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.

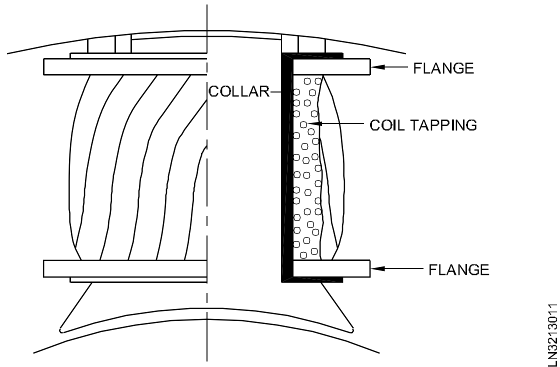
Such tables are published by all leading manufacturers of winding wires to help the winder in his task. The current-carrying capacity of the conductor shown in Table 1 is at 2.3A/mm². In general usage, a rating nearly 3 to 4 times higher in value, is used depending upon the insulation and temperature 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	Diameter inches	Diameter mm	Area sq. mm	Turns per square cm.	Current in ampere	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

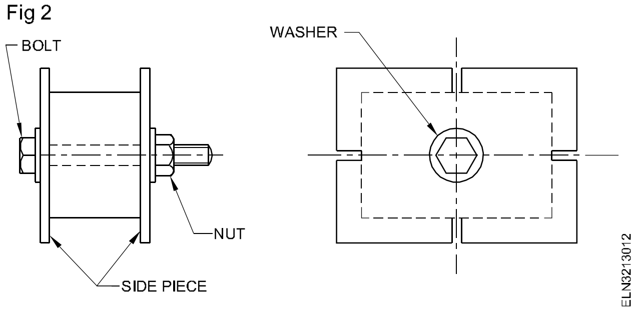


Fig 3

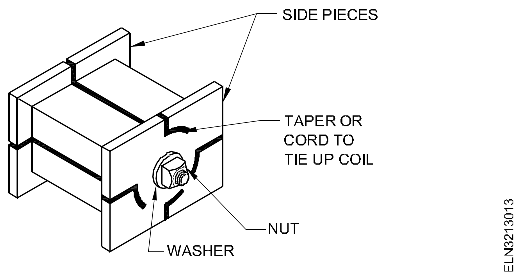
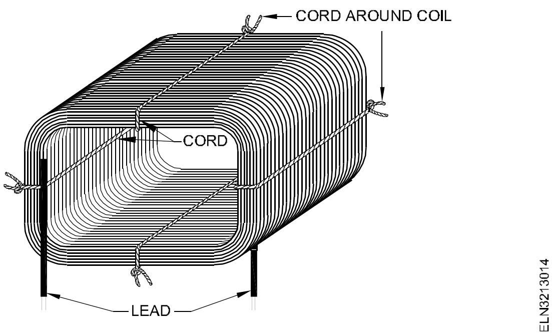
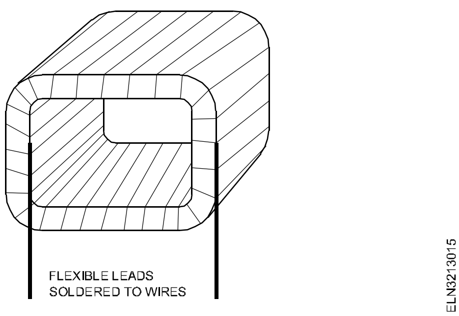


Fig 4



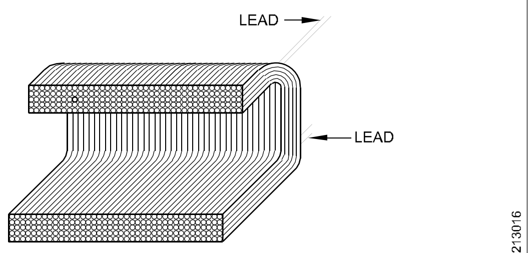
The size of the former may be obtained from the original coil or by measuring the dimensions of the field pole and allowing for the thickness of the tape. (Fig 5 shows the coil taped with cotton tape.)

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.

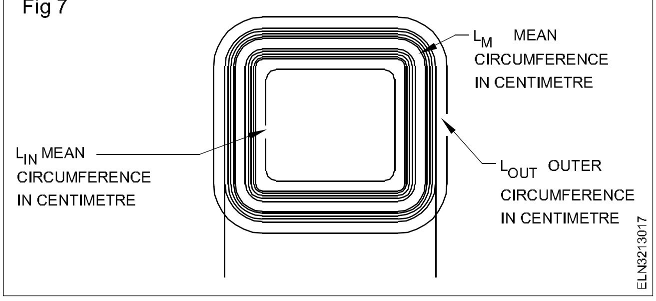
Reasons for such problems can be as follows.

- 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.

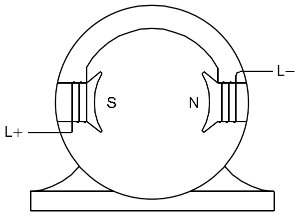
Varnishing the field coil : After preparing the field coil, preheat the coil in an oven at about 90°C for 3 to 4 hours to drive the moisture out from the field coil. Cool the coil to 60°C and dip the coil in baking varnish for 5 to 10 minutes, till the air bubbles ceases in the varnish tank. Drain the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

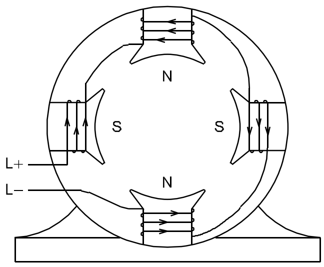
Thus, in a two-pole DC machine as shown in Fig 8, one of the poles is north and the other one is south. In a four-pole DC machine the poles must be alternately north and south as shown in Fig 9.

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.

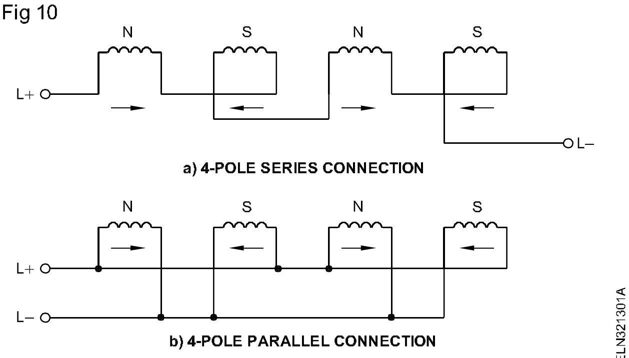
– Compass method

– 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.

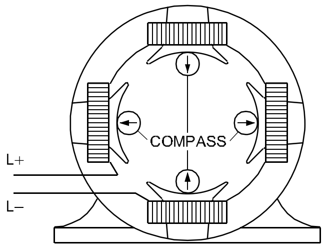
Fig.10 shows series and parallel connection of field coils to create alternate poles

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.

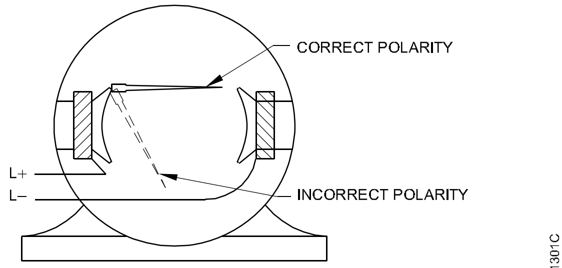
Fig 11



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.

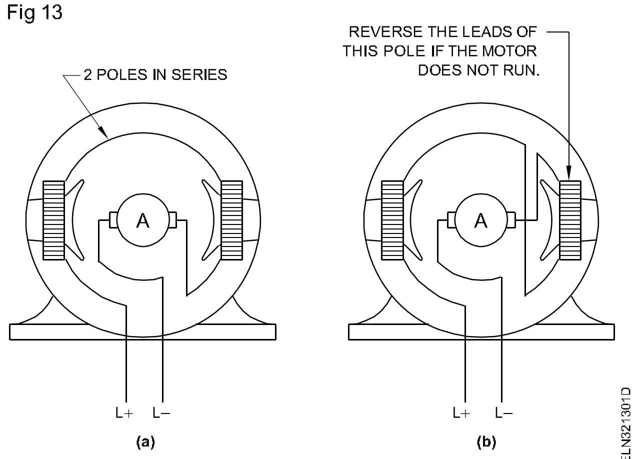
Fig 12



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.**

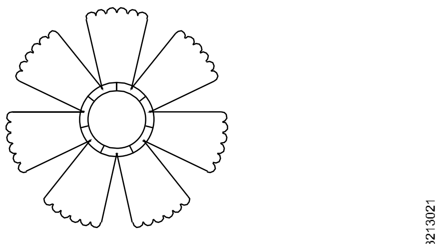
Winding : Winding is an orderly arrangement of insulated conductors in the slots of armature/stator cores with their end connection in a specified sequence.

