# SYLLABUS

**Third Semester** **Duration: Six Month**

| Week No. | Ref. Learning Outcome | Professional Skills(Trade Practical) with Indicative hours | Professional Knowledge (Trade Theory) |
|---|---|---|---|
| 53 - 54 | • Plan, Execute commis-sioning and evaluate performance of DC machines | 115. Identify terminals, parts and connections of different types of DC machines. (10 Hrs)<br>116. Measure field and armature resistance of DC machines. (10 Hrs)<br>117. Determine build up voltage of DC shunt generator with varying field excitation and performance analysis on load. (15 Hrs)<br>118. Test for continuity and insulation resistance of DC machine. (5 Hrs)<br>119. Start, run and reverse direction of rotation of DC series, shunt and compound motors. (10 Hrs) | General concept of rotating electrical machines.<br>Principle of DC generator.<br>Use of Armature, Field Coil, Polarity, Yoke, Cooling Fan, Commutator, slip ring and Brushes, Laminated core etc.<br>E.M.F. equation<br>Separately excited and self excited generators.<br>Series, shunt and compound generators |
| 55 - 56 | • Plan, Execute commissioning and evaluate performance of DC machines.<br>• Execute testing, and maintenanceof DC machines and motor starters | 120. Perform no load and load test and determine characteristics of series and shunt generators. (12 Hrs)<br>121. Perform no load and load test and determine characteristics of compound generators (cumulative and differential). (13 Hrs)<br>122. Practice dismantling and assembling in DC shunt motor. (12 Hrs)<br>123. Practice dismantling and assembling in DC compound generator. (13 Hrs) | Armature reaction,<br>Commutation, inter poles and connection of inter poles.<br>Parallel Operation of DC Generators.<br>Load characteristics of DC generators.<br>Application, losses & efficiency of DC Generators.<br>Routine & maintenance |
| 57 - 58 | • Plan, Execute commissioning and evaluate performance of DC machines.<br>• Execute testing, and maintenance of DC machines and motor starters | 124. Conduct performance analysis of DC series, shunt and compound motors. (15 Hrs)<br>125. Dismantle and identify parts of three point and four point DC motor starters. (10 Hrs)<br>126. Assemble, Service and repair three point and four point DC motor starters. (15 Hrs) | Principle and types of DC motor.<br>Relation between applied voltage back e.m.f., armature voltage drop, speed and flux of DC motor.<br>DC motor Starters, relation between torque, flux and armature current.<br>Changing the direction of rotation. |

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| | | 127. Practice maintenance of carbon brushes, brush holders, Commutator and slip-rings. (10 Hrs) | Characteristics, Losses & Efficiency of DC motors.<br>Routine and maintenance |
| 59 - 60 | • Execute testing, and maintenance of DC machines and motor starters.<br>• Distinguish, organise and perform motor winding | 128. Perform speed control of DC motors - field and armature control method. (10 Hrs)<br>129. Carry out overhauling of DC machines. (15 Hrs)<br>130. Perform DC machine winding by developing connection diagram, test on growler and assemble. (25 Hrs) | Methods of speed control of DC motors.<br>Lap and wave winding and related terms |
| 61 - 62 | • Plan, Execute commissioning and evaluate performance of AC motors.<br>• Execute testing, and maintenanceof AC motors and starters | 131. Identify parts and terminals of three phase AC motors. (5 Hrs)<br>132. Make an internal connection of automatic star-delta starter with three contactors. (10 Hrs)<br>133. Connect, start and run three phase induction motors by using DOL, stardelta and auto-transformer starters. (20 Hrs)<br>134. Connect, start, run and reverse direction of rotation of slip-ring motor through rotor resistance starter and determine performance characteristic. (15 Hrs) | Working principle of three phase induction motor.<br>Squirrel Cage Induction motor,<br>Slip-ring induction motor; construction, characteristics, Slip and Torque.<br>Different types of starters for three phase induction motors, its necessity, basic contactor circuit, parts and their functions |
| 63 - 64 | • Plan, Execute commissioning and evaluate performance of AC motors.<br>• Execute testing, and maintenance of AC motors and starters | 135. Determine the efficiency of squirrel cage induction motor by brake test. (8 Hrs)<br>136. Determine the efficiency of three phase squirrel cage induction motor by no load test and blocked rotor test. (8 Hrs)<br>137. Measure slip and power factor to draw speedtorque (slip/torque) characteristics. (14 Hrs)<br>138. Test for continuity and insulation resistance of three phase induction motors. (5 Hrs) | Single phasing prevention.<br>No load test and blocked rotor test of induction motor.<br>Losses & efficiency.<br>Various methods of speed control.<br>Braking system of motor.<br>Maintenance and repair |

