.		
124	4.6.2	Induction motor, with wound rotor, general symbol.		
125	4.6.3	Induction motor, single phase, squirrel-cage.		
126	4.6.4	Induction motor, single phase, squirrel cage, leads of split-phase brought out.		
127	4.6.5	Induction motor, three-phase, squirrel-cage.	**Simplified multiline representation** **Complete multiline representation** 	
128	4.6.6	Induction motor, three-phase, squirrel cage, both leads of each phase brought out.		
129	4.6.7	Induction motor, three-phase, with wound rotor.		
130	4.6.8	Induction motor, three-phase, star-connected, with automatic starter in the rotor.		

S.No.	BIS Code No.	Description	Symbol	Remarks
131	4.6.9	Symbol showing terminals, brushes and numerical data. *Example* : Induction motor, three-phase, with wound rotor 415V, 22 kW, 50 c/s.		
	4.7	**Synchronous converters.**		
132	4.7.1	Synchronous converter, general symbol.		
133	4.7.2	Three-phase synchronous converter, shunt excited. 72	 	
134	4.7.3	Symbol showing terminals, brushes and numerical data. *Example* : Three-phase synchronous converter, shunt excited 600 V, 1000 kW, 50 c/s.	 	
	5	**Transformers**		
	5.1	**General symbols**		
135	5.1.1	Transformer with two separate windings.	 	
			Simplified multiline representation / **Complete multiline representation**	
136	5.1.2	Transformer with three separate windings.	 	
137	5.1.3	Auto-transformers	 	
	5.2	**Transformers with two or three Windings.**		
138	5.2.1	Single-phase transformer with two separate windings.	 	

S.No.	BIS Code No.	Description	Symbol	Remarks
139	5.2.4	Three-phase transformer with two separate windings. Connection: star zig-zag.		
140	5.2.5	Three-phase transformer with two separate windings. Connection: delta 6-phase fork.		
141	5.2.6	Three-phase transformer with three separate windings. Connection: star, star-delta.	 **Simplified multiline representation** **Complete multiline representation**	
142	5.2.7	Three-phase bank of single-phase transformers with three separate windings. Connection : star, star-delta.		
	5.3	**Auto-transformers**		
143	5.3.1	Auto-transformer, single-phase.		

S.No.	BIS Code No.	Description	Symbol	Remarks
144	5.3.2	Auto-transformer, three-phase. Connection:star.		
145	5.3.3	Single-phase auto-transformer with continuous voltage regulation.		

D.O.L. starter

Objectives: At the end of this lesson you shall be able to
- **state the specification of a D.O.L. starter, explain its construction, operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is shown in Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 3.1.04 and the D.O.L.starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1. Further the overload relay can be situated between ICTP switch and contactor,or between the contactor and motor as shown in Fig 1, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own

Specification of D.O.L. starters: While giving specification, the following data are to be given.

D.O.L. STARTER

Phases - single or three.

Voltage 240 or 415V.

Current rating 10, 16, 32, 40, 63, 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.

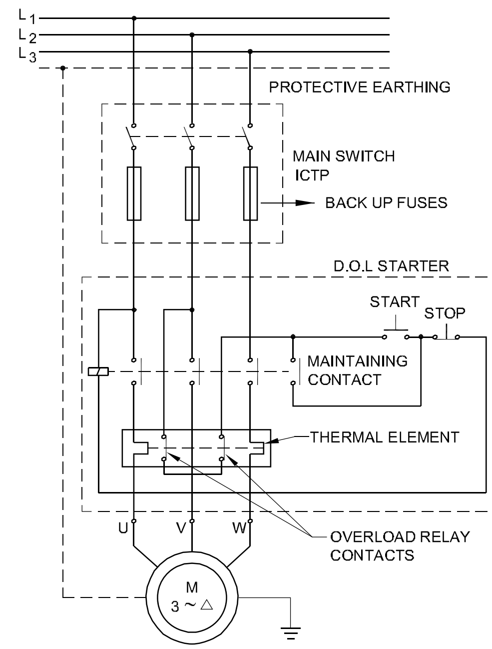
Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

ELN331361

Applications: In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Necessity of back-up fuses: Motor starters must never be used without back-up fuses. The sensitive thermal relay mechanism is designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays, due to their inherent operating mechanism, take a longer time to operate and open the circuit. Such delays will be sufficient to damage the starter motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick-action, high-rupturing capacity fuses which, when used in the motor circuit, operate at a faster rate and open the circuit. Hence H.R.C. diazed (DZ) type fuses are recommended for protecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits, the back-up fuses melt and open the circuit quickly. A reference table indicating fuse ratings for different motor ratings is given.

It is recommended that the use of semi-enclosed, rewirable, tinned copper fuses may be avoided as for as possible.

The given full load currents apply in the case of single phase, capacitor-start type motors, and in the case of 3-phase, squirrel cage type induction motors at full load having average power factor and efficiency. The motors should have speeds not less than 750 r.p.m.

Fuses upto and including 63 A are DZ type fuses. Fuses from 100 A and above are IS type fuses (type HM).

Table of relay ranges and back-up fuses for motor protection

Sl. No.	Motor ratings 240V 1-phase			Motor ratings 415V 3-phase			Relay range A	Nominal back-up fuse recommended
	hp	kW	Full load current	hp	kW	Full load current	a	c
1				0.05	0.04	0.175	0.15 - 0.5	1A
2	0.05	0.04		0.1	0.075	0.28	0.25 - 0.4	2A
3				0.25	0.19	0.70	0.6 - 1.0	6A
4	0.125	0.11		0.50	0.37	1.2	1.0 - 1.6	6A
5	0.5	0.18	2.0	1.0	0.75	1.8	1.5 - 2.5	6A
6	0.5	0.4	3.6	1.5	1.1	2.6	2.5 - 4.0	10A
7				2.0	1.5	3.5	2.5 - 4.0	15A
8	0.75	0.55		2.5	1.8	4.8	4.0 - 6.5	15A
9				3.0	2.2	5.0	4.0 - 6.5	15A
10	1.0	0.75	7.5	5.0	3.7	7.5	6.0 - 10	20A
11	2.0	1.5	9.5	7.5	5.5	11.0	9.0 - 14.0	25A
12	3.0	2.25	14	10.0	7.5	14	10.0 - 16.0	35A

Numerical problems in ac 3-phase induction motors

Objective: At the end of this lesson you shall be able to
- **solve the numerical problems in 3 phase induction motor.**

On very many occasions, an electrician may be asked to wire up a workshop well before the proposed machine is installed, having been provided with information only regarding the voltage rating and horsepower of the electrical motor.

While planning the wiring, the cable sizes need to be selected, based upon the full load current of the motor which could be calculated when sufficient data is available. The examples given below illustrate the method of determining the full-load current when other data are provided or vice versa.

To illustrate:

The output of the motor is given in metric horsepower.

Output of the motor = Metric HP x 735.6 watts.

Input of the motor = $\sqrt{3}\, E_L\, I_L \cos\theta$ watts

where E_L is the line voltage

I_L is the line current

$\cos\theta$ is the power factor

Also input = output + losses

= output + copper loss + iron loss + mechanical losses like windage, friction etc.

$$\text{Efficiency of the motor} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{\text{Metric horsepower} \times 735.5}{\sqrt{3} E_L I_L \cos\theta}$$

Example 1

A 3-phase, 6000 volts, star-connected induction motor develops 200 HP (Metric). Calculate the full load current per phase if the efficiency of the motor is 85% and the power factor is 0.8.

$$\text{Input} = \frac{\text{Output} \times 100}{\text{Efficiency}}$$

$$= \sqrt{3} E_L I_L \cos\theta$$

$$\text{Line current } I_L = \frac{\text{Output} \times 100}{\text{Efficiency} \times E_L \cos\theta \times \sqrt{3}}$$

$$= \frac{200 \times 735.5}{0.85 \times \sqrt{3} \times 6000 \times 0.8}$$

$$= 20.81\text{A}$$

In star, as the line current is equal to the phase current, we have the phase current at full load - 20.9 amps.

Example 2

A 3-phase, induction motor takes a current of 100 amps from 400V 50 HZ supply. Determine the power factor if the output of the motor is 70 HP (metric) and the efficiency is 90%.

$$\text{Input} = \frac{\text{Output}}{\text{Efficiency}}$$

$$\sqrt{3} E_L I_L \cos\theta = \frac{70 \times 735.5}{\frac{90}{100}}$$

$$\cos\theta = \frac{70 \times 735.5 \times 100}{90 \times \sqrt{3} \times 400 \times 100}$$

Power factor = 0.82.

Example 3

A 3-phase, 400V, 50 HZ, delta-connected induction motor draws a line current of 150 amps with a P.F. of 0.85 and is delivering an output of 100 (Metric) HP. Calculate the efficiency.

$$\text{\% of efficiency} = \frac{\text{Output} \times 100}{\text{Input}}$$

$$= \frac{100 \times 735.5 \times 100}{\sqrt{3} \times 400 \times 150 \times 0.85}$$

$$= 83.3\ \%$$

Example 4

A 3-phase, 400 V, induction motor takes a line current of 30 amperes with a power factor of 0.9. The efficiency of the motor is 80%. Calculate the output in metric horsepower.

$$\text{Output in watts} = \text{Input} \times \text{Efficiency}$$

$$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100}$$

$$\text{Output in metric HP} = \frac{\text{Output in watts}}{735.5}$$

$$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100 \times 735.5}$$

= 20.3 HP.

Jogging (inching) control circuits for motors

Objectives: At the end of this lesson you shall be able to
- **define the process of jogging/inching control**
- **state the purpose of jogging/inching control**
- **describe the operation of a jogging control using a selector switch**
- **describe the operation of a jogging control using a push-button station**
- **describe the operation of a jogging control using a control relay.**

Jogging (inching): In some industrial applications, the rotating part of a machine may have to be moved in small increments. This could be done by a control system called jogging (inching). Jogging is defined as the repeated closure of the circuit to start a motor from rest, producing small movements in the driven machine. By pressing the jog push-button the magnetic starter is energised and the motor runs; when the jog push-button is released, the motor stops.

When a jogging circuit is used, the motor can be energised only as long as the jog-button is depressed. This means the operator has instantaneous control of the motor drive.

Purpose of jogging/inching controls: Normally jogging (inching) controls are incorporated in the following machines for operational convenience shown against each.

- Lathe machine controls - for checking the trueness of the job and setting the tool initially.
- Milling machine controls - for checking the concentric running of the cutter at initial setting and also to set the graduated collar for depth of feed of the cutter.
- Grinding machine controls - for checking proper mounting of the wheel.
- Paper cutting machine - for adjusting the cut.

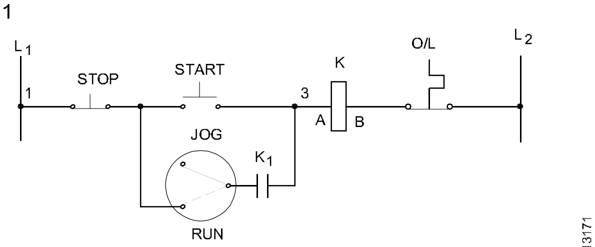
Apart from the above, the inch control is the prime control in cranes, hoists and conveyor belt mechanism so that incremental movements either vertically or horizontally could be achieved in the driven machinery.

Jogging may be accomplished by the following methods.

- Selector switch
- Push-button
- Push-button with a jog relay

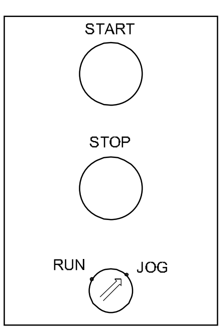
Jogging control using a selector switch: By using a selector switch, the existing start button can be used as a jogging push-button in addition to its function as a starting push-button. The holding contacts of the contactor which are in parallel to the start-button are disconnected and the selector switch is placed in the jog position as shown by the circuit in Fig 1 and the panel layout in Fig 2.

Fig 1



CONTROL CIRCUITS WITH JOG-RUN SELECTOR SWITCH.

Fig 2

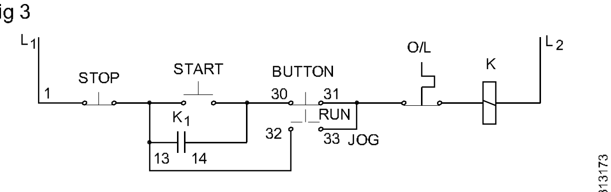


A PANEL OF A STATION IN WHICH THE START BUTTON CAN BE USED FOR INCHING OR JOGGING.

The motor can be started or stopped by jogging/inching the start button. The motor will operate as long as the start-button is held pressed.

Jogging control using a push-button: Fig 3 shows the control circuit of a D.O.L. starter connected to a start-jog-stop push-button station. When the `ON' push-button is pressed, coil K is energised as the no-volt coil circuit is complete through the normally closed `jog' button contacts 30 & 31, thereby closing the main contactor, and the motor runs. The self-holding auxiliary contact K_1 between terminals 13 and 14 gets closed, and keeps the no-volt coil circuit in function though the `ON' button is released. As soon as the jog push-button is pushed, as the circuit of the no-volt coil opens initially, the contactor is de-energised and the motor stops if it is running. Then the jog-button closes the bottom contacts 32 & 33, thereby the no-volt coil circuit closes and the motor runs as long as the jog-button is held pressed. By pushing and releasing the jog-button repeatedly, the motor starts and stops causing the driven machinery to `inch' forward to the desired position. On the other hand, pressing the start-button will make the motor to run normally.

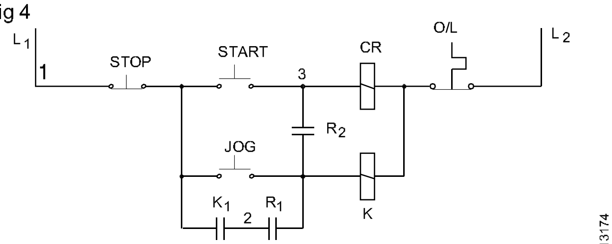
Fig 3



CONTROL CIRCUIT WITH JOG PUSH-BUTTON

Jogging control using a relay: Fig 4 shows the control circuit of a D.O.L. starter connected to a control relay with the other usual components. When the start button is pressed, the control relay coil CR is energised and closes the contacts R_1 and R_2, thereby momentarily completing the no-volt coil `K' circuit through relay contact R_2. This in turn closes the self-holding auxiliary contact K_1 of the no-volt coil relay K, and the motor runs continuously even though the pressure on the start-button is released.

Fig 4



LINE DIAGRAMS USING CONTROL RELAYS IN TYPICAL INSTALLATIONS

When the motor is not running, if the jog-button is pressed the no-volt coil, K circuit, is completed, and the motor runs only as long as the jog-button is held pressed as the holding circuit through R_1 is not completed for the starter coil as the control relay CR is not energised.