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.

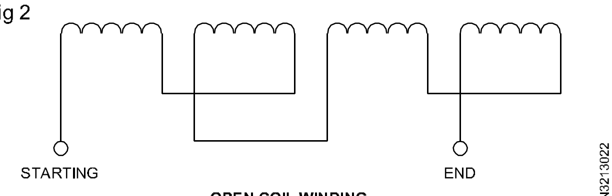
Fig 1



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

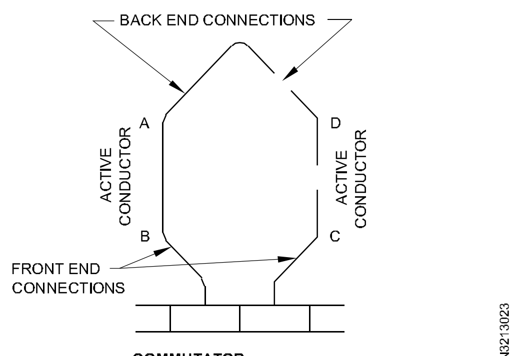
DC armature winding : It is a closed coil winding, wherein the coil ends are connected through the commutator segments to form the closed circuit.

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.

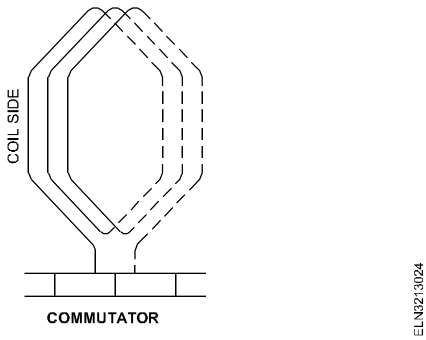
Referring to Fig 3, we find the two active conductors AB and CD along with their end connections constitute one coil or winding element of the armature winding. The coil may consist of a single turn only as shown in Fig 3 or multi-turns as shown in Fig 4. A single-turn coil or winding element will have 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



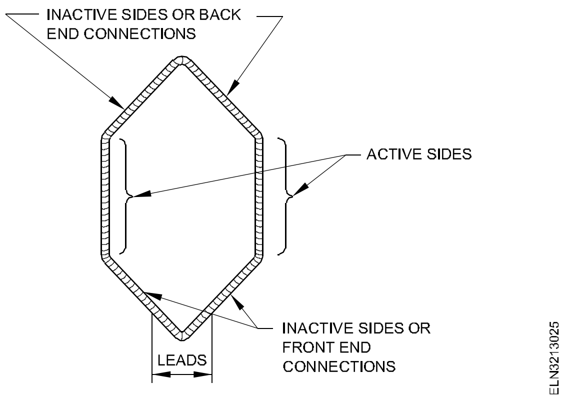
COMMUTATOR

Fig 4



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)

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

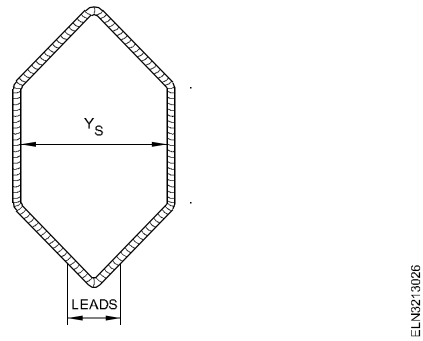
$$Y_P = \frac{\text{Number of slots}}{\text{Number of poles}} = \frac{24}{4} = 6 \text{ in terms of slots}$$

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.

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.

Fig 7

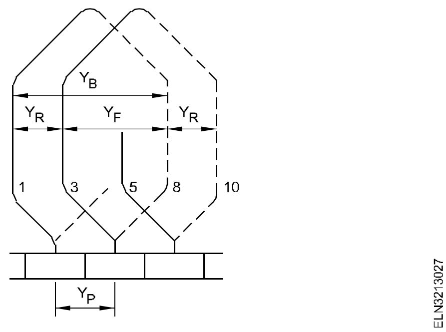
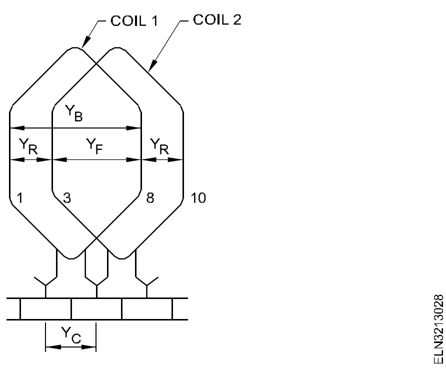
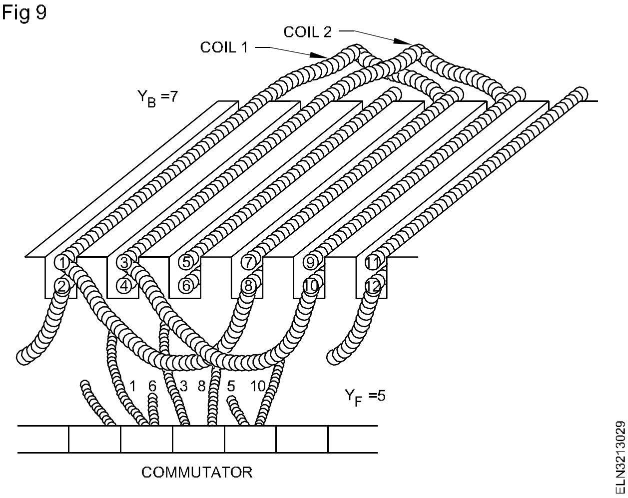


Fig 8



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.

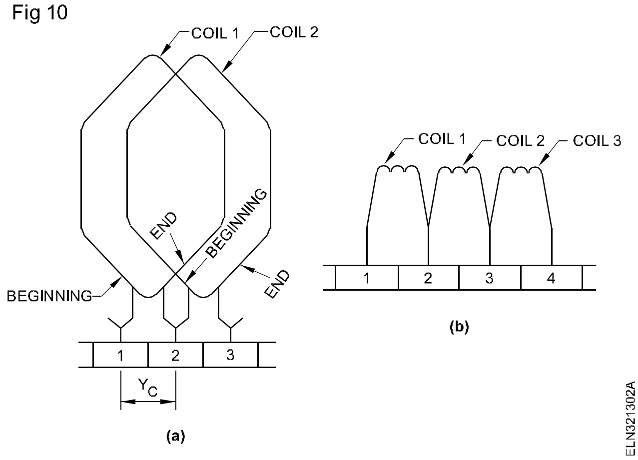
The commutator pitch Y_c varies with the type of winding, like lap or wave as well as simplex or multiplex.

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.

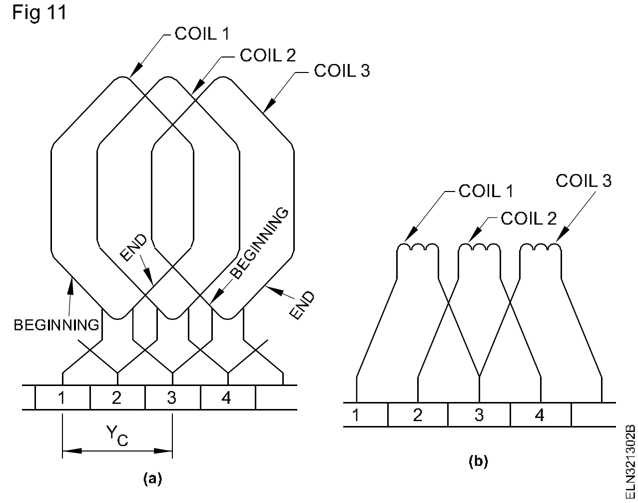
Simplex lap winding : In a simplex lap winding, the end lead of coil 1 is connected to the beginning lead of the adjacent coil(coil 2) through the commutator segments. The commutator pitch of one segment is maintained. Fig 10 shows the lead connection of a simplex lap winding.