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|  |  | 139. Perform speed control of three phase induction motors by various methods like rheostatic control, autotransformer etc. (15 Hrs) |  |
| 65 | • Distinguish organise and perform motor winding | 140. Perform winding of three phase AC motor by developing connection diagram, test and assemble. (20 Hrs)<br>141. Maintain, service and troubleshoot the AC motor starter. (05 Hrs) | Concentric/ distributed, single/ double layer winding and related terms |
| 66 - 67 | • Plan, Execute commissioning and evaluate performance of AC motors.<br>• Execute testing, and maintenance of AC motors and starters | 142. Identify parts and terminals of different types of single phase AC motors.(5 Hrs)<br>143. Install, connect and determine performance single phase AC motors.(15 Hrs)<br>144. Start, run and reverse the direction of rotation of single phase AC motors.(10 Hrs)<br>145. Practice on speed control of single phase AC motors.(10 Hrs)<br>146. Compare starting and running winding currents of a capacitor run motor at various loads and measure the speed. (10 Hrs) | Working principle, different method of starting and running of various single phase AC motors.<br>Domestic and industrial applications of different single phase AC motors.<br>Characteristics, losses and efficiency |
| 68 - 69 | • Distinguish organise and perform motor winding | 147. Carry out maintenance, service and repair of single phase AC motors. (10 Hrs)<br>148. Practice on single/double layer and concentric winding for AC motors, testing and assembling. (25 Hrs)<br>149. Connect, start, run and reverse the direction of rotation of universal motor. (10 Hrs)<br>150. Carry out maintenance and servicing of universal motor. (05 Hrs) | Concentric/ distributed, single/ double layer winding and related terms.<br>Troubleshooting of single phase AC induction motors and universal motor |

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| 70 - 71 | • Plan, execute testing, evaluate performance and carry out maintenance of Alternator / MG set.<br>• Execute parallel operation of alternators | 151. Install an alternator, identify parts and terminals of alternator. (10 Hrs)<br>152. Test for continuity and insulation resistance of alternator. (5 Hrs)<br>153. Connect, start and run an alternator and build up the voltage. (10 Hrs)<br>154. Determine the load performance and voltage regulation of three phase alternator. (10 Hrs)<br>155. Parallel operation and synchronization of three phase alternators. (15 Hrs) | Principle of alternator, e.m.f. equation, relation between poles, speed and frequency.<br>Types and construction.<br>Efficiency, characteristics, regulation, phase sequence and parallel operation.<br>Effect of changing the field excitation and power factor correction |
| 72 | • Plan, execute testing, evaluate performance and carry out maintenance of Alternator / MG set | 156. Install a synchronous motor, identify its parts and terminals. (10 Hrs)<br>157. Connect, start and plot Vcurves for synchronous motor under different excitation and load conditions. (15 Hrs) | Working principle of synchronous motor.<br>Effect of change of excitation and load.<br>V and anti V curve.<br>Power factor improvement |
| 73 | • Plan, execute testing, evaluate performance and carry out maintenanceof Alternator / MG set | 158. Identify parts and terminals of MG set. (5 Hrs)<br>159. Start and load MG set with 3 phase induction motor coupled to DC shunt generator. (20 Hrs) | Rotary Converter, MG Set description and Maintenance |
| 74 - 75 |  | Project work/Industrial visit (optional)<br>Broad Areas:<br>a) Phase sequence checker for 3 phase supply<br>b) Induction motor protection system<br>c) Motor starters with protection<br>d) Solar/wind power generation |  |
| 76 - 77 |  | Revision |  |
| 78 |  | Examination |  |