For a 3-phase, D.O.L. starter having the jog control through relay, four normally open contacts (3 for main and 1 for auxiliary) are required and the control relay should have two normally open contacts as shown in Fig 4.

Rotary type switches

Objectives: At the end of this lesson you shall be able to
- **explain the type of rotary switches - specifications like voltage rating, current rating, poles, function, position, type of mounting, type of handle, number of operations per hour and special requirement,**
- **explain the schematic diagram of rotary switches along with connection diagram of motors for ON/OFF three-pole switch, forward, stop and reverse three-pole switch, star-delta switch and pole changing switch.**

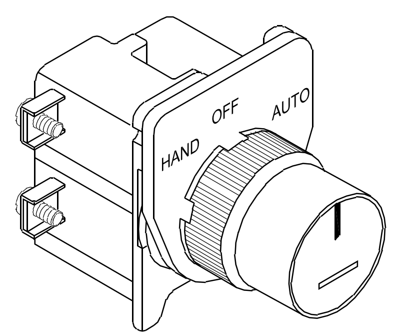
Rotary switches are most commonly used in lathes, milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which in turn operate cams inside the switch to contact various terminals in sequence by the internal contact blocks. These cams and blocks are made of hard P.V.C. and are designed to withstand many operations. It is possible to get many circuit combinations by combining various cams and contact blocks. As the contact blocks, terminals and cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs.

These rotary switches are classified according to

- poles
- function
- position
- mounting type
- handle design, and
- frequency of operations.

Poles: According to the number of independent connecting terminals and operation, they are called 2-pole (single phase, refer to Fig 1) or 3-pole (3-phase, refer to Fig 2) switches.

Fig 1

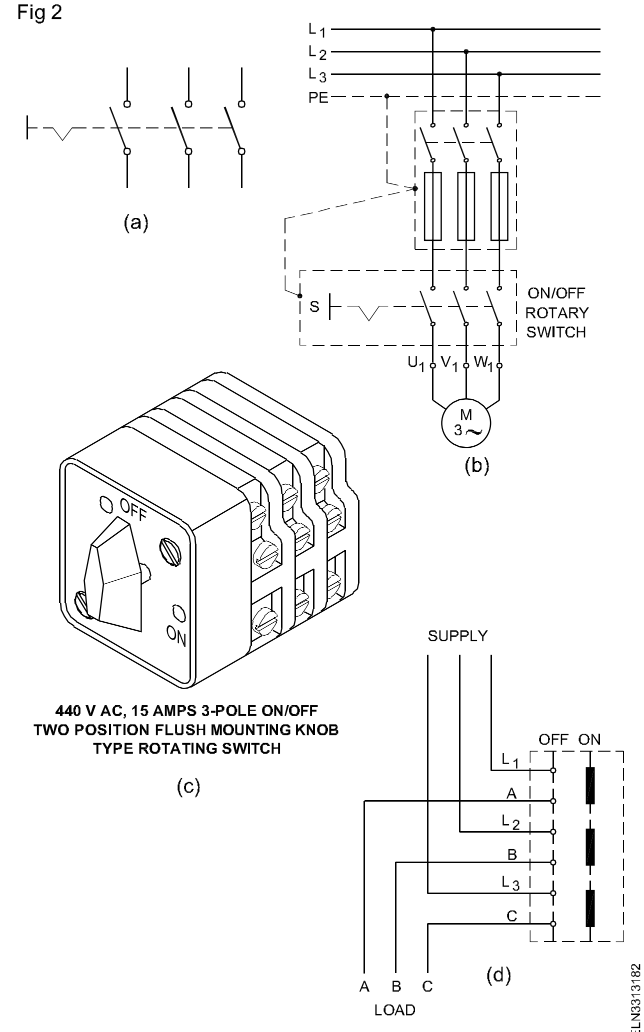


250 V AC 15 AMPS 2-POLE THREE POSITION FLUSH MOUNTING COIN-SLOT OPERATOR

Function: Rotary switches can do a number of functions depending upon the cam and contact block combinations. Accordingly they can be

- ON/OFF switches (Fig 2)
- manual forward/reversing switches (Fig 3)
- manual star-delta switches (Fig 4)
- pole changing switches for speed control. (Fig 5)

Fig 2

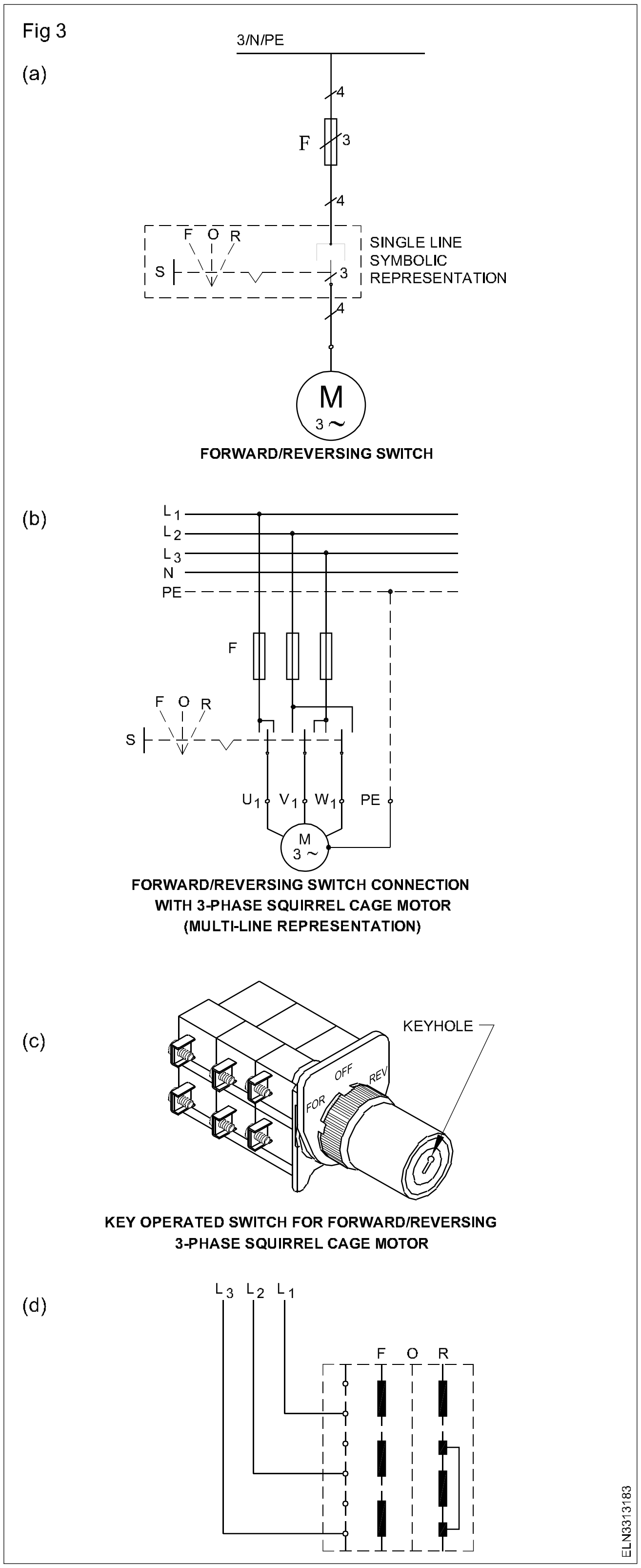


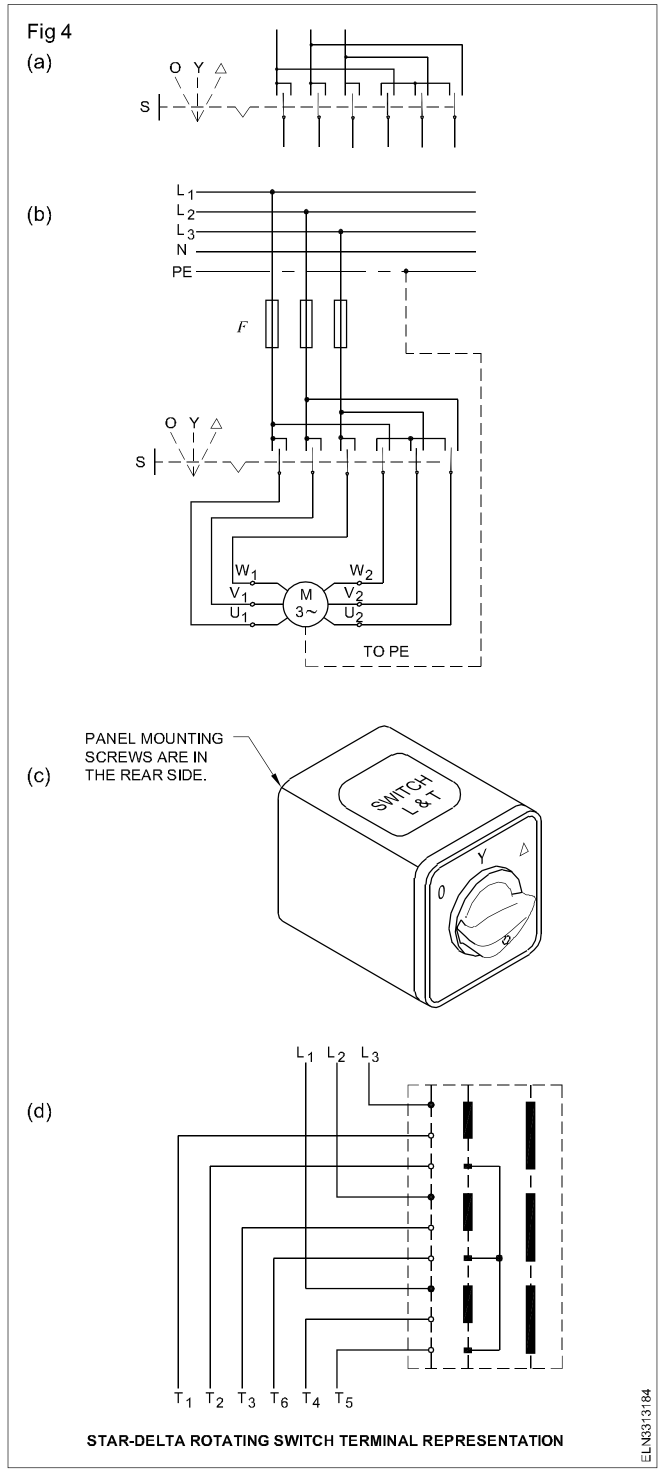
In addition to the above voltmeter/ammeter selector switches, 4-position, air-conditioner switches are also available.

Position: Selector switches of rotary type are available in two (Fig 2), three (Figs 1, 3 and 4) and four positions. They provide maintained or spring-return (momentary) control operation. Two-position and three-position switches can be either maintained or spring-returned whereas four-position switches are maintained in all four positions.

Mounting type: According to requirement, we may select any one of the following types for mounting.

- Surface mounting type
- Flush mounting type (Fig 1)
- Box mounting type (Fig 4)





Handle design: According to the nature of operation it could be done by

- a knob (Fig 2c)
- a lever (Fig 5d)
- a coin slot (Fig 1)
- key operation. (Fig 3c)

Frequency of operation: The number of operations of these switches per hour is specified in B.I.S. 10118 (Part II) 1982. The details given below are taken from the B.I.S. as per the reference cited.

Sl. No.	Description	Operations per hour
1	On-off and system selector switch	Up to 150 times
2	Pole-changing switch	Up to 150 times
3	Manual star-delta switch	Up to 30 times
4	Speed control switch	Up to 150 times

Specification: Specification of rotary switches should contain the following information, for procurement in the market.

- Working voltage and kind of operation - AC or DC
- Load current
- Poles
- Function
- Position of operation
- Type of mounting
- Desired handle type
- Frequency of operation
- Accepted maximum dimensions
- Type of casing

Schematic diagram of rotary switches

ON/OFF switch: These switches are used for a 3-phase squirrel cage motor for direct starting, which is symbolically represented in Fig 2a. The complete connection diagram shown in Fig 2b and Fig 2c shows the normal appearance of such a switch, with a knob type handle, having a box mounting type body.

Fig 2d shows the manufacturer's catalogue representation of an ON/OFF switch.

Manual forward/reversing switch: These switches are used for forward and reverse running operation of the squirrel cage induction motors. A symbolic representation is shown in Fig 3a. The complete diagram is shown in Fig 3b and Fig 3c shows the normal appearance of such a switch with a key operated type switch, having box-type enclosure mounting.

Fig 3d shows the manufacturer's catalogue representation of a forward|reversing rotary switch.

Manual star-delta starter switch: These switches are used for starting a 3-phase squirrel cage induction motor in star position and to run it in delta position.

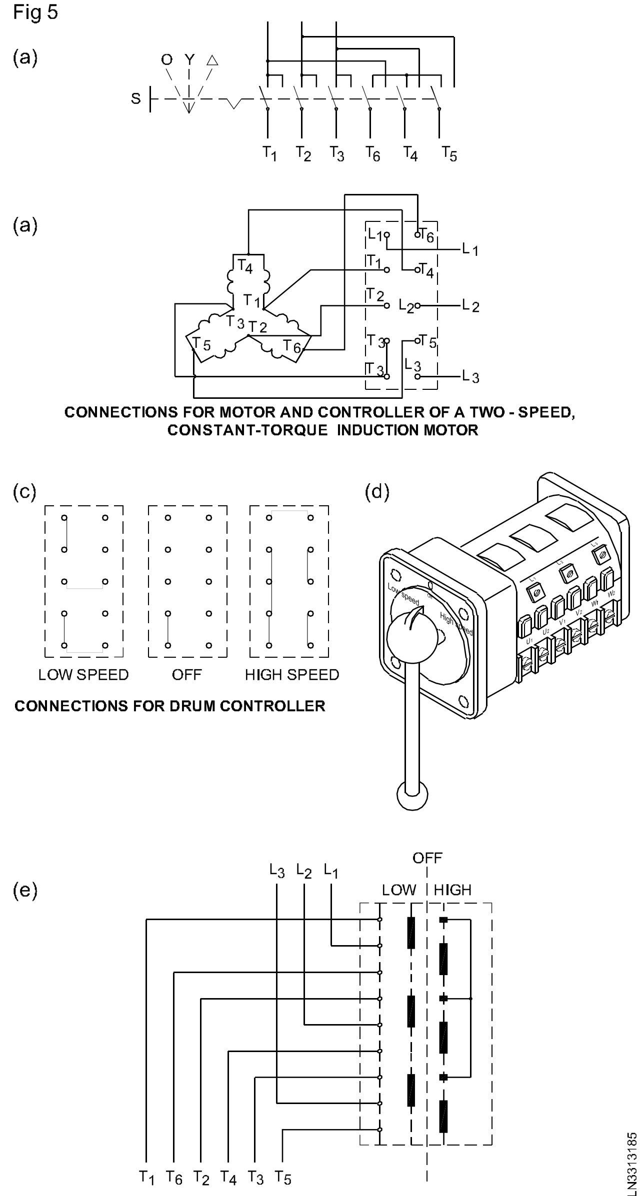
Fig 4a shows the symbolic representation of the star-delta manual switch, the complete diagram of connection to the 3-phase induction motor is shown in Fig 4b, and Fig 4c shows the normal appearance of such a starter switch with knob operation having a box-type body. Fig 4d shows the manufacturer's catalogue representation of a manual star-delta rotary switch.