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

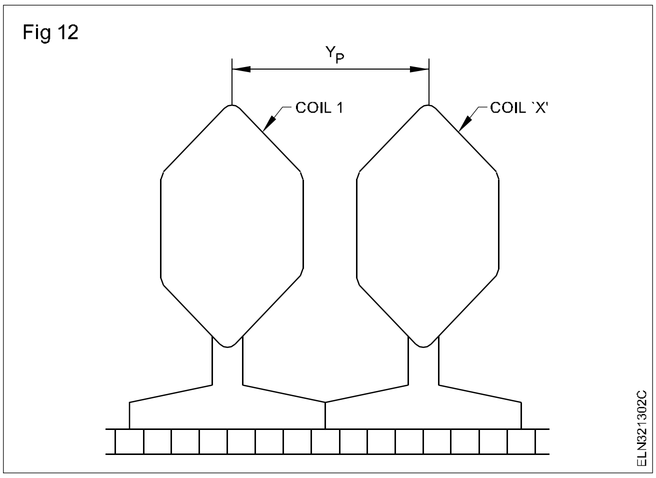
Y_c = 2 segments for duplex lap winding

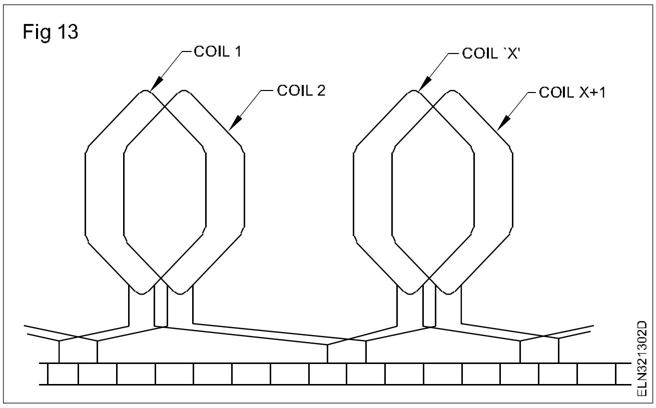
Y_c = 3 segments for triplex lap winding

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)

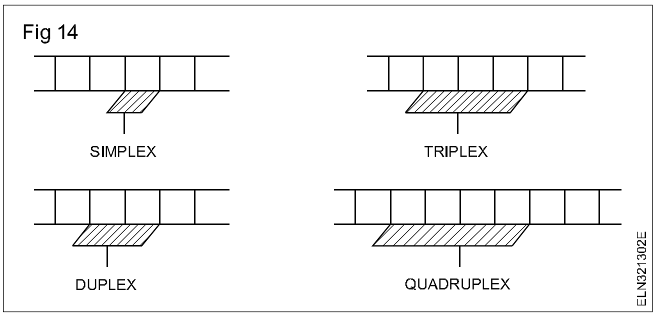
Duplex wave winding : In duplex wave winding there is parallel combination of two simplex wave windings as shown in Fig 13.





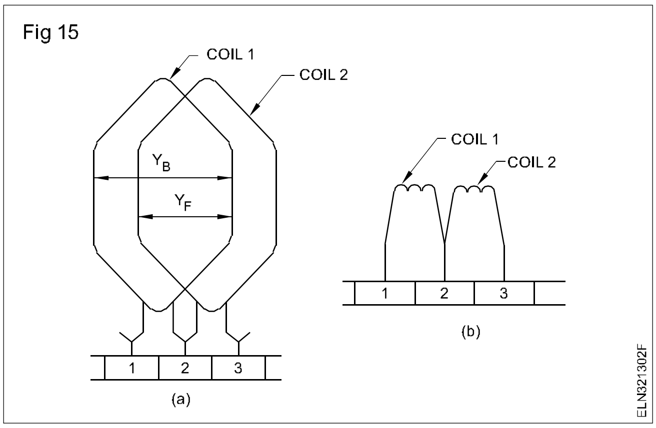
Triplex wave winding : Triplex wave winding will have a parallel combination of three simplex wave windings, and so on.

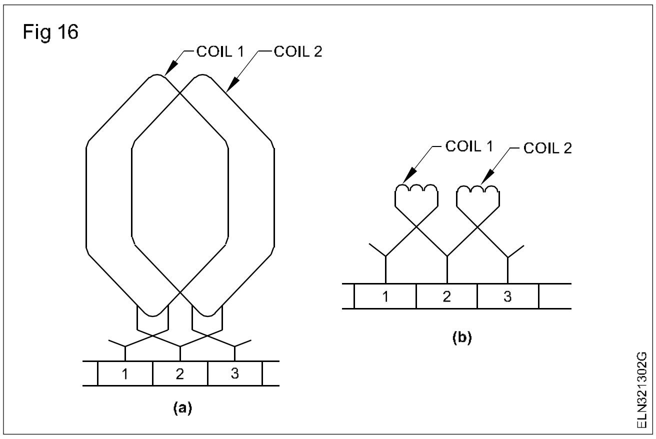
> **The width of the brush will be such that in simplex lap or wave winding, the brush will make contact with only one segment. The brush will contact two segments in duplex, three in triplex and four in quadruplex. (Refer to Fig 14)**



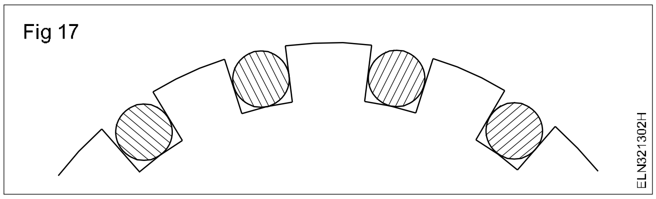
Progressive lap or wave winding : In progressive lap or wave winding, the front pitch Y_F will be less than the back pitch Y_B, i.e. as you lay the coils clock-wise, the connections to the commutator segments will also proceed clockwise as in Figs 15a and b. In progressive winding, Y_c is referred to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

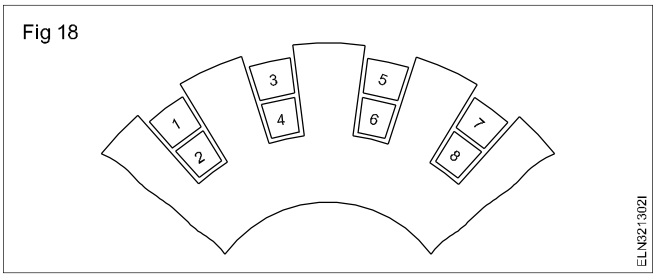




Single layer winding : A single layer winding is one in which only one coil side is placed in each armature slot, as shown in Fig 17. Such a winding is not used much.

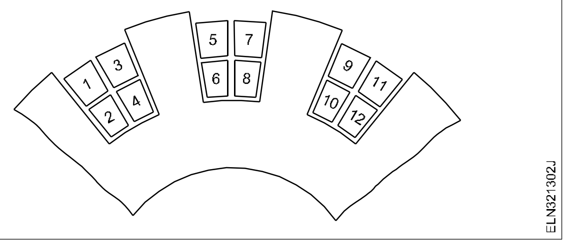


Two-layer winding : In this type of winding, there are two conductors or coil sides per slot arranged in two layers as shown in Fig 18. Usually, one side of every coil lies in the upper half of one slot and the other side of the same coil lies in the lower half of some other slot at a distance of one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



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

$$\text{Front pitch} Y_F = \frac{Z}{P} + 1 \qquad \text{Back pitch} \quad Y_B = Y_F - 2 \text{ x plex}$$

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

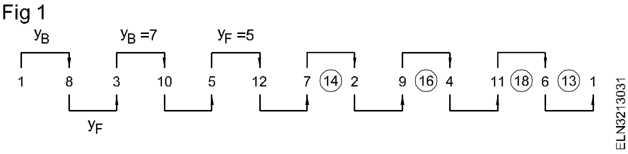
Front pitch $Y_F = Y_B - 2 \times \text{Plex} = 7 - 2 = 5$