# DC generator - principle - parts - types - function - e.m.f. equation

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

- **state the general concepts of rotating electrical machine**
- **state the principle of the DC generator**
- **explain the faraday's of laws of electro magnetic induction**
- **explain the production of dynamically induced e.m.f., its magnitude and direction**
- **describe the parts of a DC generator and their function**
- **classify and identify the different type of generators and their terminal markings**
- **explain the armature circuit resistance and its relation**
- **derive the emf equation and calculation of a DC generator**
- **explain about separately excited DC generator with different types of windings.**

## General concept of rotating electrical machine

In rotating machines, there are two parts, the stator and rotor. Rotating electrical machines are also of two types - DC and AC machines. Electrical machines are widely used. In DC machines the stator is used as a field and the rotor is used as an armature, while reverse is the case for AC machines. That is synchronous generators and synchronous motors. The induction motor is another kind of AC machine, which is singly excited; that is AC supply voltage is only given to the stator and no supply is given to the rotor. In DC machines and synchronous machines, the field is always excited.

**Generator**:An electrical generator is a machine which converts mechanical energy into electrical energy.

**Principle of the generator**:To facilitate this energy conversion, the generator works on the principle of Faraday's Laws of Electromagnetic Induction.

**Faraday's Laws of Electromagnetic Induction**: There are two laws.

**The first law states:**

**First law:** Whenever the flux linking to a conductor or circuit changes, an emf will be induced.

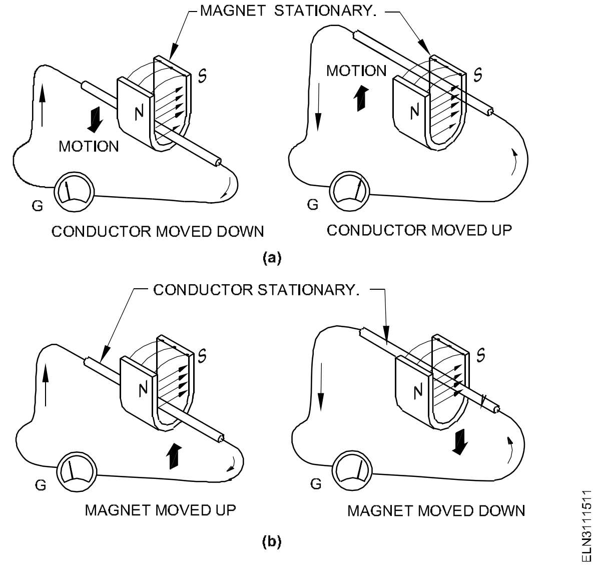
**The second law states:** The magnitude of such induced emf depends upon the rate of change of the flux linkage.

$$\text{emf} \propto \frac{\text{Change of flux}}{\text{Time taken for change}}.$$

**Types of emf**: According to Faraday's Laws, an emf can be induced, either by the relative movement of the conductor and the magnetic field or by the change of flux linking on a stationary conductor.

**Dynamically induced emf**: In case, the induced emf is due to the movement of the conductor in a stationary magnetic field as shown in Fig 1a or by the movement of the magnetic field on a stationary conductor as shown in Fig 1b, the induced emf is called dynamically induced emf.

Fig 1

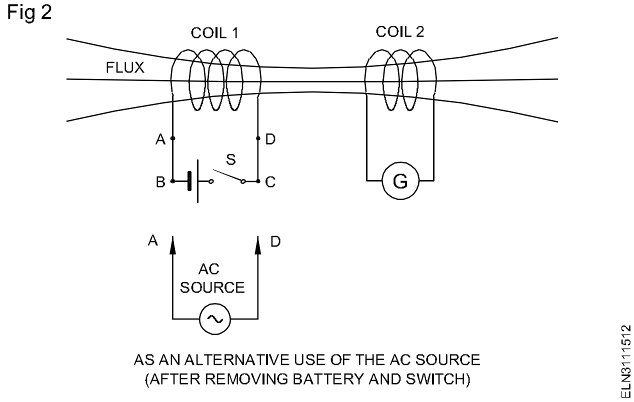


As shown in Figs 1a & 1b, the conductor cuts the lines of force in both cases to induce an emf, and the presence of the emf could be found by the deflection of the needle of the galvanometer `G'. This principle is used in DC and AC generators to produce electricity.