Pole-changing rotary switch: This is used for changing the speed of a three-phase squirrel cage induction motor from one speed to another with the help of either two separate windings or by six windings arranged for series delta (low speed) or parallel star (high speed) connection. (Fig 5)

Fig 5a shows the symbolic representation of the pole-changing rotary switch, Figs 5b and 5c show the complete connection diagram of the pole-changing switch with motor connection, and Fig 5d shows the normal appearance of such a switch with lever operation.

Fig 5e shows the manufacturer's catalogue representation of the pole-changing rotary switch shown in Figs 5a, b and c.

Fig 5



Manual star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor**
- **explain the construction, connection and working of a star-delta switch and starter**
- **specify the back-up rating of the fuse in the motor circuit.**

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

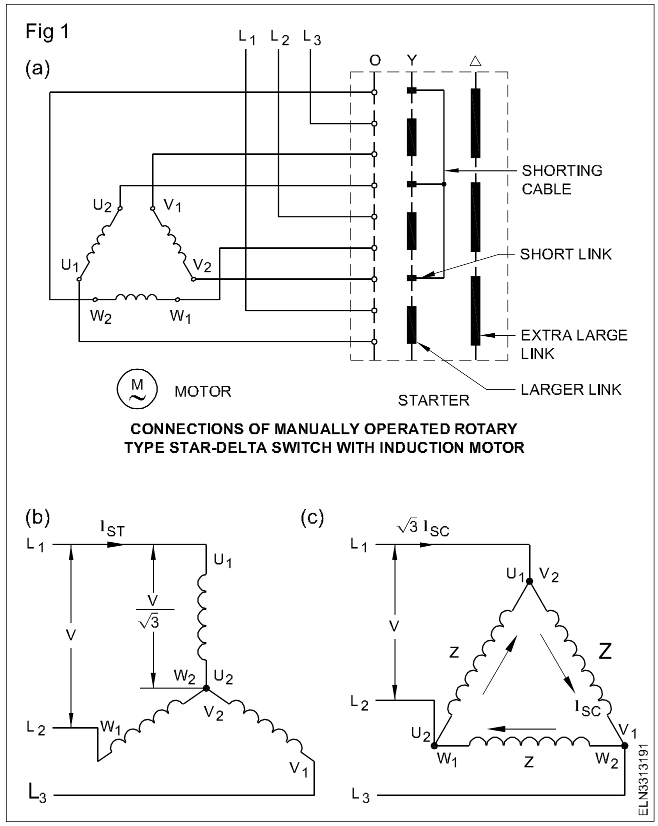
- Star-delta switch or starter
- Auto-transformer starter
- Step-down transformer starter

Star-delta starter: A star-delta switch is a simple arrangement of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to $1/\sqrt{3}$ times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply L_1, L_2 and L_3 are connected to the beginning of windings U_1, W_1 and V_1 respectively by the larger links, whereas the short links, which connect V_2 U_2 and W_2, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig 1b)

When the switch handle is changed over to delta position, the line supply L_1, L_2 and L_3 are connected to terminals U_1 V_2, W_1 U_2 and V_1 W_2 respectively by the extra large links to form a delta connection. (Fig 1c)

Manual star-delta starter: Fig 2a shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on) coil is energised. When the hold-on coil circuit is closed through the supply taken from U_2 and W_2, the coil is energised and it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in delta position in the first moment. It is only when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.



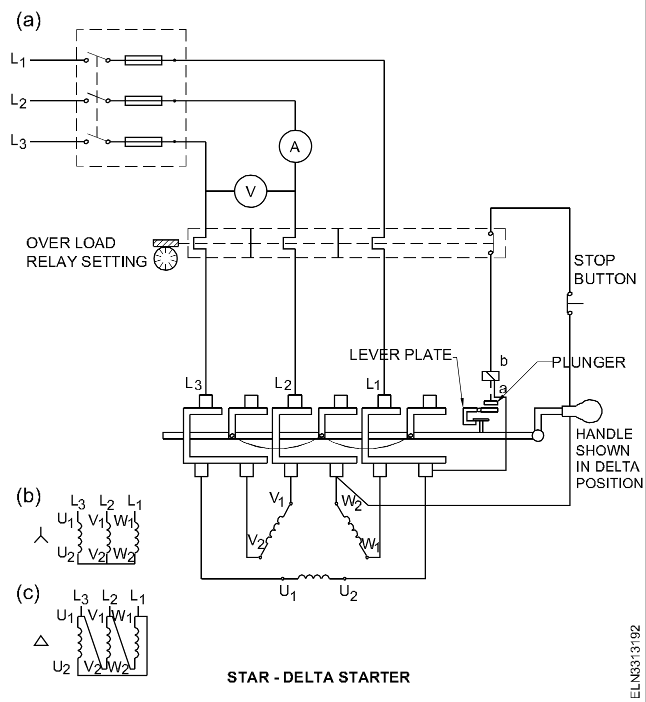
CONNECTIONS OF MANUALLY OPERATED ROTARY TYPE STAR-DELTA SWITCH WITH INDUCTION MOTOR

The handle has a set of baffles insulated from each other and also from the handle. When the handle is thrown to star position, the baffles connect the supply lines L_1, L_2 and L_3 to beginning of the 3-phase winding W_1, V_1 and U1 respectively. At the same time the small baffles connect V_2, W_2 and U_2 through the shorting cable to form the star point. (Fig 2b)

When the handle is thrown to delta position, the larger end of the baffles connect the main supply line L_1, L_2 and L_3 to the winding terminals W_1U_2, V_1W_2 and U_1V_2 respectively to form the delta connection. (Fig 2c)

The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

Fig 2



STAR - DELTA STARTER

The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

Back-up fuse protection: Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example, a 10 HP 3-phase 415V motor will have approximately 15 amps as its full load current.

To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be 23 amps, or say 25 amps.

Comparison of impact of star and delta connections on starting current and torque of the induction motor: When the three-phase windings of the squirrel cage motor are connected in star by the starter, the phase voltage across each winding is reduced by a factor of $1/\sqrt{3}$ of the applied line voltage (58%), and hence the starting current reduces to 1/3 of that current which would have been drawn if the motor were directly started in delta. This reduction in starting current also reduces the starting torque to 1/3 of the starting torque which would have been produced in the motor, if it were started directly in delta.

The above statement could be explained through the following example.

Example

Three similar coils of a 3-phase winding of a squirrel cage induction motor, each having a resistance of 20 ohms and inductive reactance of 15 ohms, are connected in (a) star (b) delta through a star-delta starter to a 3-phase 400V 50 Hz supply mains.

Calculate the line current and total power absorbed in each case. Compare the torque developed in each case.

Solution

Impedence per phase

$$Z_{ph} = \sqrt{R^2 + X^2}$$

$$= \sqrt{20^2 + 15^2} \qquad = 25\Omega$$

Star connection

$$E_{Ph} = \frac{E_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231 \text{ volts}$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{231}{25} = 9.24\text{amps}$$

$$I_L = I_{sh} = 9.24\text{amps.}$$

Power absorbed = $\sqrt{3}\, E_L I_L \cos\theta$

$= \sqrt{3}$ x 400 x 9.24 x 1

Assuming PF = 1, we have = 6401 watts.

Delta connection

$$E_{ph} = E_L = 400V$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{400}{25} = 16A$$

$$I_L = \sqrt{3}\, I_{ph} = 1.732 \times 16 = 27.7 \text{ A}$$

Power absorbed = $\sqrt{3}\, E_L I_L \cos\theta$

(assume PF = 1)

$= \sqrt{3}$ x 400 x 27.7 x 1

= 19190 W. (19.19W)

The torque developed is proportional to the square of the voltage across the winding.

In the case of star, the voltage across the winding E_{ph}

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$= \frac{E^2{}_L}{\sqrt{3}} \text{ K in star}$$

In the case of delta, the voltage across the E_{ph} winding

$E_{ph} = E_L$.

Hence torque

$(E_L)^2 K = E^2_L K.$

By comparison the torque developed in star connection at the time of starting is 1/3 of the torque developed in a delta connection (running).

As the torque is 3 times less in starting due to the star connection, whenever a motor has to be started with heavy loads, the star-delta starter is not used. Instead an auto-transformer or step-down transformer starter could be used as the voltage tapping can be changed to more than 58% of the line voltage to suit the torque requirement.

Semi-automatic star-delta starter

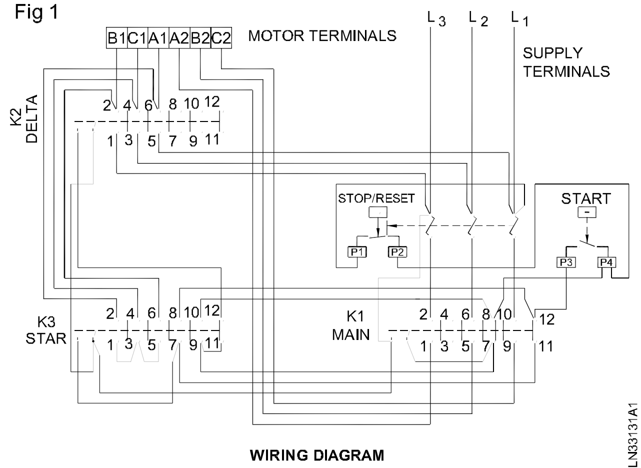
Objectives: At the end of this lesson you shall be able to
- **explain the wiring diagram of semi-automatic star-delta starter**
- **describe the operation of semi-automatic star-delta starter.**

The standard squirrel cage induction motors with both ends of each of the three windings brought out (six terminals) are known as star-delta motors. If the starter used has the required number of properly wired contactors, the motor can be started in star and run in delta.

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Fig 1 shows the wiring diagram and Fig 2 shows the line diagram of power circuit and the control circuit.

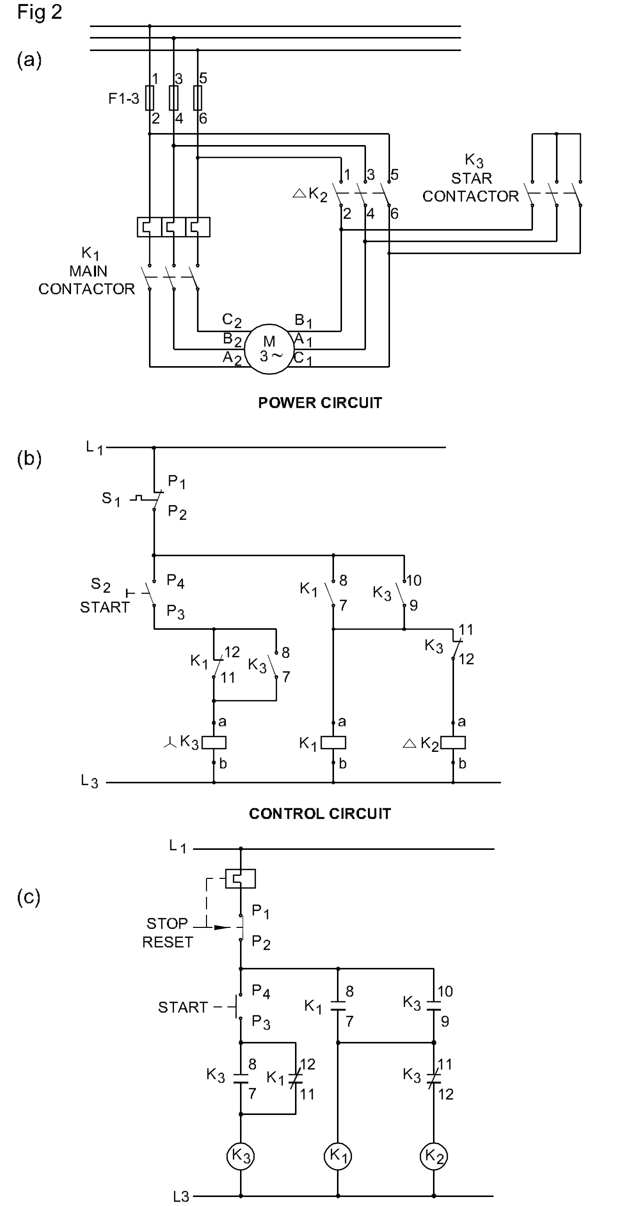
Fig 1



WIRING DIAGRAM

Operation: Refer to the control circuit and power circuit diagrams shown in Fig 2. When the start button S_2 is pressed the contactor coil K_3 energises through P_4, P_3 and K_1 normally closed contact 12 and 11. When K_3 closes, it opens the normally closed contact K_3 between 11 and 12 and makes contact between 10 and 9 of K_3. The mains contactor K_1 energies through P_4, 10 and 9 of K_3. Once K_1 energises the NO contact of K_1 point 8 and 7 establishes a parallel path to K_3 terminals 10 and 9.

Fig 2



LINE DIAGRAM OF SEMI - AUTOMATIC STAR - DELTA STARTER

The star contactor K_3 remains energised so long as the start button is kept pressed. Once the start button is released, the K_3 coil gets de-energised. The K_3 contact cannot be operated because of the electrical interlock of K_1 and normally closed contacts between terminals 12 and 11.

When the K_3 contactor get de-energised the normally closed contact of K_3 between terminals 11 and 12 establishes contact in the contactor K_2 - coil circuit. The delta contactor K_2 closes.

The operator has to observe the motor starting and reaching about 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 2c shows the alternative form of drawing control circuit.