$Y_B = 7$ 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



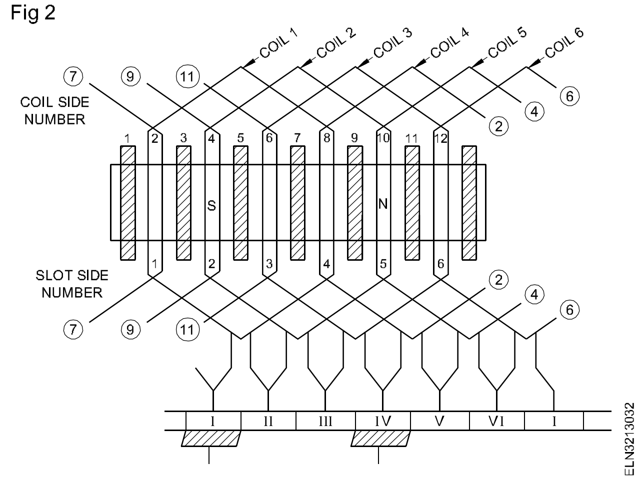
Winding Table

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

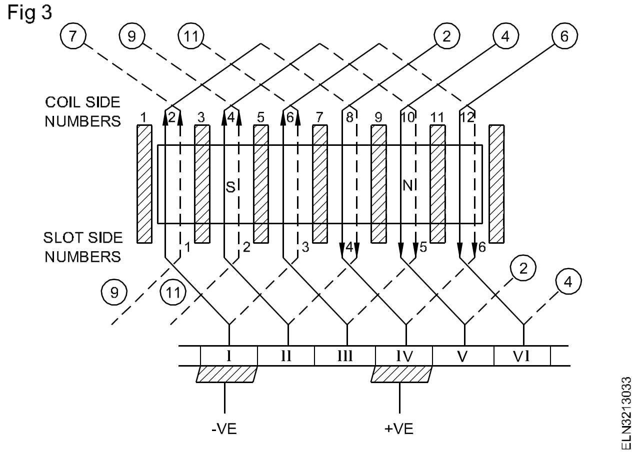
Fig 2 shows the arrangement of coils in the respective slots and the connection of the coils with the segments.

Fig 2



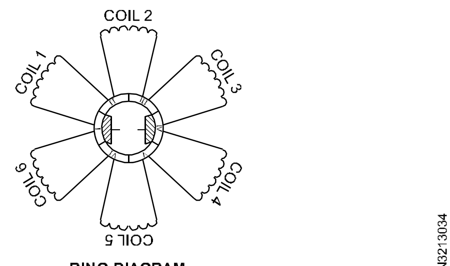
Development diagram with conductors : Fig 3 shows the arrangement of armature conductors in the slots and connections to commutator segments.

Fig 3



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

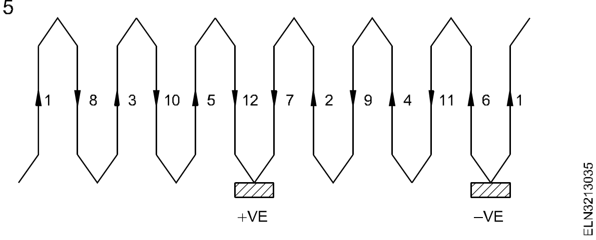
Fig 4



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.

  $Z = P \times Y_A \pm 2$ 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 Pole pitch $Y_P = \frac{\text{No.of slots}}{\text{No. of poles}} = 7/2 = 3.5$ 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 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

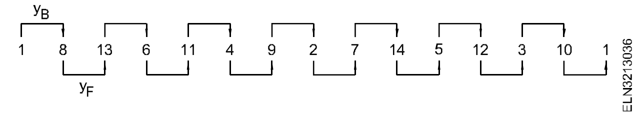
$2Y_A = 2 \times 6 = 12 = Y_B + Y_F$

$Y_B - Y_F = 12.$

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



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

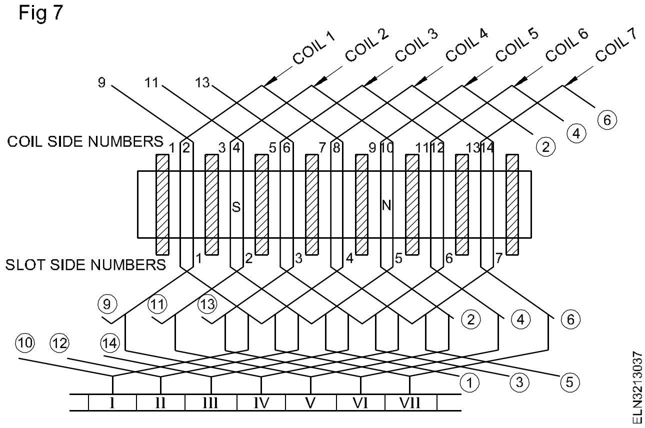
Winding Table

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

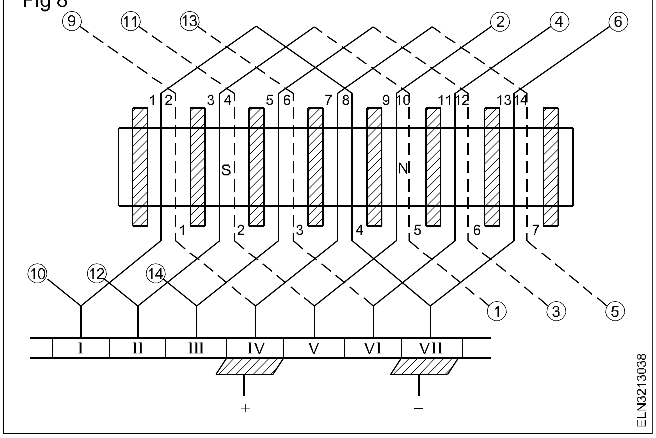
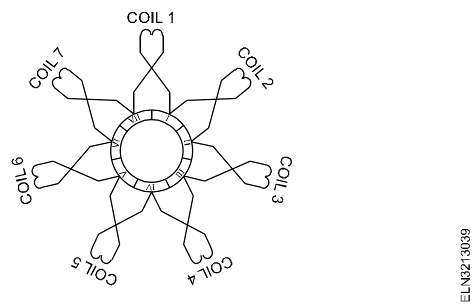
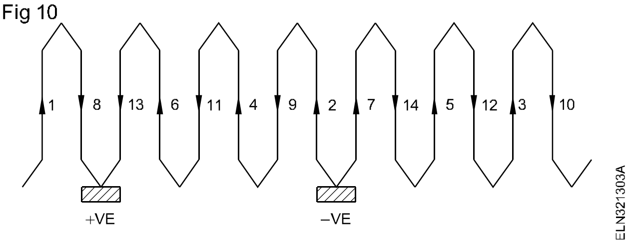


Fig 9



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^o geometrical (app.155^o).

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.**

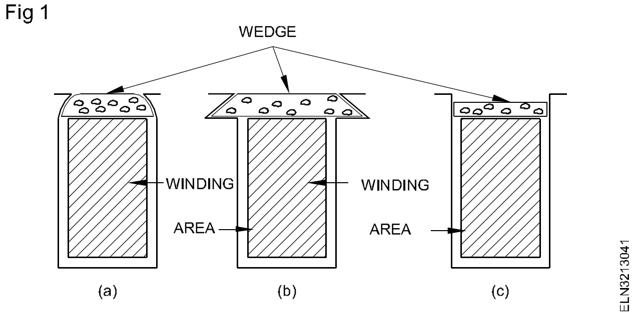
Slots : Slots are provided in the armature laminated core, to house the armature conductors in position.

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

- Open type
- Semi-enclosed type
- Closed type

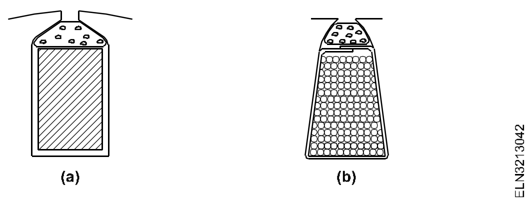
Open type slots : Open type slots are used for medium and high voltage machines. The slots are tapered a little or dovetailed on the top to receive the wedges after rewinding, as shown in Figs1 a, b & c. Former wound coils after being properly insulated are housed in the slots. To prevent the coils from 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



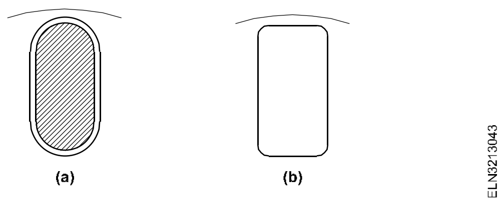
Semi-enclosed type slots : Semi-enclosed types of slots are used for low and medium voltage machines. The slots in this type of armature are tapered towards the periphery, i.e. openings towards the teeth are smaller as compared to the base, as shown in Figs 2 a & b. So reluctance is less than in open 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



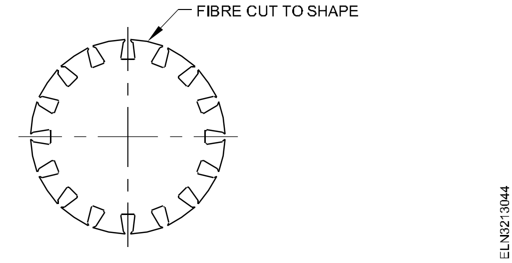
They have no opening on the periphery to receive the conductors. Therefore, conductors are pushed through the slots. The reluctance is lower than in the above two types, and so the efficiency is high.