**Statically induced emf**: In case, the induced emf is due to change of flux linkage over a stationary conductor as shown in Fig 2, the emf thus induced is termed as statically induced emf. The coils 1 and 2 shown in Fig 2 are not touching each other, and there is no electrical connection between them.

According to Fig 2, when the battery (DC) supply is used in coil 1, an emf will be induced in coil 2 only at the time of closing or opening of the switch S. If the switch is permanently closed or opened, the flux produced by coil 1 becomes static or zero respectively and no emf will be induced in coil 2. EMF will be induced only when there is a change in flux which happens during the closing or opening of the circuit of coil 1 by the switch in a DC circuit.

Fig 2



Alternatively the battery and switch could be removed and coil 1 can be connected to an AC supply as shown in Fig 2. Then an emf will be induced in coil 2 continuously as long as coil 1 is connected to an AC source which produces alternating magnetic flux in coil 1 and links with coil 2. This principle is used in transformers.

**Production of dynamically induced emf**: Whenever a conductor cuts the magnetic flux, a dynamically induced emf is produced in it. This emf causes a current to flow if the circuit of the conductor is closed.

For producing dynamically induced emf, the requirements are:

- magnetic field
- conductor
- relative motion between the conductor and the magnetic field.

If the conductor moves with a relative velocity 'v' with respect to the field, then the induced emf `E' will be

E = BLV Sin$\theta$ Volts

where

B = magnetic flux density, measured in tesla

L = effective length of the conductor in the field in metres

V = relative velocity between field and conductor in metre/second

$\theta$ = the angle at which the conductor cuts the magnetic field.

Let us consider Fig 3a in which conductors A to I are placed on the periphery of the armature under magnetic poles. Assume for this particular generator shown in Fig 3a, the value of BLV = 100V.

Accordingly the conductor A induces an emf

= BLV Sin $\theta$ where $\theta$ = zero and Sin zero is equal to zero

= 100 x 0 = zero.

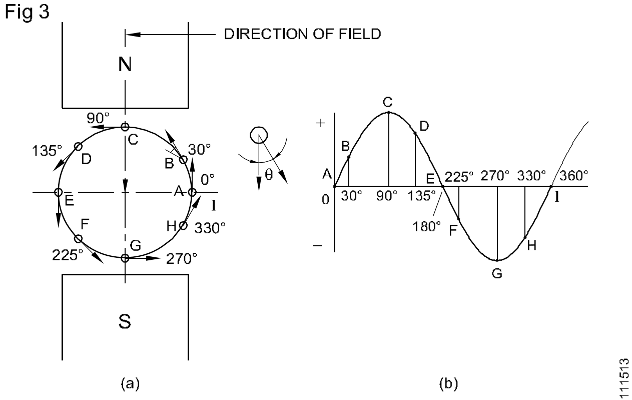
emf induced in

Conductor B = BLV Sin 30°

= 100 x 0.50

= 50 volts.

Fig 3



PRODUCTION OF THE SINEWAVE

emf induced in

Conductor C = BLV Sin 90°

= 100 x 1

= 100 V.

emf induced in

Conductor D = BLV Sin 135°

= BLV Sin 45°

= 100 x 0.707

= 70.7 volts.

emf induced in

Conductor E = BLV Sin 180°

= Sin 180°= 0

= 100 x 0

= zero.

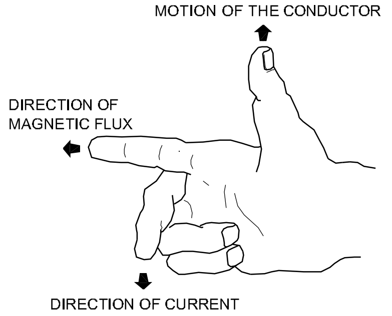
Likewise for every position of the remaining conductors in the periphery, the emf induced could be calculated. If these values are plotted on a graph, it will represent the sine wave pattern of induced emf in a conductor when it rotates under N and S poles of uniform magnetic field.

As in Fig 3b the emf induced by this process is basically alternating in nature, and this alternating current is converted into direct current in a DC generator by the commutator.

**Fleming's right hand rule**: The direction of dynamically induced emf can be identified by this rule. Hold the thumb, forefinger and middle finger of the right hand at right angles to each other as shown in Fig 4 such that the forefinger is in the direction of flux and the thumb is in the direction of the motion of the conductor, then the middle finger indicates the direction of emf induced, i.e. towards the observer or away from the observer.