Automatic star-delta starter

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

- **state the applications of automatic star-delta and overload relay setting**
- **describe the operations of automatic star-delta starter.**

Applications : The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation : Fig 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor K_3. (Current flows through K_4T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 1

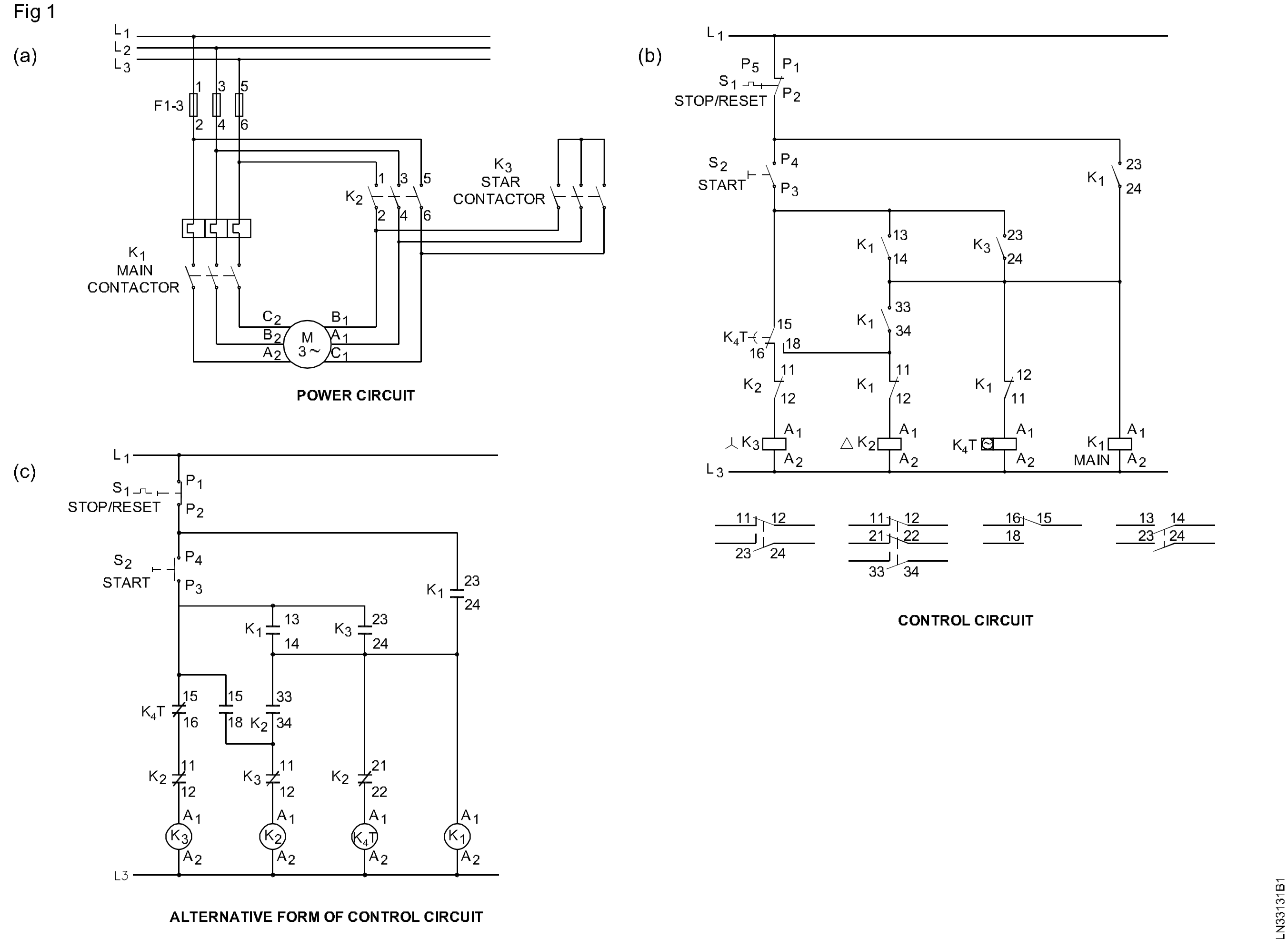
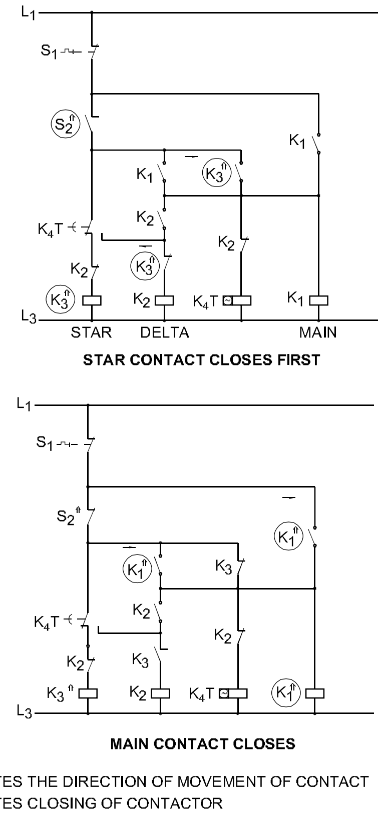


Fig 2 shows the current direction and closing of contacts as explained above.

Fig 2



Similarly Fig 3 shows the action taking place after the timer relay operating the contact K_4T.

Time delay contact changes opening star contact.

Fig 4 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed.

Delta contact closes.

Fig 3

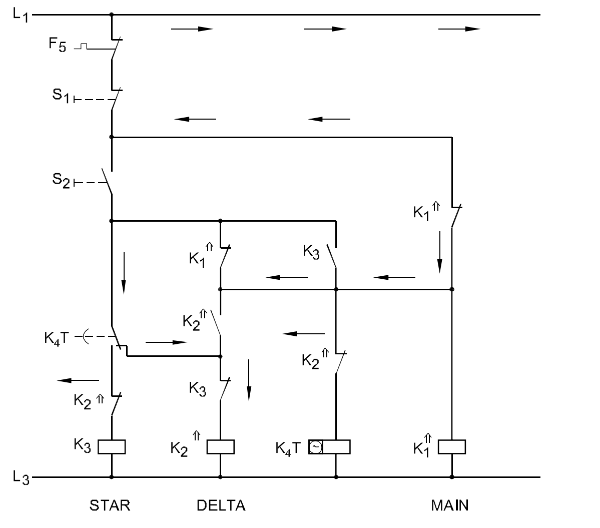
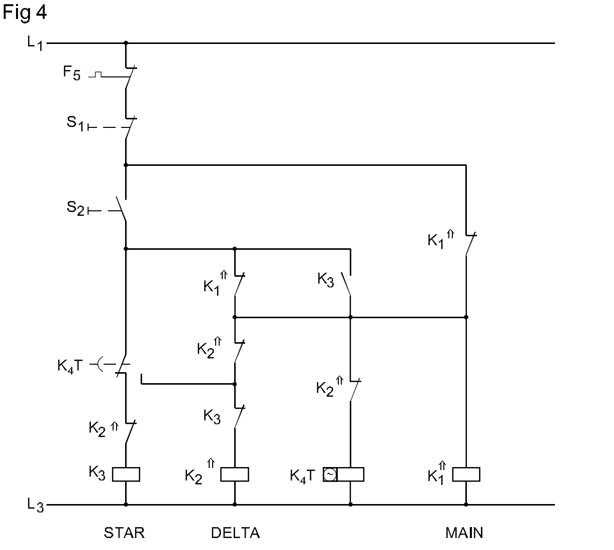


Fig 4



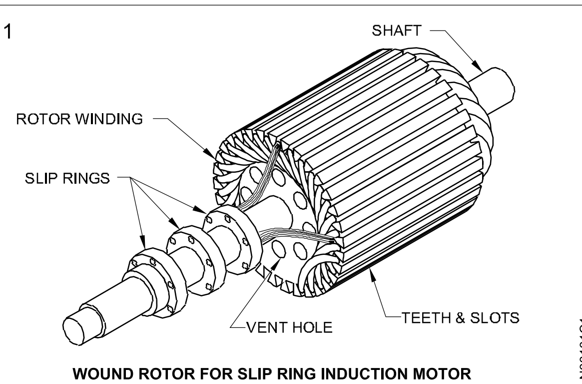
Three-phase, slip-ring induction motor

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

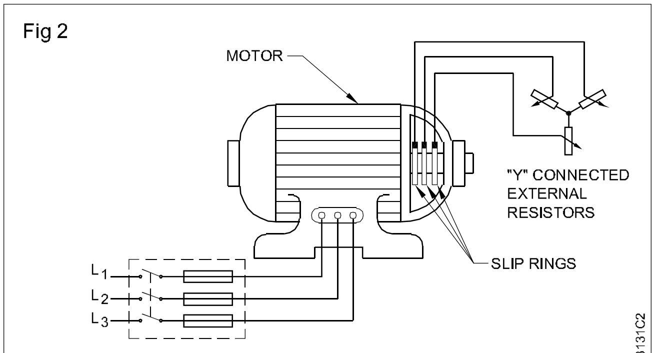
- **explain briefly the construction and working of a three-phase, slip-ring induction motor**
- **explain how the starting torque is high due to insertion of rotor resistance**
- **state the characteristic of the slip-ring induction motor**
- **compare the slip-ring induction motor with the squirrel cage induction motor.**

Construction : The slip-ring induction motor could be used for industrial drives where variable speed and high starting torque are prime requirements. The stator of the slip-ring induction motor is very much the same as that for a squirrel cage motor but the construction of its rotor is very much different. Stator windings can be either star or delta connected depending upon the design. The rotor consists of three-phase windings to form the same number of poles as in a stator. The rotor winding is connected in star and the open ends are connected to three slip-rings mounted in the rotor shaft, as shown in Fig 1. The rotor circuit is, in turn, connected to the external star-connected resistances through the brushes, as shown in Fig 2.

Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR



CIRCUIT FOR A WOUND - ROTOR INDUCTION MOTOR

Working : When the stator-winding of the slip-ring motor is connected to the 3-phase supply, it produces a rotating magnetic field in the same way as a squirrel cage motor. This rotating magnetic field induces voltages in the rotor windings, and a rotor current will flow through the closed circuit, formed by the rotor winding, the slip-rings, the brushes and the star-connected external resistors.

At the time of starting, the external resistors are set for their maximum value. As such, the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the rotor power factor, and thereby, the torque developed at the start becomes much higher than the torque developed in squirrel cage motors.

As the motor speeds up, the external resistance is slowly reduced, and the rotor winding is made to be short-circuited at the slip-ring ends. Because of the reduced rotor resistance, the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. However at increased rotor resistance, the motor's slip will be greater, the speed regulation poorer and it will have low efficiency. The resistance in the external circuit could be designed and varied to change the speed of the slip-ring motor between 50 to 100 percent of the rated speed. However, the I^2R losses in the rotor due to increased resistance is inevitable.

Starting torque : The torque developed by the motor at the instant of starting is called the starting torque. In some cases it is greater than the normal running torque whereas in some other cases it is somewhat less.

Let E_2 be the rotor emf per phase at standstill

X_2 be the rotor reactance per phase at standstill and R_2 be the rotor resistance per phase.

Therefore $Z_2 = \sqrt{(R_2)^2 + (X_2)^2}$ = rotor impedance per phase at standstill.

Then $I_2 = \frac{E_2}{Z_2}, \cos\theta_2 = \frac{R_2}{Z_2}$

Standstill or starting torque $T_{st} = K_1 E_2 I_2 \cos q_2$ or

$$T_{st} = K_1 E_2 \times \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \times \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

If the supply voltage V is constant, then the flux, f and hence E_2 is constant.

Therefore $T_{st} = K_2 \frac{R_2}{Z_2}$ where K_2 is another constant.

The starting torque of such a motor is increased by adding external resistance in the rotor circuit. The resistance is progressively cut out as the motor gain speed.

Rotor emf and reactance under running condition : When the starter is stationary i.e. S = 1, the frequency of the rotor emf is the same as that of the stator supply frequency. The value of emf induced in the rotor at standstill is maximum because the relative speed between the rotor and the rotating stator flux is maximum.

When the rotor starts running, the relative speed between the rotor and the rotating stator flux is decreased. Hence the rotor induced emf is also decreased. The rotor emf become zero if the rotor speed become equal to the speed of stator rotating flux.

Hence, for a slip (s), the rotor induced emf will be s times the induced emf at standstill.

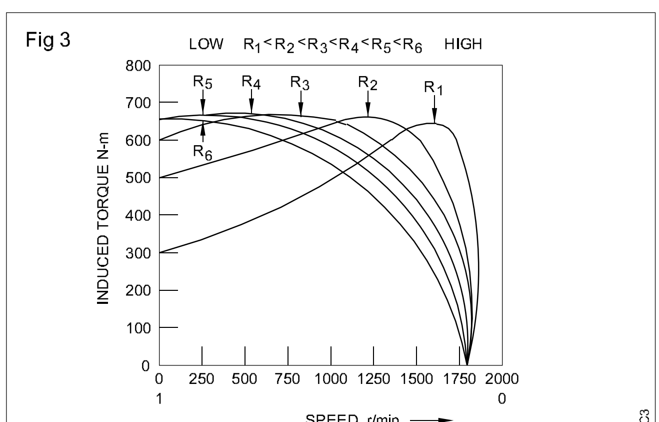
Therefore, under running condition $E_r = sE_2$.

The frequency of induced emf will likewise become $f_r = sf_2$ where f_2 is the rotor current frequency at standstill.

Due to decrease in frequency of the rotor emf, the rotor reactance will also decrease.

Therefore $X_r = sX_2$.

Characteristic and application of slip-ring induction motor: Insertion of higher, external resistance alters the starting torque to a higher value, as shown in Fig 3, by the torque speed characteristic.



THE TORQUE-SPEED CHARACTERISTIC FOR A WOUND - ROTOR INDUCTION MOTOR

By inserting the suitable value rotor resistance, the speed of the slip ring motor could be controlled inspite of power loss in resistance.

As shown in the curve, higher, external resistance improves the starting torque to a higher value. However the maximum torque remains constant for the variation of the rotor resistance.

By these curves, it is clear that the slip-ring motor could be used to start heavy loads by insertion of high resistance in the rotor to facilitate higher starting torque. At the same time the running efficiency of the motor could be achieved by cutting out the external resistance when the motor picks up its speed.

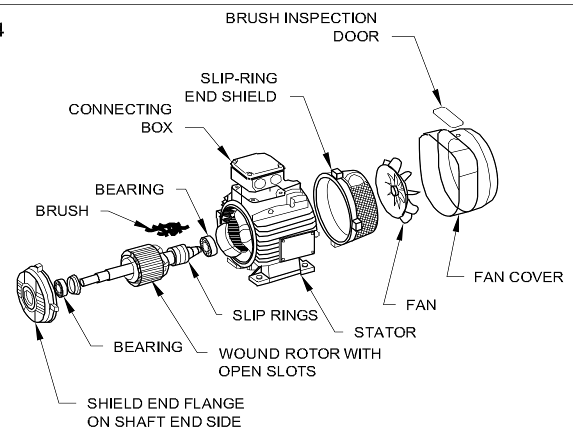
This motor could be used for drive which demands a higher starting torque and also a variable speed control - like compressors, conveyors, cranes, hoists, steel mills and printing presses.