Insulation scheme for armature

For armature winding, the following insulation schemes are required.

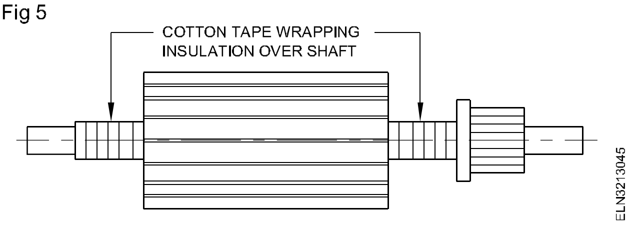
Armature core insulation : Both the sides of the armature core ends have to be insulated with fibre or insulation paper cut in the shape of the stampings. (Fig 4)

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)

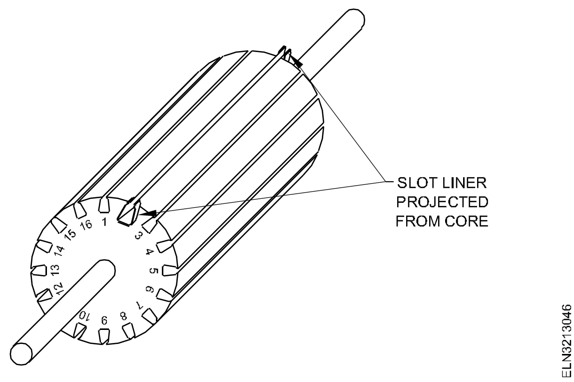
Fig 5



Slot insulation

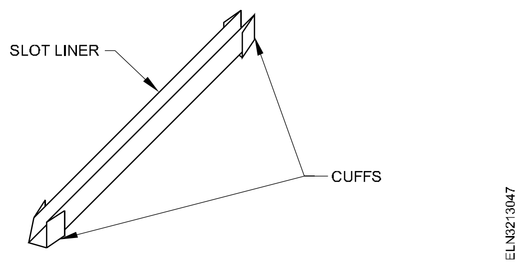
Slot liner : The slot liner is an insulation sheet cut to the inner dimensions of the slots and projected on either side of the slots. (Fig 6)

Fig 6



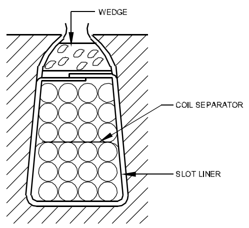
Cuffing : In some applications, the edges of the slot liner are folded on either end to prevent them from sliding in the slots. (Fig 7)

Fig 7



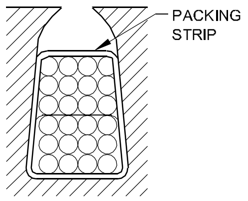
Coil separator : When multi-layer windings are used to insulate the winding layers from each other, coil separators are used. They should be extended on either side of the slot. (Fig 8)

Fig 8



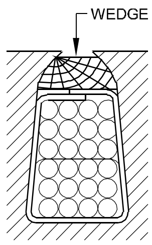
Packing strip : The thick insulation paper used in between the slot liner and wedge is called a packing strip. This should extend beyond each end of the armature core. (Fig 9)

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

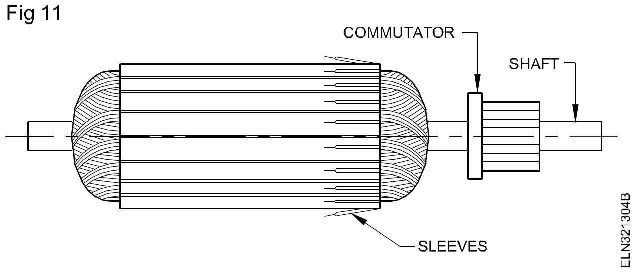


Coil insulation : In some applications, the slot portions of the coil sides are taped with cotton or fibre glass tapes. This is known as coil insulation.

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.

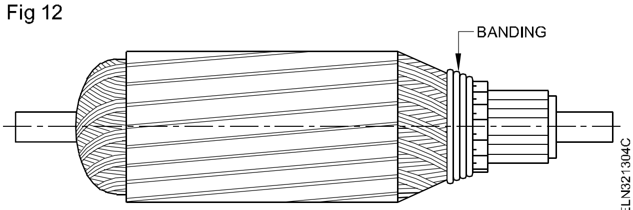
Lead insulation : Lead insulation is one where the end leads of armature conductors are insulated with sleeves, like empire or fibre glass, before soldering with the commutator segments. (Fig 11)

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

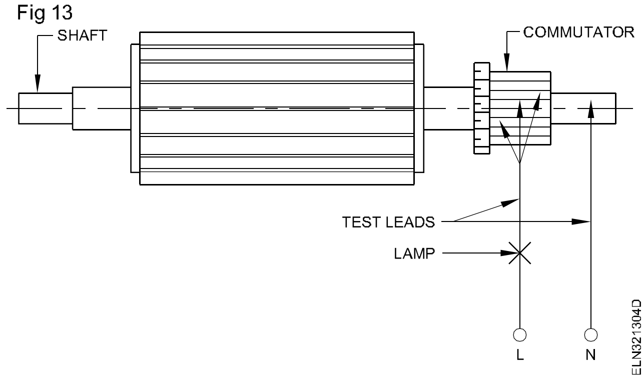


Varnishing : Baking varnish is used for impregnation of armature windings. This process is known as varnishing.

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.

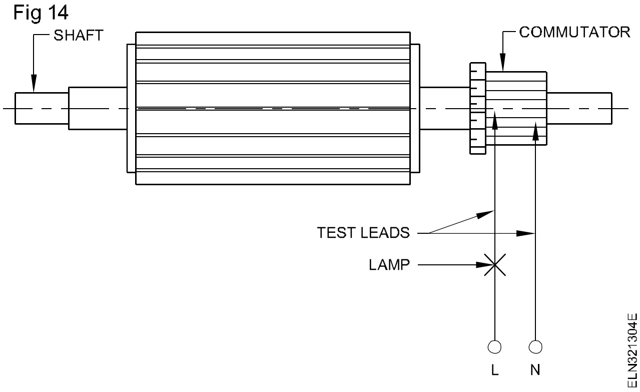
Test for grounded commutator : A commutator is grounded when one or more bars contact the iron core of the commutator or shaft. This can be tested by a test lamp as shown in Fig 13. Touch one lead of the test lamp permanently to the shaft of the armature. Touch the other lead of the test lamp on the 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

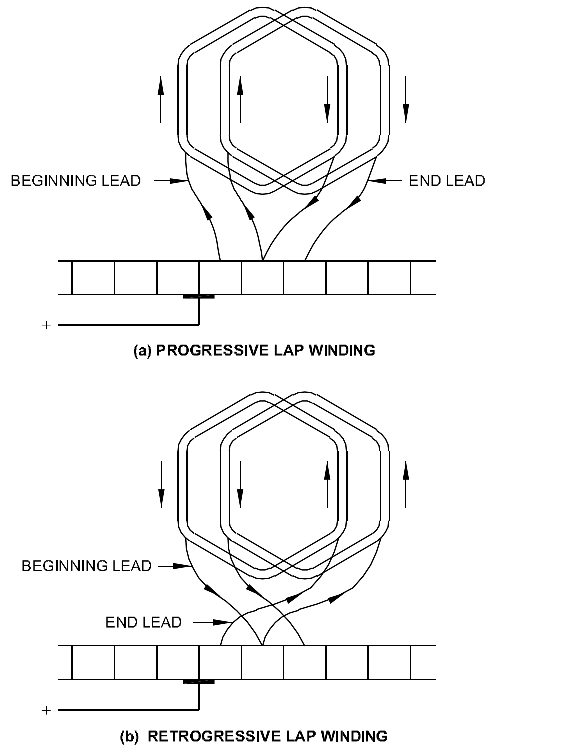
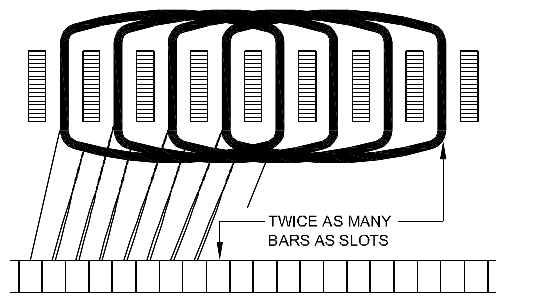


Fig 2



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.