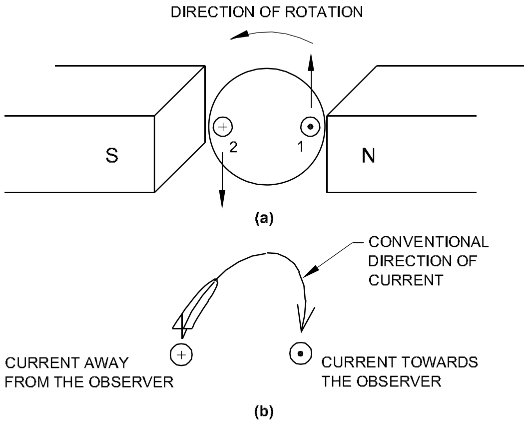
Imagine a conductor moving in between north and south poles in an anticlockwise direction as shown in Fig 5a.

Fig 4



FLEMINGS RIGHT HAND RULE

Fig 5



DIRECTION OF THE INDUCED CURRENT

Applying Fleming's right hand rule, we find that the conductor 1 which is moving upwards under the north pole will induce an emf in the direction towards the observer indicated by the dot sign and the conductor 2 which is moving down under the south pole will induce an emf in the direction away from the observer indicated by the plus sign.

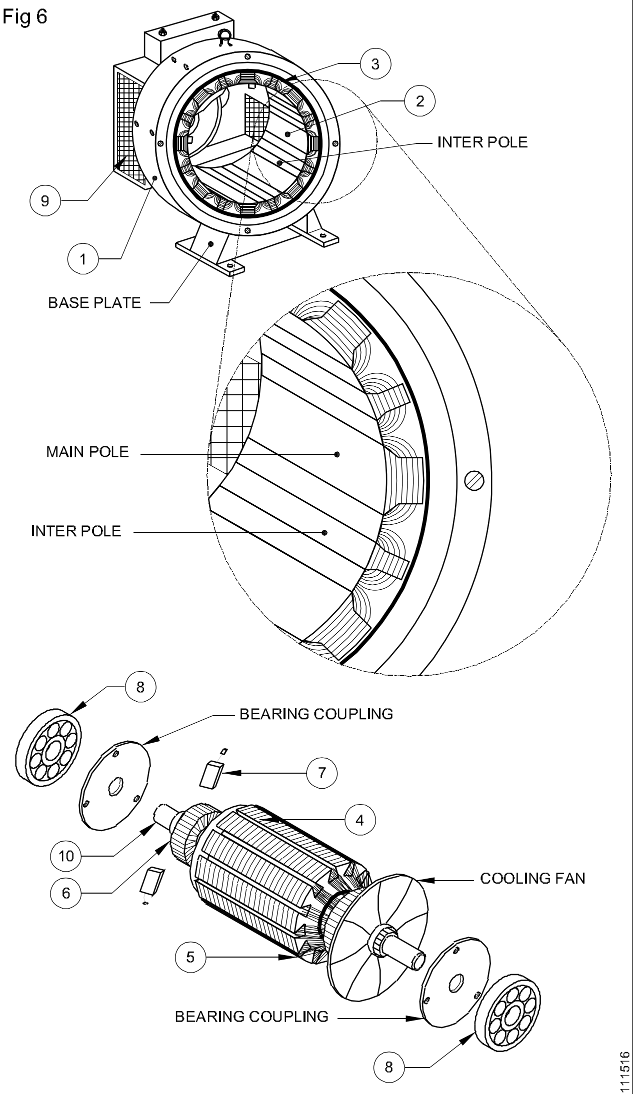
Fig 5b indicates the current direction in the form of an arrow. The dot sign indicates the pointed head of the arrow showing the current direction towards the observer and the plus sign indicates the cross-feather of the arrow showing the current direction away from the observer.

## Parts of DC generator

A DC generator consists of the following essential parts as shown in Fig 6.