Comparison between squirrel cage and slip-ring induction motors is given below:

Sl. No.	Property	Squirrel cage	Slip-ring motor
1	Rotor construction	Bars are used in rotor. Squirrel cage rotor is very simple, rugged and long lasting. No slip-rings.	Winding wire is used. Wound rotor requires attention Slip-ring and brush gear need frequent main-tenance.
2	Starting	Can be started byDOL star-delta, auto-transformer starters.	Rotor resistance starter is required
3	Starting torque	Low	Very high
4	Starting current	High	Low
5	Speed variation	Not easy, but could be varied in larger steps by pole-changing or smaller incre--mental steps through thyristors or by frequency variation.	Easy to vary speed,but speed change through pole-changing is not possible. Speed change possible by - insertion of rotor resistance - using thyristors - using frequency variation - injecting emf in the rotor circuit - cascading
6	Acceleration on load	Just satisfactory	Very good
7	Maintenance	Almost nil	Requires frequent maintenance
8	Cost	Low	Comparatively high

Fig 4 shows the exploded view of the slip ring induction motor.

Fig 4



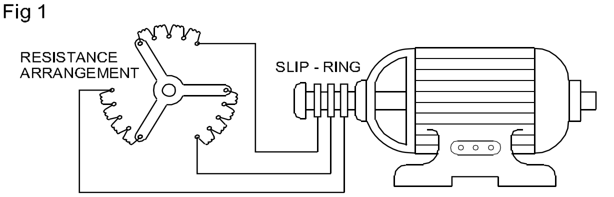
PARTS OF 3 PHASE SLIP RING INDUCTION MOTOR

Resistance starter for 3-phase, slip-ring induction motor

Objective: At the end of this lesson you shall be able to
- **explain the rotor resistance starters used for a 3-phase, slip-ring induction motor.**

Slip-ring induction motors are started with full-line voltage across the stator winding. However, to reduce the heavy rush of the starting current, a star-connected external resistance is added in the rotor circuit as shown in Fig 1. The external resistances are cut out, and the rotor winding ends are shorted once the motor picks up its speed.

Fig 1



SLIP RING INDUCTION MOTOR WITH RESISTANCE STARTER

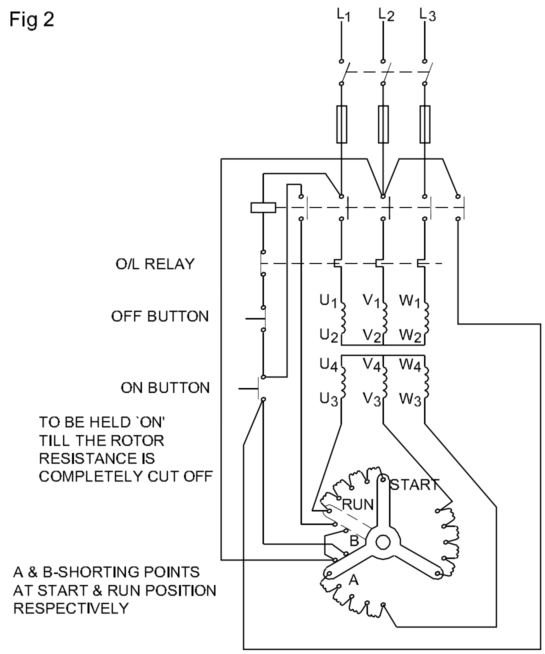
If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in a completely cut-out position, resulting in heavy rush of the starting current and poor starting torque. This could be eliminated by the use of a protective circuit in the resistance starter; thereby motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter is shown in Fig 2.

By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at the rotor resistance is in a closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cutout the rotor resistance.

The position of the handle clearly indicates that at the start position, the contact 'A' is in the closed position, and at the run position, contact 'B' is in the closed position, but both cannot close at the same time. The 'ON' push-button needs to be held in the pushed-position till the handle is brought to the run-position. During the run-position, the handle contact 'B' closes the no-volt coil circuit, and the pressure on the 'ON' button can be released.

In general, for small machines, the rotor resistance is air-cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown is intended to start the motor only. As speed regulation through the rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.

Fig 2



ROTOR RESISTANCE STARTER FOR SLIP RING INDUCTION MOTOR

ELN33131D2

Method of measurement of slip in induction motor

Objectives: At the end of this lesson you shall be able to
- **explain the method of measurement of slip by actual motor speed**
- **describe the method of measurement of slip by comparing motor and starter frequencies**
- **explain the method of measurement of slip by stroboscope method.**

Measurement of slip

Following are the methods used for finding the slip of an induction motor

(i) By actual measurement of motor speed: This method requires measurement of actual motor speed N and calculation of synchronous speed N_s. N is measured with the help of a speedometer and N_s calculated from the knowledge of supply frequency and the number of poles of the motor (Since an induction motor does not have salient poles, the number of poles is usually inferred from the no-load speed or from the rated speed of the motor). Then slip can be calculated by using the equation

$S = (N_s - N) \times 100 / N_s$

(ii) By comparing rotor and stator supply frequencies: This method is based on the fact that $s = f_r/f$. Since f is generally known, s can be found if frequency of rotor current can be measured by some method. In the usual case, where f is 50 Hz, f_r is so low that individual cycles can be easily counted. For this purpose, a DC moving coil preferably of centre-zero milli-voltmeter, is employed as described below:

a) In the case of a slip-ring motor, the leads of the centre zero milli-ammeter is connected to adjacent slip-rings as they revolve (Fig 1). Usually, there is sufficient voltage drop in the burshes and their short-circuiting strap to provide an indication on the milli-ammeter. The current in the milli-ammeter follows the variations of the rotor current and hence the pointer oscillates about its mean zero position. The number of complete cycles made by the pointer per second can be easily counted (it is worth remembering that one cycle consists of a movement from zero to a maximum to the right, back to zero and on to a maximum to the left and then back to zero).

   As an example, consider the case of a 4-pole motor fed from a 50-Hz supply and running at 1,425 rpm. Since N_s = 1,500 rpm its slip is 5% or 0.05. The frequency of the rotor current would be $f_r = S_f = 0.05 \times 50 = 2.5$ Hz which (being slow enough) can be easily counted.

b) For squirrel-cage motors (which do not have slip-rings) it is not possible to employ the centre zero milli ammeter.

iii) By Stroboscopic Method: In this method, a circular metallic disc is taken and painted with alternately black and white segments. The number of segments (both black and white) is equal to the number of poles of the motor. For a 6-pole motor, there will be six segments, three black and three white, as shown in Fig 2a.

Fig 1

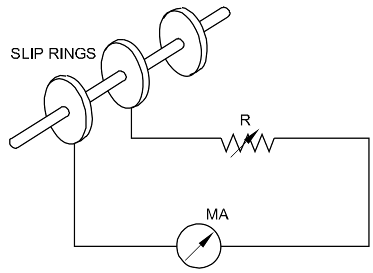
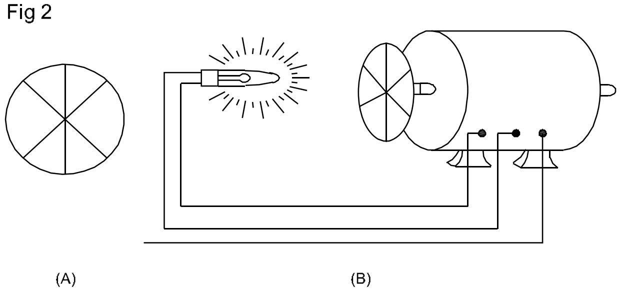


Fig 2

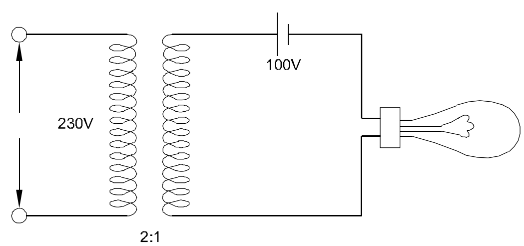


The painted disc is mounted on the end of the shaft and illuminated by means of a neon-filled stroboscopic lamp, which may be supplied preferably with a combined d.c. and a.c. supply although only a.c. supply will do (When combined d.c. and a.c. supply is used, the lamp should be tried both ways in its socket to see which way it gives better light.). The connections for combined supply are shown in Fig 3 whereas Fig 2b shows the connections for single supply only. It must be noted that with combined d.c. and a.c. supply, the lamp will flash once per cycle (It will flash only when the two voltages add and remain extinguished when they oppose). But with a.c. supply, it will flash twice per cycle.

Consider the case when the revolving disc is seen in the flash light of the bulb which is fed by the combined d.c. and a.c. supply.

If the disc were to rotate at synchronous speed, it would appear to be stationary, Since in actual practice, its speed is slightly less than the synchronous speed, it appears to rotate slowly backwards.

Fig 3



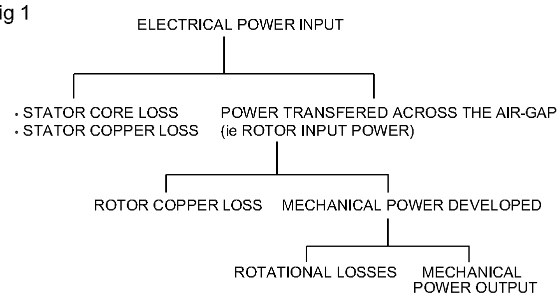
Efficiency - characteristics of induction motor- no load test - blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **state the power flow diagram of an induction motor indicating the losses**
- **calculate the efficiency from the given data.**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes I_2 to increase to that value which, when inserted into the equation for torque calculation (i.e $T = K\phi_s I_2 \cos \phi_s$), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined. The power flow diagram in a statement form is shown in Fig 1. Note that the loss quantities are placed on the left side of the flow point. Fig 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Fig 1



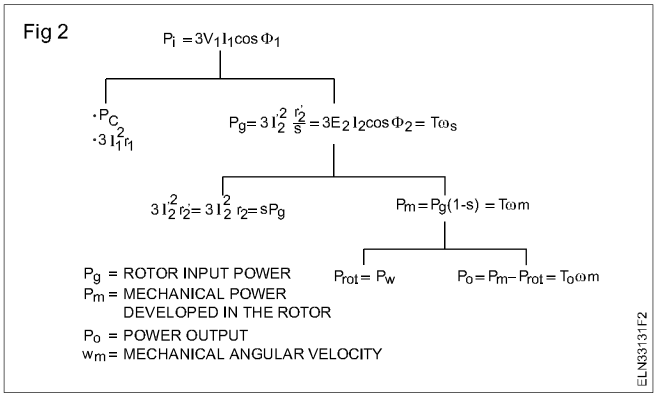
Torque, Mechanical power and Rotor output : Stator input P_i = stator output + stator losses.

The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input P_g = stator output.

Rotor gross output, P_m = rotor input P_g - rotor cu. losses.

Fig 2



This rotor output is converted into mechanical energy and gives rise to the gross torque T. Out of this gross torque developed, some is lost due to windage and friction losses in the rotor, and the rest appear are useful torque T_o.

Let n r.p.s be the actual speed of the rotor and if it is in Nm, then

T x 2πn = rotor gross output in watts, P_m.

$$\text{Therefore, } T = \frac{\text{rotor gross output in watts, } P_m}{2\pi\, n} \text{ N.m}$$

The value of gross torque in kg.m is given by

$$T = \frac{\text{rotor gross output in watts}}{9.81 \times 2\pi\, n} \text{ Kg m}$$

$$= \frac{P_m}{9.81 \times 2\pi\, n} \text{ Kg m}$$

If there were no copper losses in the rotor, the rotor output will equal the rotor input and the rotor will run at synchronous speed.

$$\text{Therefore, } T = \frac{\text{rotor input } P_g}{2\,\pi\, n_s}$$

From the above two equation we get,

Rotor gross output = P_m = Tw = T x 2πn

Rotor input = P_g = TW_s = T x $2\pi n_s$

The difference between the two equals the rotor copper loss.

Therefore, rotor copper loss = s x rotor input

= s x power across air gap

= sP_g.

$$\text{Also rotor input, } P_g = \frac{\text{rotor copper loss}}{s}$$

Rotor gross output P_m = Input P_g - rotor cu.loss

= (1 - s) P_g

$$\text{or } \frac{\text{rotor gross output, } p_m}{\text{rotor input, } p_g} = 1 - s$$

rotor gross output. Pm = (1 - s)P_g

$$\text{Therefore rotor efficiency} = \frac{n}{n_s}$$

Example

The power input to a 4-pole, 3-phase, 50 Hz. induction motor is 50kW, the slip is 5%. The stator losses are 1.2 kW and the windage and friction losses are 0.2 kW. Find (i) the rotor speed, (ii) the rotor copper loss, (iii) the efficiency.

Data given

No. of poles	P = 4
Frequency	f = 50 Hz
Phases	= 3
Input power	= 50kW
% Slip	s = 5%
Stator losses	= 1.2 kW
Friction & Windage losses	= 0.2 kW

Find:

Rotor speed	= N
Rotor copper loss	= s x input power to rotor
efficiency	= η

SOLUTION

$$\text{Synchronous speed} = N_s = \frac{120f}{p} = \frac{6000}{4} = 1500 \text{ rpm}$$

$$\text{Fractional slip} = s = \frac{N_s - N_r}{N_s}$$

$$\frac{5}{100} = \frac{1500 - N_r}{1500}$$

$$75 = 1500 - N_r$$

Therefore, rotor speed, Nr = 1500 - 75 = 1425 rpm.

Input power to rotor = (50 - 1.2)kW

Rotor copper loss = s x input power to rotor

= 0.05 x 48.8

= 2.44 kW.

Rotor output = Rotor input - (Friction and windage loss + rotor cu.loss)

= 48.8 - (0.2 + 2.44)

= 46.16 kW

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{44.56 \times 100}{50} = 92.32\%.$$

Characteristics of squirrel cage induction motor

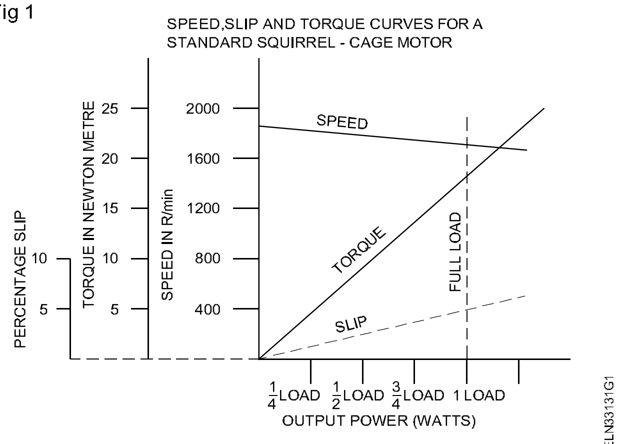
Objective: At the end of this lesson you shall be able to
- **describe the characteristics and application of a 3-phase squirrel cage induction motor.**

The most important characteristic of the induction motor is the speed torque characteristic which is also called the mechanical characteristic. A study of this characteristic will give an idea about the behaviour of the motor in load conditions. As the torque of the motor is also dependent on the slip, it will be interesting to study the characteristic of the squirrel cage induction motor to find the relationship between load, speed, torque and slip.