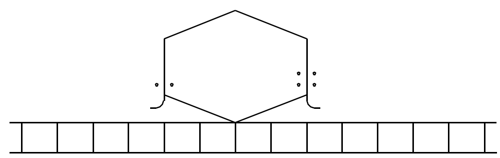
After taking the name plate details, dismantle the mixer and strip the winding carefully. During this process collect the information as detailed in the data sheet shown in Table 2.

Table 1

Name-plate details

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

Table 2

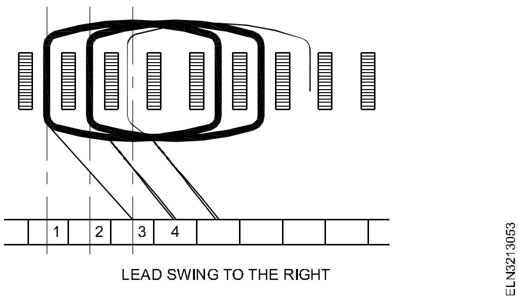
	Size of wire	Turns	Insulation	Connection
STATOR				
	Size of wire	No.of turns	Coil pitch	Coils/Slots
ROTOR			Draw the end connection and show the lead swing.	
	No.of slots	Bars		
Details of lead swing Centre of slots to	Centre of bars Centre of mica			
Lap	Commutator pitch	Wave		

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

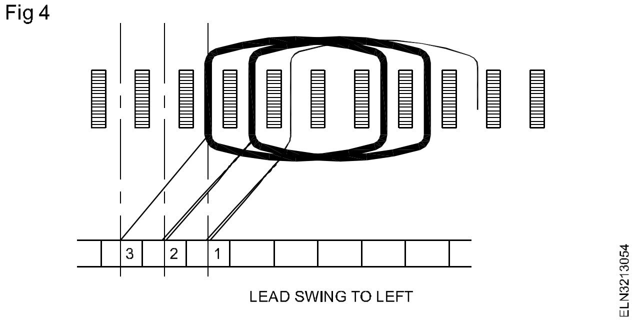
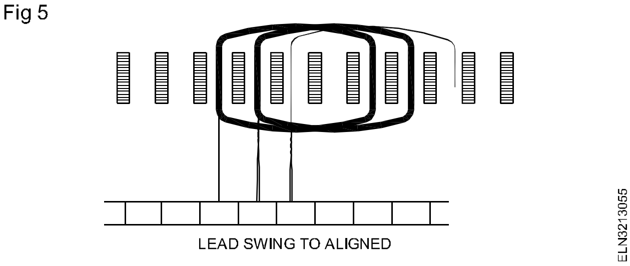
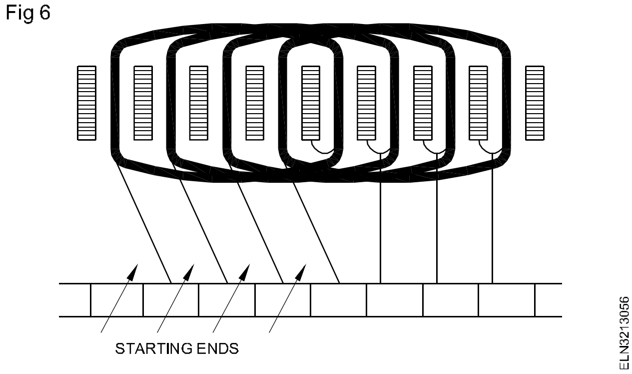


Fig 5



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

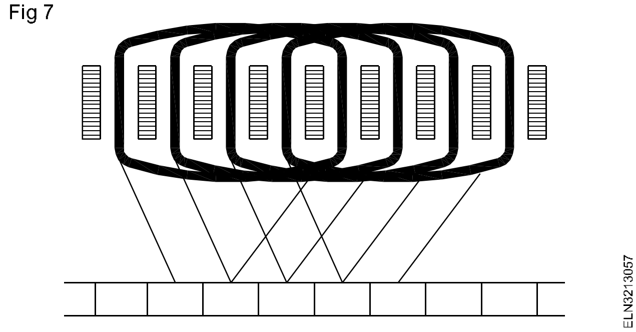


Fig 8

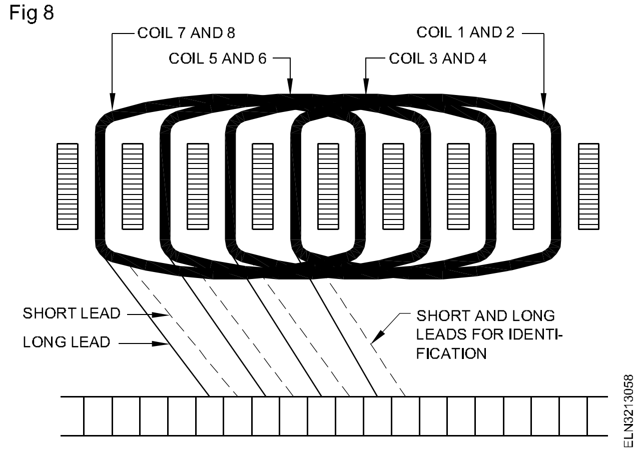
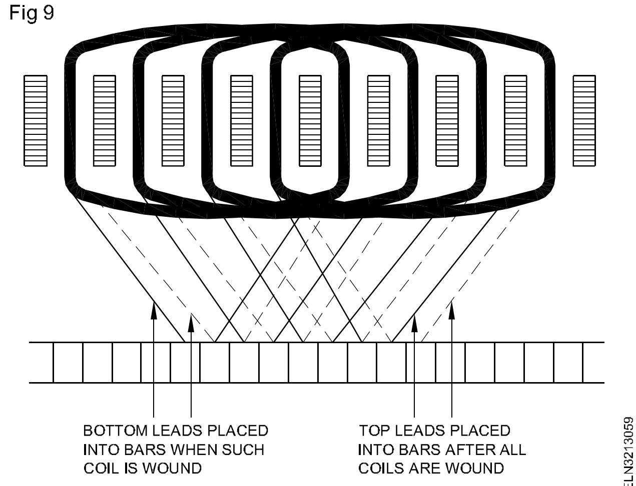


Fig 9



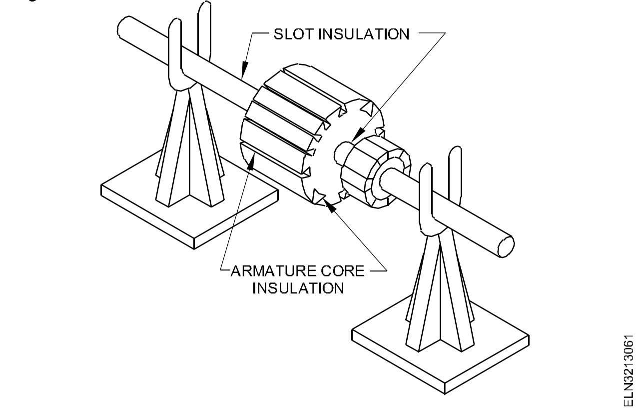
Sleeving of different colours is used for identification of the leads. One colour is used for the beginning and end of the first coil and another colour for the second coil in the same slot, the third coil uses the same colour as the first and so on. It will be necessary to test the first top lead and 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



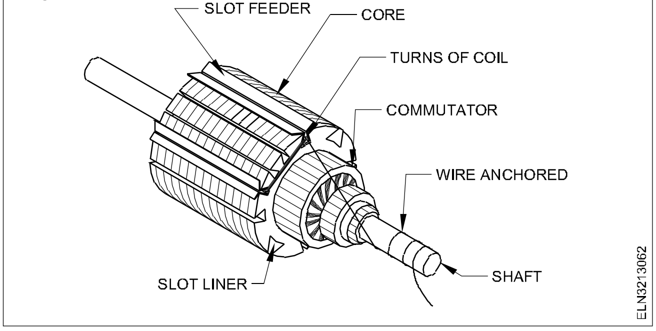
Winding methods : There are two methods of winding the armature.