1. Frame or yoke
2. Field poles and pole-shoes (Figs 8,9 & 10)
3. Field coils or field winding (Fig 11)
4. Armature core
5. Armature windings or armature conductors
6. Commutator
7. Brushes
8. Bearings and end plates
9. Air filter for fan
10. Shaft

Fig 6



PARTS OF A DC MACHINE

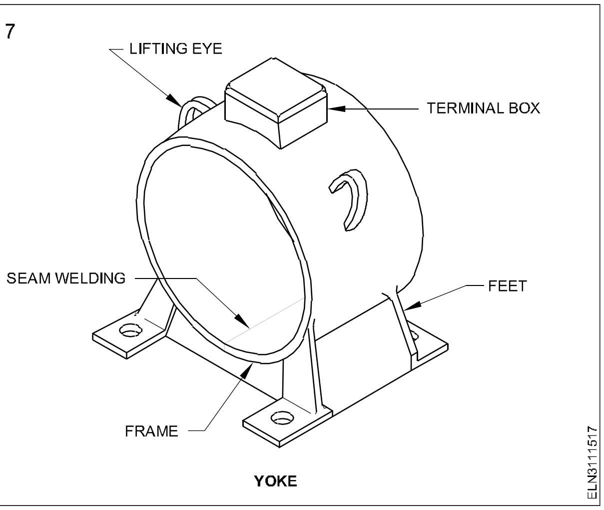
The yoke, the pole cores, the armature core and the air gaps between the poles and the armature core form the magnetic circuit, whereas the armature conductors, field coils, commutators, and brushes form the electrical circuit.

**Yoke**: The outer frame or yoke serves a dual purpose. Firstly, it provides mechanical support for the poles and acts as a protecting cover for the whole machine as shown in Fig 6. Secondly, it allows the magnetic circuit to complete through it.

In small generators where cheapness rather than weight is the main consideration, yokes are made of cast iron. But for large machines usually cast steel or rolled steel is used. The modern process of forming the yoke consists of rolling a steel slab round a cylindrical mandrel, and then welding it at the seams. The feet, the terminal box etc. are welded to the frame afterwards as shown in Fig 7. Such yokes possess sufficient mechanical strength and have high permeability.

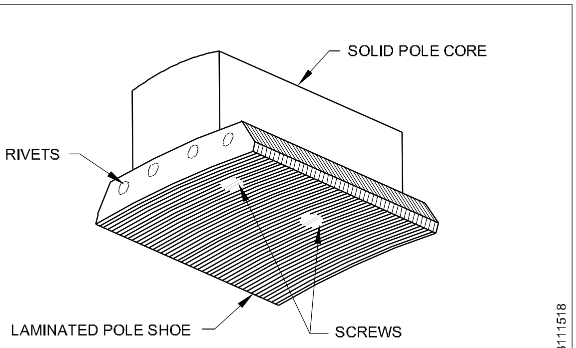
**Poles cores and pole shoes** (Fig 8): The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes; (i) they spread out the flux in the air gap uniformly and also, being of a larger cross-section, reduce the reluctance of the magnetic path, and (ii) they also support the field coils.

Fig 7



YOKE

Fig 8



SEPERATE POLE SHOE BOLTED TO POLE CORE

There are two main types of pole construction.

The pole core itself may be a solid piece made out of either cast iron or cast steel but the pole shoe is laminated and is fastened to the pole face by means of countersunk screws as shown in Fig 8.

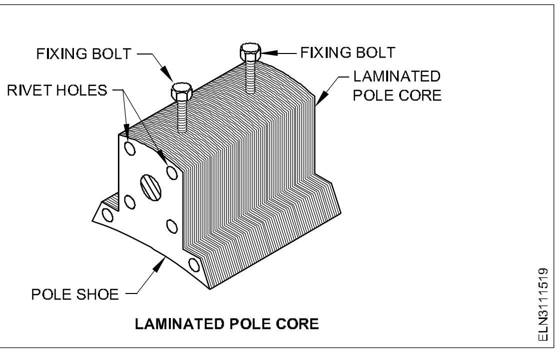
In modern designs, the complete pole cores and pole shoes are built of thin laminations of annealed steel which are riveted together under hydraulic pressure. The thickness of laminations varies from 1mm to 0.25mm. The laminated poles may be secured to the yoke in any of the following two ways.

Either the pole is secured to the yoke by means of screws bolted through the yoke and into the pole body as in Fig 9 or holding screws are bolted into a steel bar which passes through the pole across the plane of laminations as in Fig 10.