Speed, torque and slip characteristics : It has already been made clear that the rotor speed of a squirrel cage motor will always lag behind the synchronous speed of the stator field. The rotor slip is necessary in order to induce the rotor currents required for the motor torque. At no load, only a small torque is required to overcome the motor's mechanical losses, and the rotor slip will be very small, say about two percent. As the mechanical load is increased, however, the rotor speed will decrease, and hence, the slip will increase. This increase in slip inturn increases the induced rotor currents, and the increased rotor current in turn, will produce a higher torque to meet the increased load.

Fig 1 shows the typical speed torque and slip characteristic curves for a standard squirrel cage motor. The speed curve shows that a standard squirrel cage motor will operate at a relatively constant speed from no load to full load.

Fig 1



Since the squirrel cage rotor is constructed basically of heavy copper/aluminium bars, shorted by two end rings, the rotor impedance will be relatively, low and hence, a small increase in the rotor induced voltage will produce a relatively large increase in the rotor current. Therefore, as the squirrel cage motor is loaded, from no-load to full load, a small decrease in speed is required to cause a relative increase in the rotor current. For this reason, regulation of a squirrel cage motor is very good. But the motor is often classified as a constant speed device.

The slip curve shows that the percentage slip is less than 5% load, and is a straight line.

Since the torque will increase in almost direct proportion to the rotor slip, the torque graph is similar to the slip graph which also has a straight line characteristic as shown in Fig 1.

Relationship between torque, slip rotor resistance and rotor inductive reactance : It was stated earlier that torque is produced in an induction motor by the interaction of the stator and the rotor fluxes. The amount of torque produced is dependent on the strength of these two fields and the phase relation between them. This may be expressed mathematically as

$T = K \phi_s I_R \cos\phi$

where T = torque in Newton metre

K = a constant

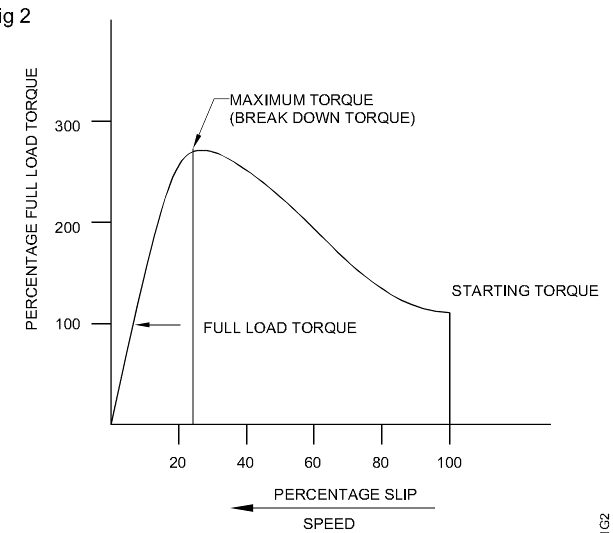
ϕ_s = stator flux in weber

I_R = rotor current in ampere

Cos ϕ = rotor power factor

From no load to full load, the torque constant (K), the stator flux (ϕ_s) and the rotor power factor (Cos ϕ) for a squirrel cage motor will be practically constant. Hence the motor's torque will vary almost directly with the induced rotor current (I_R) since the rotor current inturn will vary almost directly with its slip. Variation of the torque of a squirrel cage motor is often plotted against its rotor slip as shown in Fig 2.

Fig 2



TORQUE VARIATION VERSUS SLIP FOR A STANDARD SQUIRREL - CAGE MOTOR

The increase in the rotor current, and hence, the increase in the rotor torque for a given increase in the rotor slip is dependent on the rotor power factor. The rotor resistance for a squirrel cage motor will be constant. However, an increase in slip will increase the rotor frequency, and the resulting inductive reactance of the rotor from no load to full load and even upto 125 percent of rated load, the amount of rotor slip for a standard squirrel cage motor is relatively small and the rotor frequency will seldom exceed 2 to 5 Hz. Therefore, for the above range of load the effect of frequency change on impedance will be negligible, and as shown in Fig 2, the rotor torque will increase in almost a straight relationship with the slip.

Inbetween 10 to 25 percent slip the squirrel cage motor will attain its maximum possible torque. This torque is referred to as the maximum breakdown torque, and it may reach between 200 and 300 percent of the rated torque as shown in Fig 2. At the maximum torque, the rotor's inductive reactance will be equal to its resistance.

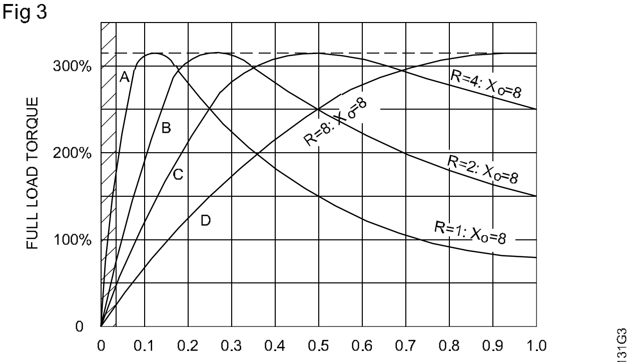
However, when the load and the resulting slip are increased much beyond the rated full load values, the increase in rotor frequency, and hence, the increase in rotor reactance and impedance become appreciable. This increase in rotor inductive reactance and the resulting decrease in rotor power factor will have two effects; first, the increase in impedance will cause a decrease in the rate at which the rotor current increases with an increase in slip, and second, the lagging rotor power factor will increase; that means, the rotor flux will reach its maximum sometime after the stator peak flux has been swept by it. The out-of-phase relationship between these two fields will reduce their interaction and their resulting torque. Hence, if the motor load is increased beyond the breakdown torque value, the torque falls rapidly due to the above two effects and the motor operation becomes unstable, and the motor will stall.

Effect of rotor resistance upon the torque/slip relationship: Fig 3 shows the relationship between torque and slip when the rotor resistance is changed. The shaded portion of the curve shows the actual operating area. Curve A for an induction motor with low rotor resistance, say 1 ohm, Curve B is for 2 ohm, Curve C is for 4 ohm and Curve D for 8 ohm.

Breakdown torque : In all these cases the standstill inductive reactance of the rotor is the same, say 8 ohm. From the curves it is clear that the maximum (breakdown) torque is the same for the four values of R. Further it is also clear that the maximum torque occurs at greater slip for higher resistance.

Starting torque : At the time of starting, the fractional slip is 1, and the starting torque is about 300% of the full load torque for the rotor having maximum resistance as shown by curve D of Fig 3, and at the same time the rotor having low resistance will produce a starting torque of 75% of the full load torque only, as shown by curve A of Fig 3. Hence, we can say that an induction motor having high rotor resistance will develop a high torque at the time of starting.

Fig 3



FRACTIONAL SLIPS TORQUE/SLIP CURVES FOR AN INDUCTION MOTOR

Running torque : While looking at the normal operating region in the shaded portion of the graph, it will be found the torque at running is appreciably high for low resistance rotor motors and will be conspicuously less for high resistance rotor motors.

As squirrel cage induction motors will have less rotor resistance, their starting torque is low but running torque is quite satisfactory. This is partly compensated by the double squirrel cage motors which produce high starting and normal running torque. On the other hand, the slip ring induction motor, due to its wound rotor, has the possibility of inclusion of resistance at the time of starting and reducing the same while running.

Application of squirrel cage induction motor : Single squirrel cage motors are used widely in industries and in irrigation pump sets where fairly constant speed is required. This motor has fairly high efficiency, costs less and is found to be robust in construction.

Double squirrel cage induction motors are used in textile mills and metal cutting tool operations where high starting torque is essential.

No-load test of induction motor

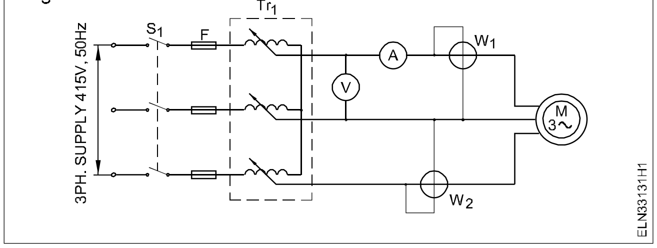
Objectives: At the end of this lesson you shall be able to
- **determine the constant (mechanical and iron losses of induction motor) by no-load test**
- **calculate the total equivalent resistance per phase.**

No-load test

The induction motor is connected to the supply through a 3-phase auto-transformer (Fig 1). The 3-phase auto-transformer is used to regulate the starting current by applying low voltage at the start, and then gradually increased to rated voltage. The ammeter and voltmeters are selected based upon the motor specification. The no-load current of the motor will be very low, up to 30% of full load.

As the power factor of the motor on no-load is very low, in the range of 0.1 to 0.2, the wattmeters selected are such as to give a current reading at low power factor. The wattmeter full scale reading will be approximate equal to the product of the ammeter and voltmeter full scale deflection values.

Fig 1



The calculation is done as follows to determine the constant losses of the induction motor.

At no-load, the output delivered by the motor is zero. All the mechanical power developed in the rotor is used to maintain the rotor running at its rated speed. Hence the input power is equal to the no-load copper loss plus iron losses and mechanical losses.

Calculation

V_{NL} is ® line stator voltage

I_{NL} is ® line current

P_{NL} is ® Three-phase power input.

The input power consists of the core loss P_c, friction and windage loss $P_{(rot)}$, and the stator copper loss.

$P_{NL} = P_c + P_{rot} + 3\, I^2_{NL}\, R_S$

This permits the sum of rotational loss to be evaluated.

$P_{rot+C} = P_{NL} - 3\, I^2_{NL}\, R_S$

where the stator resistance Rs per phase obtained from a resistance measurement at the stator terminal.

In star connection $R_S = R/2$.

Delta connection $R_S = 2/3\ R$.

Blocked rotor test

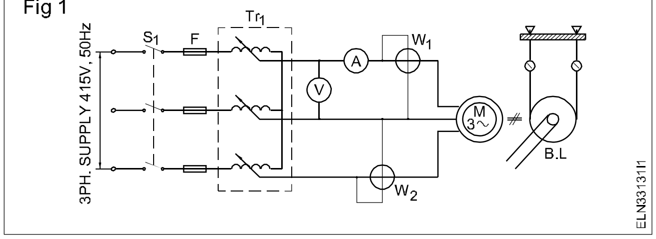
Objectives: At the end of this lesson you shall be able to

- **determine the full load copper loss of a 3-phase induction motor by blocked rotor test**
- **calculate the total equivalent resistance per phase and efficiency.**

The connections are made similar to that of the no-load test. In this case the ammeter is selected to carry the full load current of the motor. Wattmeters will be of a suitable range and its power factor is 0.5 to unity.

An auto-transformer is used to give a much lower percentage of the rated voltage. The rotor is locked by a suitable arrangement such that it cannot rotate even if the supply is given to the motor. One such arrangement is shown in Fig 1. The belt is over-tightened on the pulley to prevent rotation.

Fig 1



As the rotor is in a locked condition it is equivalent to the short circuit secondary of a transformer. Therefore, a small induced voltage in the rotor cage winding will be sufficient to cause a large current to flow in the cage.

It is very essential to limit the supply voltage to a value less than 5% at start and then gradually increase until the starter current is equal to the full load current. The frequency of the starter supply voltage is maintained at normal rated supply frequency.

The method of calculating the copper losses from the result is illustrated through the example given below.

Example

A 5 HP 400V, 50 Hz, four-pole, three-phase induction motor was tested and the following data were obtained.

Blocked rotor test: $V_s = 54$. $P_s = 430$, $I_s = 7.5$ A.

The resistance of the stator winding gives a 4 V drop between the terminals' rated DC current flowing.

Find the power factor at short circuit and R_e and X_e and full load copper loss.

Given:

Output	= 5 HP
Voltage	= 400 V
Frequency	= 50 Hz.
Blocked rotor voltage, V_S	= 54 V
Power P_S,	= 430 W
Current, I_S	= 7.5 A

Find:

Power factor at short circuit	= $\cos\theta_S$
Equivalent resistance, R_e/phase	
Equivalent reactance X_e/phase	
Full load copper loss	= $3I^2R_e$.

Known:

$W_S = \sqrt{3}\, V_S I_S\ \cos\varnothing_S$

$$\text{Equivalent impedance } Z_e = \frac{V_s}{\sqrt{3}I_s} = \sqrt{R_e^2 + X_e^2}$$

$$R_e = \text{equivalent resistance} = \frac{P_s}{3I_s^2}$$

$$X_e = \text{equivalent reactance} = \sqrt{Z_e^2 - R_e^2}$$

Solution:

$$W_S = \sqrt{3}\, V_S I_S \quad \text{Cos} \varnothing_S$$

$$\text{Cos}\phi_s = \frac{W_s}{\sqrt{3}\, V_s I_s}$$

$$\text{Cos}\,\phi_S = \frac{430}{1.72 \times 54 \times 7.5}$$

$$= \frac{430}{696.6}$$

$$= 0.61$$

$$\text{Equivalent resistance } R_e\text{/phase} = \frac{P_s}{3 \times I_s{}^2}$$

$$= \frac{430}{3 \times (7.5)^2}$$

$$= \frac{430}{168.75} = 2.5\Omega$$

$$X_e = \text{equivalent reactance/phase} = \sqrt{Z_e^2 - R_e^2}$$

$$Z_e = \frac{54}{\sqrt{3} \times 7.5} = \frac{54}{12.90} = 4.1\Omega.$$

$$X_e = \sqrt{4.1^2 - 2.5^2} = \sqrt{16.81 - 6.25}$$

$$= \sqrt{10.56} = 3.24\Omega.$$

Full load copper loss $= 3\, I^2 R_e$

$= 3 \times 7.5^2 \times 2.5 = 421.875$ watts

Answer

i $\cos\phi_s = 0.61$

ii Equivalent resistance R_e/phase = 2.5 Ω

iii Equivalent reactance X_e/phase = 3.24 Ω

iv Full load copper loss = 421.875 watts

Efficiency from no-load and blocked rotor test

Objective: At the end of this lesson you shall be able to
- **determine the efficiency at full load.**

Example

A 5 HP 220V, 50 Hz four-pole, three-phase induction motor was tested and the following data were obtained.