Hand winding

Formed coil winding

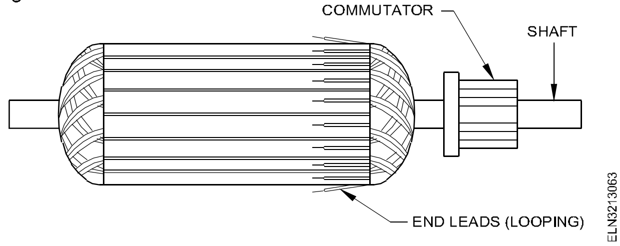
Hand winding : For hand winding, four numbers of slot feeders are placed in the two designated slots at a distance from the coil pitch. The required number of turns are wound into the slots, say slots Nos.1 and 4 as in Fig 2. Enough tension is applied on the wire to make a tight winding without breaking 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.

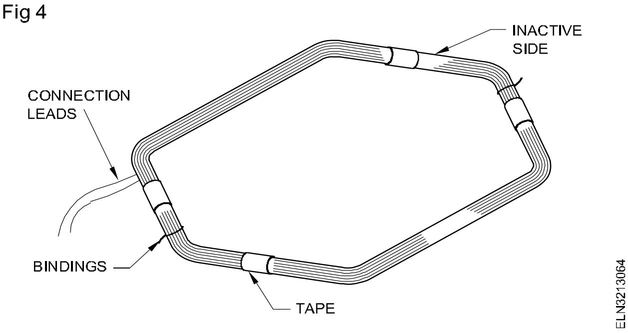
Fig 3



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

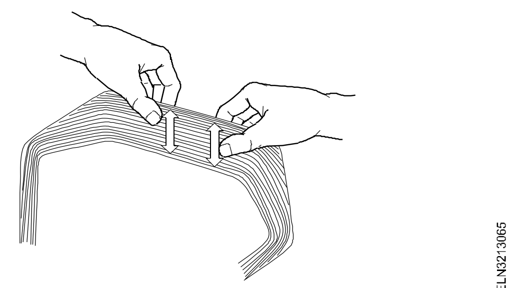
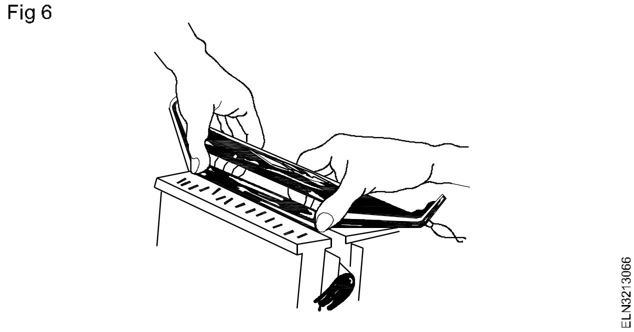


Fig 6

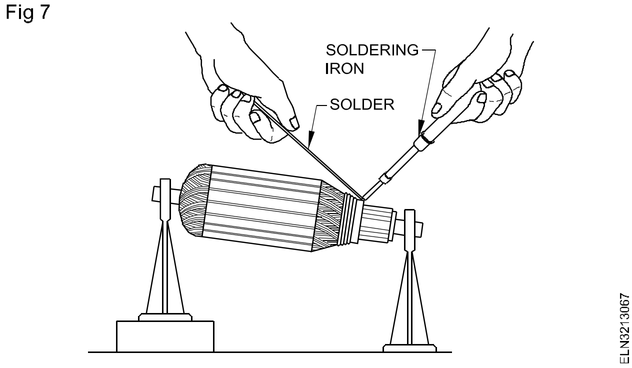


Connection of winding ends with the commutator segments : After winding the armature, the end leads of the armature conductors are placed in the slits of the commutator raisers. (Raiser slits should be properly cleaned and well prepared to receive the conductors.) For secure and good electrical contact, 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.

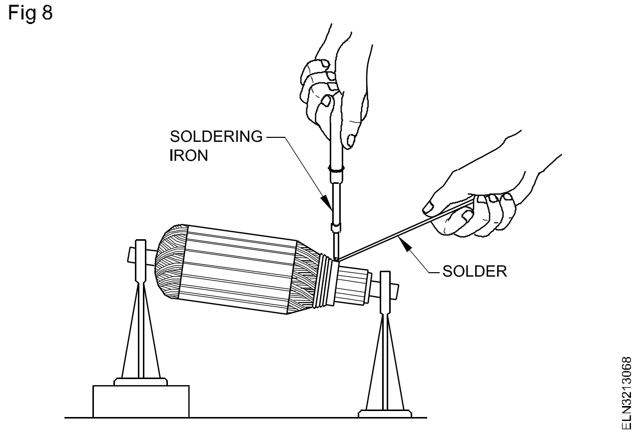
Fig 7



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



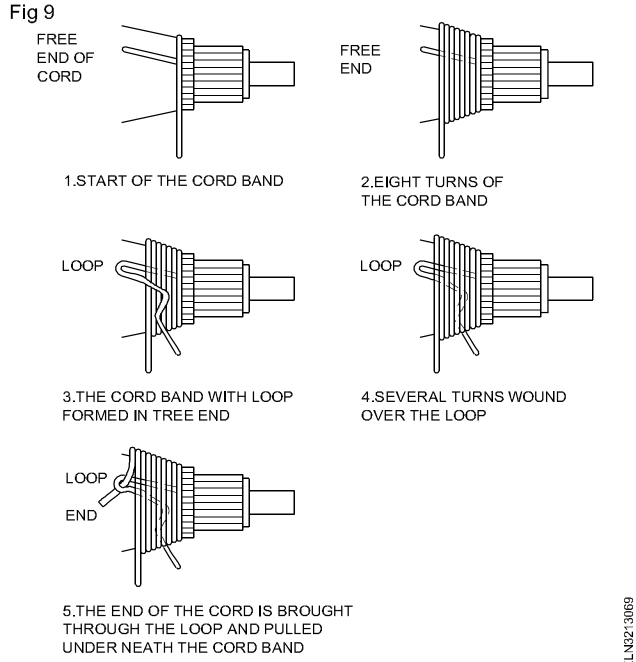
Hot stacking : In the case of small DC armatures, the armature conductors are kept in the commutator raiser slits and spot-welded. This is called hot stacking. A specially designed hot-stacking machine is available for this purpose.

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.

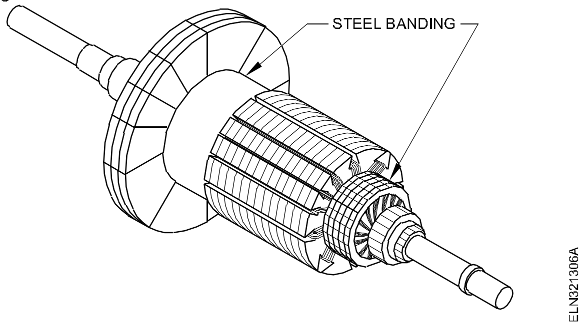
Fig 9



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.

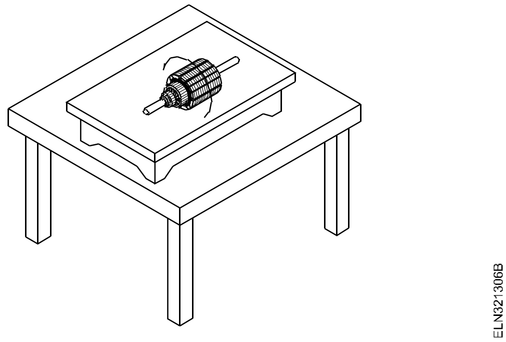
Importance of balancing the armature : The armature used in mixers/liquidizers runs at 3000 to 6000 r.p.m. depending on the load. As such these armatures should have equal weight in all directions. The causes of unbalance in weight are given below :

- 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.

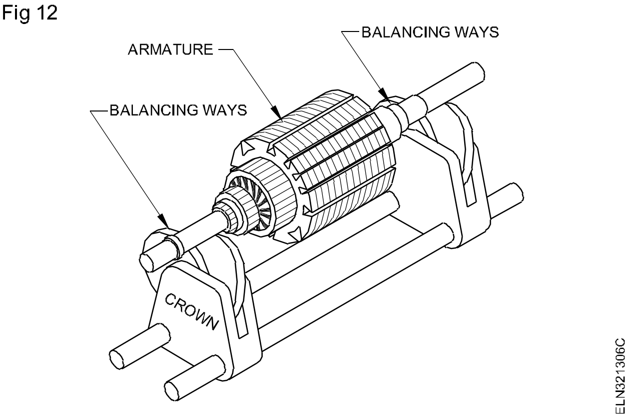
To avoid such unbalanced condition, the armature winder should see to it the causes of unbalancing are removed at the time of winding itself.