**Pole coils (Field coils):** The field coils or pole coils, which consist of copper wire or strip are former-wound for the correct dimension. Then the former is removed and the wound coils are put into place over the core as shown in Fig 11.

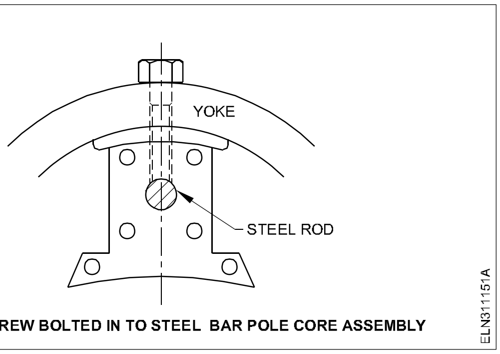
When a current is passed through the coils, they magnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

Fig 9



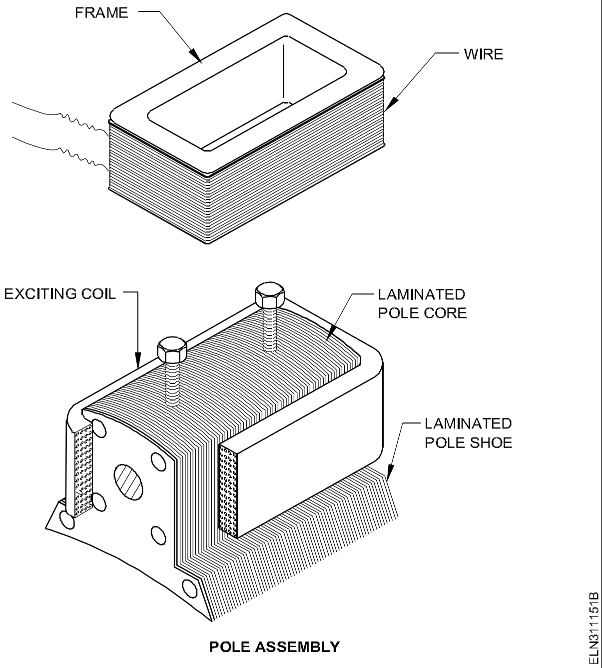
LAMINATED POLE CORE

Fig 10



HOLDING SCREW BOLTED IN TO STEEL BAR POLE CORE ASSEMBLY

Fig 11



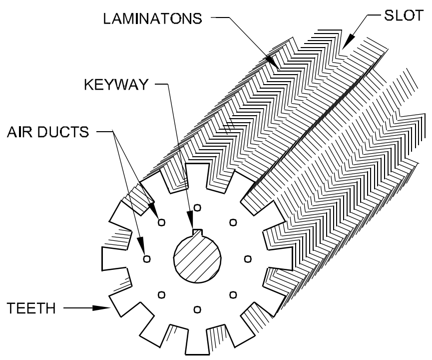
POLE ASSEMBLY

Both thick gauge wire winding (series) and thin gauge winding (shunt) are wound, one over the other with separate insulations, and the terminals are brought out separately.

**Armature core**: The armature core houses the armature conductors and rotate in the magnetic field so as to make the conductors to cut the magnetic flux. In addition to this, its most important function is to provide a path of very low reluctance to the field flux, thereby allowing the magnetic circuit to complete through the yoke and the poles.

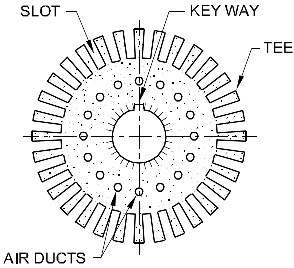
The armature core is cylindrical or drum-shaped as shown in Fig 12, and build up of circular sheet steel discs or laminations approximately 0.5mm thick as shown in Fig 13.

Fig 12



ARMATURE CORE MADE OF LAMINATION

Fig 13



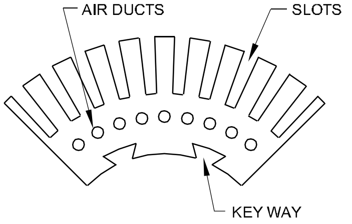
ARMATURE CORE LAMINATIONS

The slots are either die-cut or punched on the outer periphery of the disc and the keyway is located on the inner diameter as shown. In small machines, the armature stampings are keyed directly to the shaft. Usually these laminations are perforated for air ducts which permit axial flow of air through the armature for cooling purposes. Such ventilating holes are clearly visible in the laminations shown in Figs 12,13 and 14.