No load test = V_{NL} = 220V, P_{NL} = 340 W, I_{NL} = 6.2 A

Blocked rotor test = V_{BR} = 54V, P_{BR} = 430W,

I_{BR} = 15.2 A

Application 4V DC across two stator terminals causes the rated current flow with stator (assume star connection). Determine the efficiency at full load.

Assuming star connection DC resistance/phase = R/2

SOLUTION:

$R_1 + R_2$ = 4/15.2 = 0.263 W

Resistance/phase = 0.263/2 = 0.1315 Ω

Effective AC resistance $R_s = 1.4\, R_{ph}$

= 1.4 x 0.1315

= 0.1841 Ω

$R_{(rot + c)} = P_{NL} - 3I^2_{NL} R_s$

$= 340 - 3 \times 6.2^2 \times 0.1841$

= 340 - 21.23

= 318.77 W(constant loss)

Copper loss $= 3I^2 R_e$ = 430 W

Output = 5 x 735.5 = 3677.5 W

$$\text{Efficiency} = \frac{3677.5}{3677.5 + 318.77 + 430} = \frac{3677.5}{4426.2}$$

= 0.830

% efficiency = 0.830 x 100

i.e. = 83%.

Effect of external resistance in slip ring motor rotor circuit

Objective: At the end of this lesson you shall be able to
- **explain the effect of introducing additional rotor resistance in an induction motor.**

We have seen that the slip-ring induction motor is started by controlling resistance in the form of a rheostat connected in star. By increasing the rotor resistance, the rotor current is reduced at starting. Hence the starter current is also reduced. The starting torque is high because of improvement in the rotor power factor.

The introduction of external resistance in the rotor circuit is applicable to slip-ring motors only. The motor speed is reduced by introducing an external resistance in the rotor circuit.

We know that the torque under running condition is

$T \alpha E_r I_r \cos \phi_2$

or $T \alpha \phi I_r \cos \phi_2$ because $E_r \alpha \phi$

where E_r = rotor emf/phase under running condition

I_r = rotor current / phase under running condition

$E_r = s E_2$

Therefore

At normal speeds close to synchronous speed, the sX_2 is small and hence negligible with respect to the value of R_2.

Hence T as/R_2

It is obvious that for a given torque, slip can be increased, that is, speed can be decreased by increasing the rotor resistance. This method is used to control the speed of a slip-ring motor.

One serious disadvantage of this method of speed control is that with the increase in rotor circuit resistance, I^2R losses also increases. Thus the operating efficiency of the motor decreases. This method of speed change is used only where such changes are needed for short periods only.

Auto-transformer starter

Objectives: At the end of this lesson you shall be able to
- **explain the construction and operation of auto-transformer starter**
- **explain power circuit and control circuit of auto-transformer starter.**

Auto-transformer starter

By connecting series resistances reduced voltage is obtained at the motor leads. It is simple and cheap, but more power is wasted in the external series resistances.

In auto transformer starting method the reduced voltage is obtained by taking tappings at suitable points from a three phase auto -transformer as shown in Fig 1. The auto transformers are generally tapped at 55, 65, 75 percent points. So that the adjustment at these voltages may be made for proper starting torque requirements. Since the contacts frequently break, large value of current acting some time quenched effectively by having the auto-transformer coils immersed in the oil bath.

The power circuit of the auto-transformer is shown in Fig 2a and control circuit of auto-transformer is shown in Fig 2b.

Auto-transformer starter - operation

In this type of starter reduced voltage for starting the motor is obtained from a three-phase star connected auto-transformer. While starting, the voltage is reduced by selecting suitable tappings from the auto-transformer. Once the motor starts rotating 75% of its synchronous speed, full line voltage is applied across the motor and the auto-transformer is cut off from the motor circuit.

Fig 1

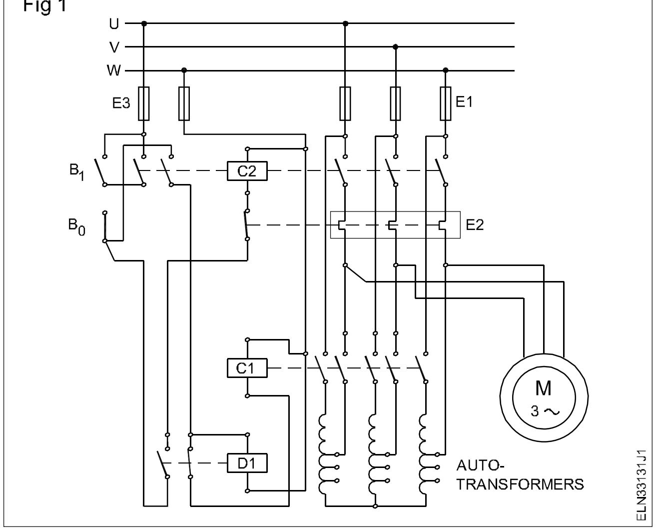


Fig 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Fig 2

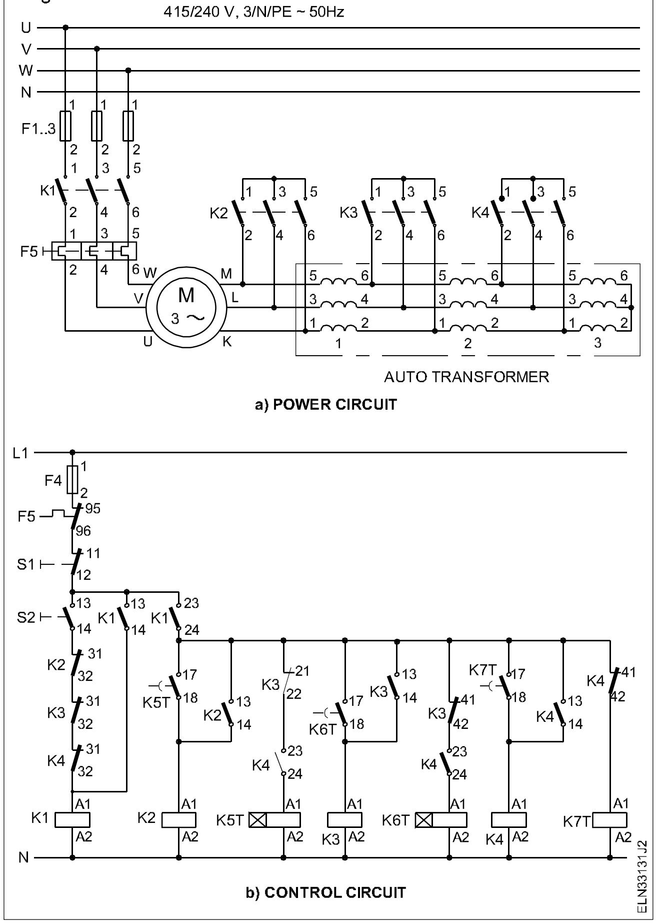
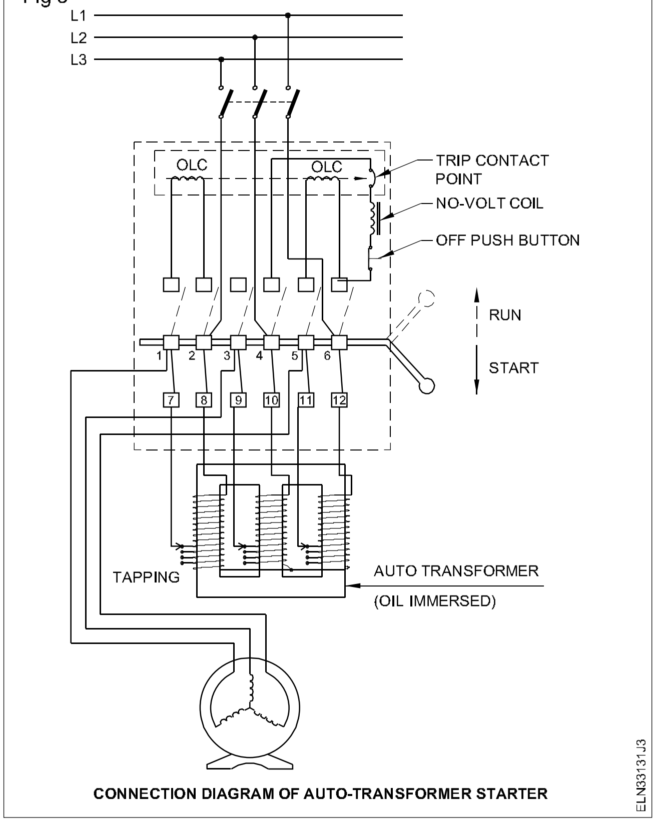


Fig 3



Hand operated auto-transformer starters are suitable for motors from 20 to 150 hp whereas automatic auto-transformer starters are used with large horse-power motors upto 425 hp.

Single phasing preventer/phase failure relay

Objectives: At the end of this lesson you shall be able to
- **define single phasing**
- **state the effects of single phasing**
- **explain the necessity of a single phasing preventer**
- **classify the single phasing preventers**
- **explain the installation procedure**
- **explain the procedure for troubleshooting and servicing of single phasing preventer.**

Single phasing preventer/phase failure relay : When one of the three lines of a three-phase supply system fails or opens, the load current flows between the other two lines only and the fault is known as single phasing.

Effect of single phasing: The effect of single phasing is different with different types of loads as follows

- In 3-phase heating loads, the heat produced decreases to around 50%; at the same time it does not harm the equipment.
- In three-phase motors, the effect of single phasing is different on different occasions. i) During starting, if single phasing occurs, the motor fails to start or stalls as proper rotating magnetic field is not created. But the motor draws a very large current and motor windings gets heated up. ii) During running, if single phasing occurs, the motor may or may not run depending upon the load condition and the phase in which supply is available will draw a large current and the winding is likely to burn out due to overheating.

Necessity of single phasing preventor/phase failure relay: If two phases of the supply to a three-phase induction motor are interchanged, the motor will reverse its direction of rotation. This action is called phase reversal. In the operation of elevators and in many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire connected to the motor breaks while the motor is running, the motor will continue to operate on two phase but will experience serious overheating. To protect motors against these conditions of phase failure, a sinlge phase preventor is used.

Types of preventors: Single phasing preventors are available in three types.

- Mechanical
- Current sensing
- Voltage sensing

Single phasing preventor - mechanical type : One type of single phasing preventor is incorporated with bimetal relays which opens the NVC circuit similar to that of normal OLR. This type of single phasing preventor is slow in operation and, also not fully reliable, and hence, not preferred nowadays.

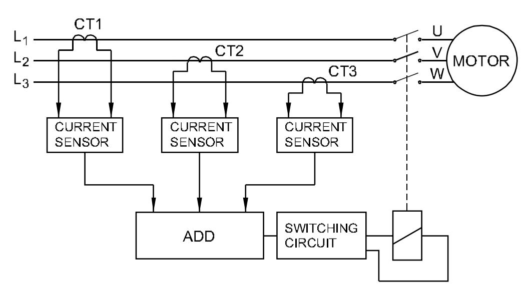
The second type of mechanical phase failure relay uses coils connected to two lines of the three-phase supply. The currents in these coils set up a rotating magnetic field that tends to turn a copper disc clockwise. This clockwise torque actually is the resultant of two torques acting in opposite direction. Out of two torques, one polyphase torque tends to turn the disc clockwise, and one single-phase torque tends to turn the disc anti-clockwise.

The disc is kept from turning in the clockwise direction by a projection resting against a stop. However, if the disc begins to rotate in the anti-clockwise direction, the projecting arm will move a toggle mechanism to open the starter and disconnect the motor from the line. In other words, if one line is opened, the poly-phase torque disappears and the remaining single-phase torque rotates the disc in anti-clockwise direction. As a result, the motor is disconnected from the line. In the case of phase reversal, the poly-phase torque helps the single-phase torque to turn the disc anti-clockwise, and again, the motor is disconnected from the line.

Single phasing preventers - current sensing : It operates on the principle of equal currents with balanced loads developing secondary voltage on current transformers. These secondary voltages are so connected so as to add and the added voltage is rectified, filtered and sensed and applied to operate a relay which operate to close the NVC circuit of the starter.

Fig 1 shows the block diagram of a current sensing single phasing preventor.

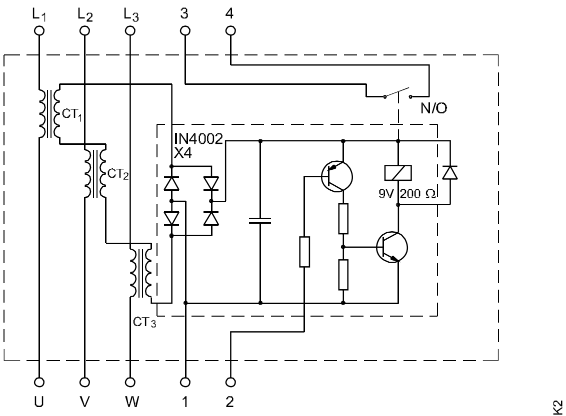
Fig 1



SINGLE PHASING PREVENTOR

Fig 2 shows a typical circuit diagram of current sensing single phase preventor. The terminals 1 and 2 are used if any time delay circuit is to be introduced. Otherwise they are kept shorted.

Fig 2



TYPICAL CIRCUIT DIAGRAM OF CURRENT SENSING SINGLE PHASING PREVENTOR

Terminals 3 and 4 are connected in series with the NVC circuit of starter. The relay will not operate if the motor draws a current lesser than the specified value or the circuit is unbalanced thereby keeps the motor off.

This type of single phasing preventors are suitable only where the motors run with a constant load such as pump motors, compressor motors etc. It also serves as dry run protection unit as and when the motor is out of load, such as a pump running without water, the load current decreases and the circuit senses and trips the motor circuit.

Single phasing preventer - voltage sensing : In an AC three-phase supply the order in which three -phase voltages reach the maximum value is known as phase sequence. The phase voltage reaches their maximum positive value one after another at 120° in clockwise known as positive phase sequence and in anti-clock wise known as negative phase sequence. In the case of phase reversal or unbalanced voltages or no voltage in a line it results in a super-imposition of negative phase sequence over the normal positive phase sequence of supply voltages. This negative sequence is filtered by a resistance capacitance or resistance, capacitance and inductor network and de-energise the relay in the voltage the sensing single phasing preventor.

Fig 3 and Fig 4 shows the block diagram and circuit diagram of a typical voltage sensing single phasing preventor. In this a resistance, capacitance network is utilized to sense the negative phase sequence. When phase sequences and voltages are correct, no voltage will be generated across the filtered output i.e. across capacitor. C_4 in the circuit which drives the transistor Q_1 to cut off transistor Q_2 to drive the relay.