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

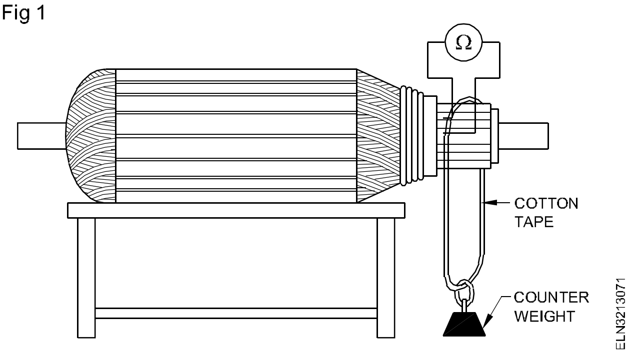
Objectives: At the end of this lesson you shall be able to
- **describe the methods of testing armature, such as the**
  - **– winding resistance test**
  - **– insulation resistance test**
  - **– growler test**
  - **– voltage drop test.**

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.

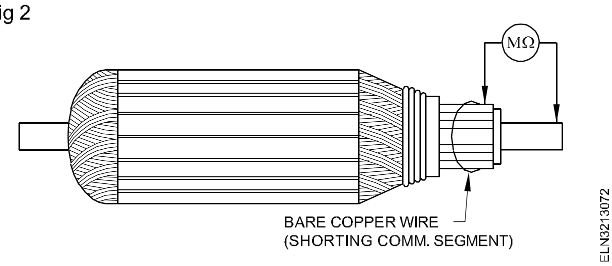
Fig 1



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

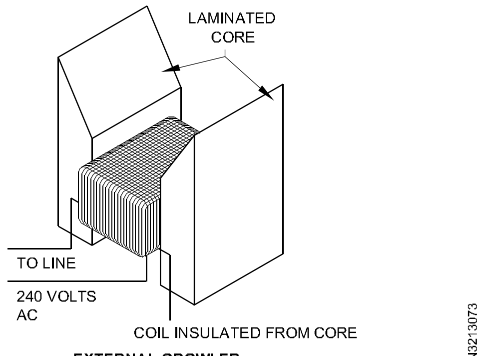


Growler test : A simple and most common method to test armature winding for short and open coils is by a growler.

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.

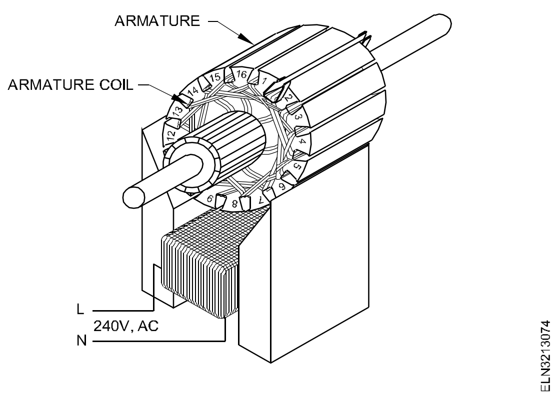
Fig 3



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.

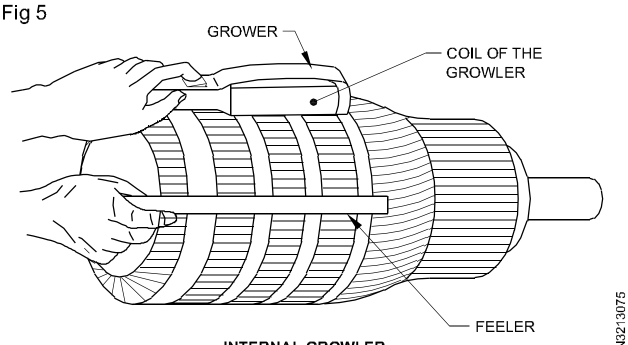
Fig 4



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.

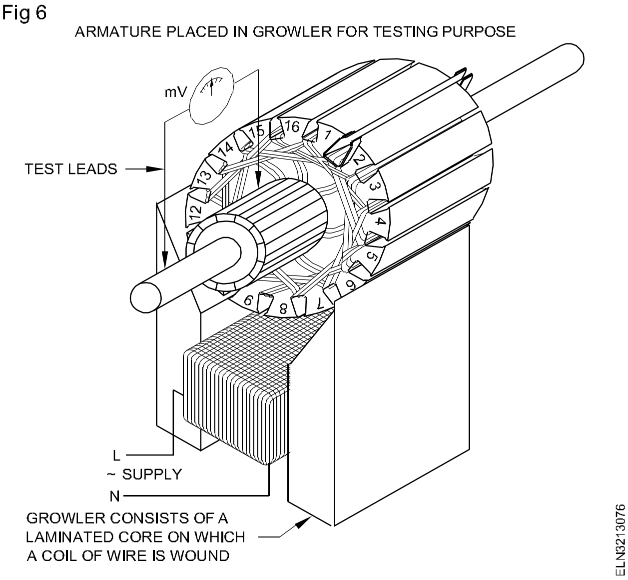
Fig 5



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

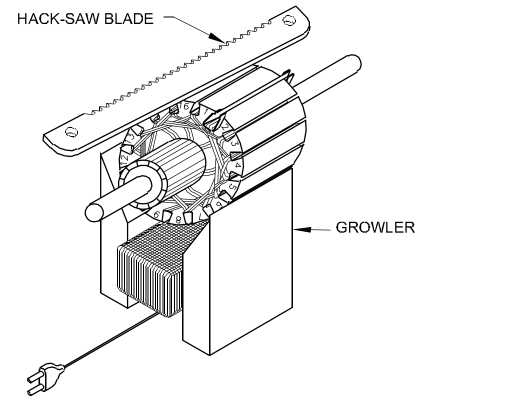


If a reading is noticed on the meter, turn the armature so that the next commutator bar is in the same position as the earlier one, and test as before. Continue in this manner until all the bars are tested. Where the meter gives no deflection, it is an indication that the grounded coil is connected to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

Fig 7

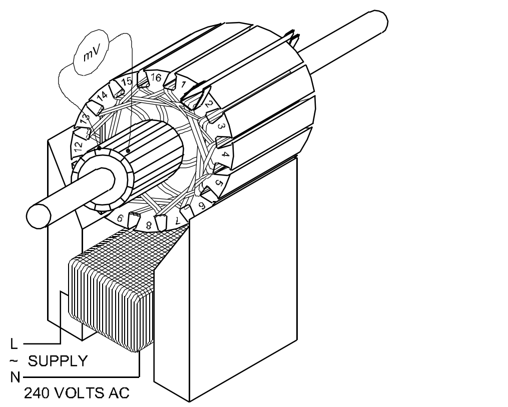


An armature having cross connections or equalizers cannot be given the hacksaw blade test. This type of armature will cause the blade to vibrate at every slot, which would seem to indicate that possibly every coil is shorted.

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.

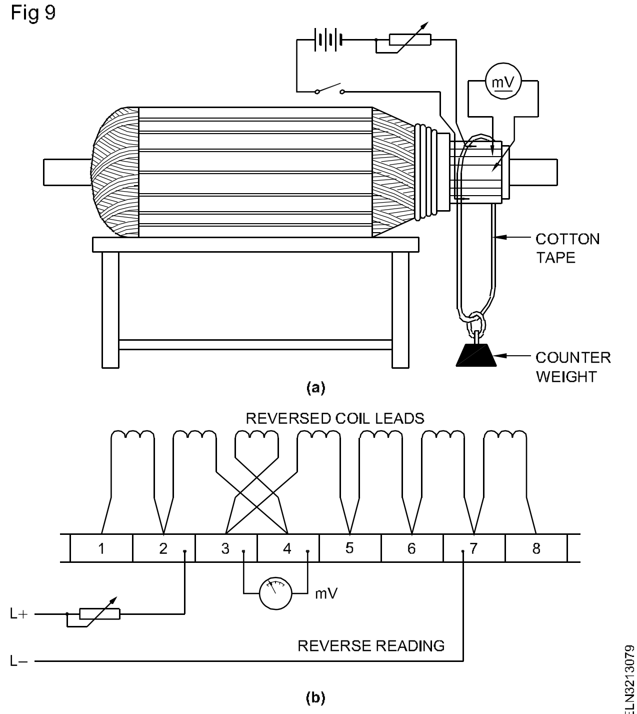
Growler test for an open coil : To locate an open coil with a growler, set up the armature on the growler in the usual manner. Test the top two adjacent bars with an AC milli-voltmeter as shown in Fig 8. Rotate the armature and continue testing the adjacent bars. When the milli-voltmeter bridges the 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.

Fig 8



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.

Fig 9



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.