When the negative sequence occurs due to unbalanced supply voltage or phase reversal, a voltage is developed across the capacitor C_4 which drives the transistor Q_1 to saturation and transistor Q_2 to cut off. This results in switching off the relay circuit.

Some of the single phasing preventors are provided with the facility to adjust unbalanced settings. For example when the relay is found to operate very frequently for the set value, the unbalanced pre-set can be changed by operating the pre-set P_5 in Fig 4.

Fig 3

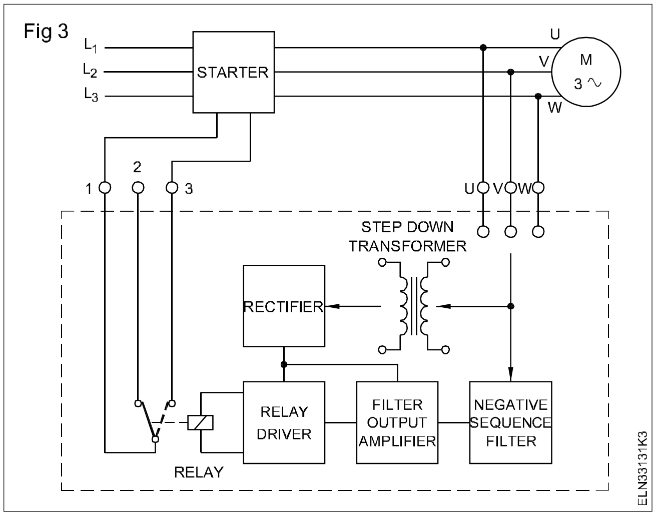
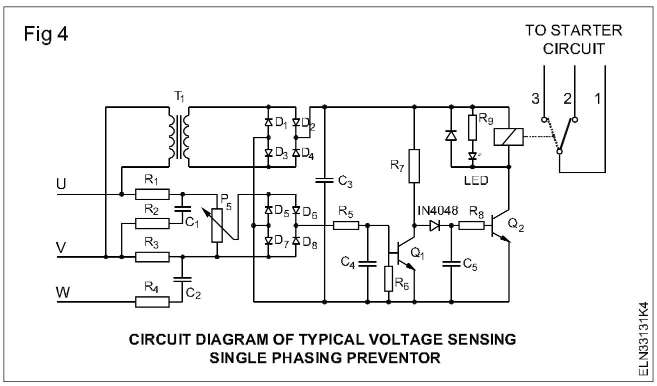


Fig 4



CIRCUIT DIAGRAM OF TYPICAL VOLTAGE SENSING SINGLE PHASING PREVENTOR

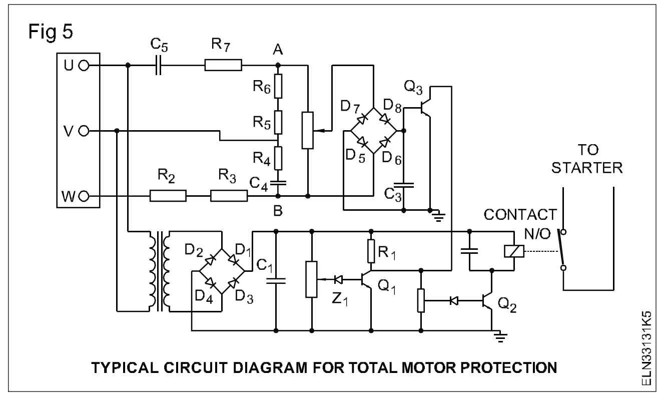
Single phasing preventor with over-voltage and under voltage cut off (Total motor protection) : When a motor is fed with reduced voltage, the motor draws excess current to drive the load and with an over -voltage, also it draws excess current. To protect the motor from under-voltage or over-voltage and also from single phasing a preventor with over and under voltage protection is used for total motor protection.

Fig 5 shows an arrangement of over-voltage and under - voltage cut off circuit along with single phasing preventor.

In the circuit transistor Q_1 serves as over-voltage cut off and transistor Q_2 serves as under-voltage cut off where- as transistor Q_3 serves as single phasing preventor.

Installation of single phasing preventor : Installation and connection of single phasing preventor shall be done as recommended by the manufacturer. Preferably single phasing preventors shall be located nearer to the equipment and not subjected to abnormal vibration. Care should be taken to locate the unit away from a heat generating source such as oven, furnace etc.

Fig 5



TYPICAL CIRCUIT DIAGRAM FOR TOTAL MOTOR PROTECTION

A single phase preventor shall be connected with the supply line and starter to the appropriate terminals and circuits.

Some of the commonly used single phasing preventors and their connection with starter are shown in Figs 6 & 7 for your reference.

Fig 6

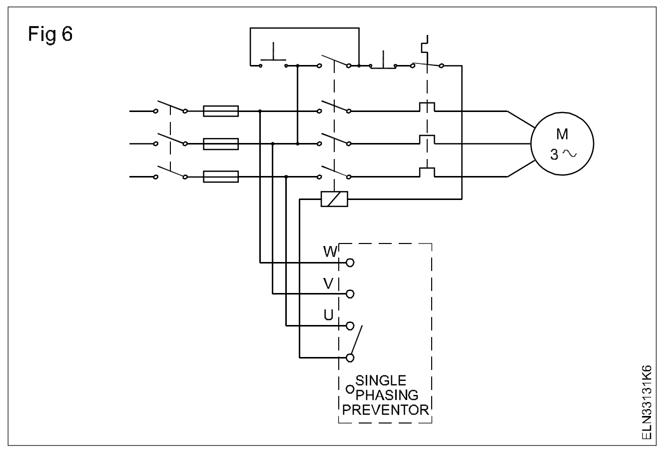
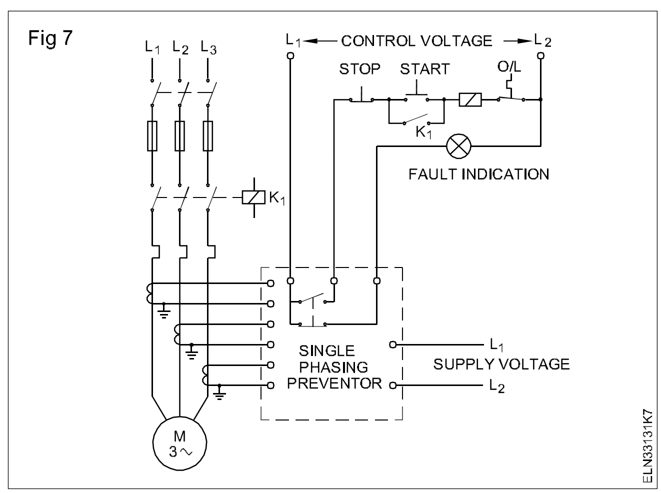


Fig 7



Troubleshooting and maintenance of single phasing preventor : The arrangement of components and their circuits of single phasing preventors vary from one make to another make as well as from one type to another type.

It is preferred to follow the manufacturer's recommendations for troubleshooting and maintenance of single phase preventors. A few general guide lines for troubleshooting of single phase preventors are given in the Table-1.

Table 1

S.No.	Symptoms	Possible causes	Remedy
1.	Starter with single phase preventor does not start.	No supply. Low supply voltage.	Check and resume supply. Verify and correct the voltage.
		Unbalanced line voltages.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence by interchanging any two incoming lines.
		Single phasing	Check and rectify.
		No control circuit voltage.	Check and rectify.
2.	Starter with single phase preventor does not hold on.	Low supply voltage. Unbalanced line voltages.	Verify and correct. Verify and correct.
		Single phasing.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence.
		Defect in single phase preventor electronic circuit.	Check, repair or replace.
		Relay of single phase preventor is not energised.	Check, rectify or replace.
		Improper function of relay contacts.	Check, rectify or replace.
		Open in holding circuit.	Check and correct.
3.	Starter with single phase preventor trips frequently.	Abnormal fluctuations in line voltages.	Check and rectify.
		Improper settings or unbalanced settings.	Adjust the unbalanced settings.
		Loose contact in supply lines/ control circuit.	Check and rectify.

Braking system of motors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of braking system for motors**
- **list and explain each type of braking system.**

Necessity of braking system

The term braking comes from the term brake. The brake is an equipment to reduce the speed of any moving or rotating equipment, like vehicles, locomotives etc. The process of applying brakes can be termed as **braking.**

The term braking in two parts **i) Mechanical braking** and the **ii) Electrical braking.** In mechanical braking the speed of the machine is reduced solely by mechanical process but in electrical braking the whole process is depended on the flux and torque directions. Each type of electrical braking is the reversal of the direction of the flux. **Braking** is the process of reducing speed of any rotating machine. The application of braking is in factories, industrial areas or be it in locomotives or vehicles. Everywhere the use of mechanical and electrical brakes is inevitable.

Types of braking

Brakes are used to reduce or cease the speed of motors. There are various types of motors available (DC motors, induction motors, synchronous motors, single phase motors etc.) and the specialty and properties of these motors are different from each other, hence this braking methods also differs from each other. Braking can be divided in to three methods mainly, which are applicable for almost every type of motors.

1 Plugging type braking

2 Regenerative Braking

3 Dynamic braking.

1 Plugging type braking: In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases. During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.

2 **Regenerative braking:** Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This braking method is called regenerative braking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

3 **Dynamic braking:** Another method of reversing the direction of torque and braking the motor is dynamic braking. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self -excited generator. When the motor works as a generator the flow of the current and torque reverses.

Method of speed control of 3 phase induction motor

Objectives: At the end of this exercise you shall be able to
- **list the speed control methods from stator and rotor side**
- **explain the speed control methods of 3 phase induction motor.**

In 3 phase induction motor, speed can be controlled from both stator and rotor side

1 Speed control methods from stator side
   - By changing the applied voltage
   - By changing the applied frequency
   - By changing the number of stator poles

2 Speed control from rotor side
   - Rotor rheostat control
   - Cascade operation
   - By injecting EMF in rotor circuit

1. Speed control from stator side

a) By changing the applied voltage: Torque equation of induction motor is

$$T = \frac{k_1 sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$= \frac{3}{2\pi N_s} \frac{sE_2^2 R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Rotor resistance R_2 is constant and if slip s is small then sX_2 is so small that it can be neglected. Therefore, $T \alpha$ sE_2^2 where E_2 is rotor induced emf and $E_2 \alpha V$

And hence $T \alpha V^2$, thus if supplied voltage is decreased, torque decreases and hence the speed decreases.

This method is the easiest and cheapest, still rarely used because-

1 A large change in supply voltage is required for relatively small change in speed.

2 Large change in supply voltage will result in large change in flux density, hence disturbing the magnetic conditions of the motor.

b) By changing the applied frequency: Synchronous speed (N_s)of the rotating magnetic field of induction motor is given by,

$$N_s = \frac{120f}{P} \text{rpm}$$

where, f = frequency of the supply and P = number of stator poles.

Thus, synchronous speed changes with change in supply frequency, and thus running speed also changes. However, this method is not widely used. This method is used where, only the induction motor is supplied by a generator (so that frequency can be easily changed by changing the speed of prime mover).

c) Changing the number of stator poles: From the above equation, it can be also seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors, as squirrel cage rotor adapts itself for any number of stator poles. Change in stator poles is achieved by two or more independent stator windings wound for different number of poles in same slots.

For example, a stator is wound with two 3phase windings, one for 4 poles and other for 6 poles.

for supply frequency of 50 Hz

i) Synchronous speed when 4 pole winding is connected, Ns = 120 x (50/4) = 1500 RPM

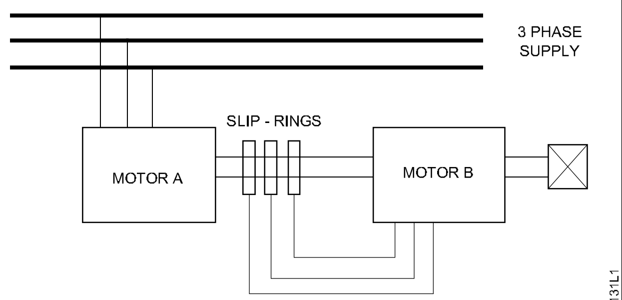
ii) Synchronous speed when 6 pole winding is connected, Ns = 120 x (50/6) = 1000 RPM

2 Speed control from rotor side

a) **Rotor rheostat control:** This method is similar to that of armature rheostat control of DC shunt motor. But this method is only applicable to slip ring motors, as addition of external resistance in the rotor of squirrel cage motors is not possible.

b) **Cascade operation:** In this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at same speed. One motor is fed from a 3phase supply and other motor is fed from the induced emf in first motor via slip-rings. The arrangement is as shown in Fig 1.

Fig 1



CASCADE OPERATION

Motor A is called main motor and motor B is called auxiliary motor.

Let, N_{s1} = frequency of motor A

N_{s2} = frequency of motor B

P_1 = number of poles stator of motor A

P_2 = number of stator poles of motor B

N = speed of the set and same for both motors

f = frequency of the supply

Now, slip of motor A, $S_1 = (N_{s1} - N) / N_{s1}$.

Frequency of the rotor induced emf in motor A, $f_1 = S_1 f$. Now, auxiliary motor B is supplied with the rotor induce emf therefore, $N_{s2} = (120f_1) / P_2 = (120S_1 f) / P_2$. Now putting the value of $S_1 = (N_{s1} - N) / N_{s1}$

$$N_{s2} = \frac{120f\,(N_{s1} - N)}{P_2 N_{s1}}$$

At no load, speed of the auxiliary rotor is almost same as its synchronous speed. i.e. $N = N_{s2}$. From the above equations, it can be obtained that

$$N = \frac{120f}{P_1 + P_2}$$

With this method, four different speeds can be obtained

1 When only motor A works, corresponding speed = $N_{s1} = 120f / P_1$

2 When only motor B works, corresponding speed = $N_{s2} = 120f / P_2$

3 If cumulative cascading is done, speed of the set = $N = 120f / (P_1 + P_2)$

4 If differential cascading is done, speed of the set = $N = 120f\,(P_1 - P_2)$

c) **By injecting EMF in rotor circuit:** In this method, speed of induction motor is controlled by injecting a voltage in rotor circuit. It is necessary that voltage (emf) being injected must have same frequency as of slip frequency. However, there is no restriction to the phase of injected emf. If we inject emf which is in opposite phase with the rotor induced emf, rotor resistance will be increased. If we inject emf which is in phase with rotor induced emf, rotor resistance will decrease. Thus, by changing the phase of injected emf, speed can be controlled. The main advantage of this method is a wide range of speed control (above normal as well as below normal) can be achieved. The emf can be injected by various methods such as Kramer system, Scherbius system etc.