Up to armature diameters of about one metre, the circular stampings are cut out in one piece as shown in Fig 13. But above this size, these circles, especially of very thin sections, are difficult to handle because they tend to distort and become wavy when assembled together. Hence, the circular laminations, instead of being cut out in one piece, are cut in a number of suitable sections of segments which form part of a complete ring.

A complete circular lamination is made up of four or six or even eight segmental laminations. Usually, two keyways are notched in each segment and are dovetailed or wedge-shaped to make the laminations self-locking in position as shown in Fig 14.

Fig 14



SEGMENTAL LAMINATION

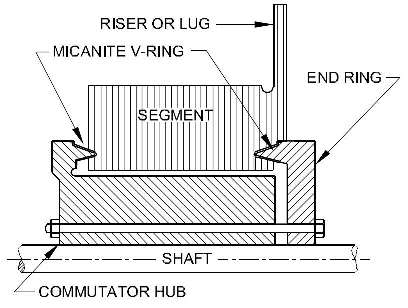
The purpose of using lamination is to reduce the loss due to eddy currents. Thinner the laminations are, greater the resistance offered against eddy current loss.

**Armature windings**: The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape with a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots which are lined with tough insulating material. After placing the conductors in the slot, this slot insulation is folded over the armature conductors, and is secured in place by special, hard, wooden or fibre wedges.

**Commutator**: The function of the commutator is to facilitate collection of current from the armature conductors. It rectifies i.e. converts the alternating current induced in the armature conductors into uni-directional current for the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high conductivity, hard-drawn or drop-forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils.

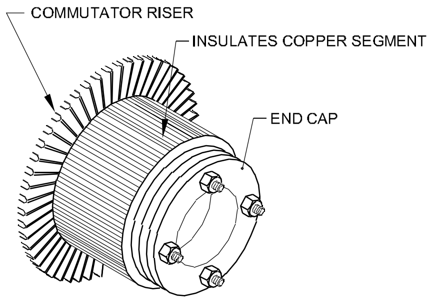
Each commutator segment is connected to the armature conductor by means of a copper lug or riser. To prevent them from flying out under the action of centrifugal forces, the segments have V-grooves, these grooves being insulated by conical micanite rings. A sectional view of a commutator is shown in Fig 15, whose general appearance when assembled is shown in Fig 16.

Fig 15



SECTIONAL VIEW OF COMMUTATOR

Fig 16

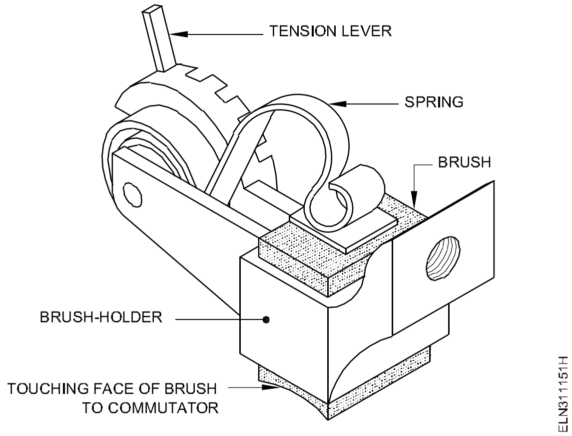


COMPLETE ASSEMBLY OF COMMUTATOR

**Brushes**: The brushes whose function is to collect current from the commutator are usually made of carbon and graphite and are in the shape of a rectangular block.

These brushes are housed in brush-holders, shown in Fig 17, which have a box-holder for the brush, a spring to maintain the brush tension and a hole to fix the holder to the rocker arm. The brushes can slide in the rectangular box, open at both ends. The brushes are made to bear down on the commutator by a spring whose tension can be adjusted by changing the position of the tension lever in the notches. A flexible, copper pigtail mounted at the top of the brush conveys the current from the brushes to the holder. The number of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

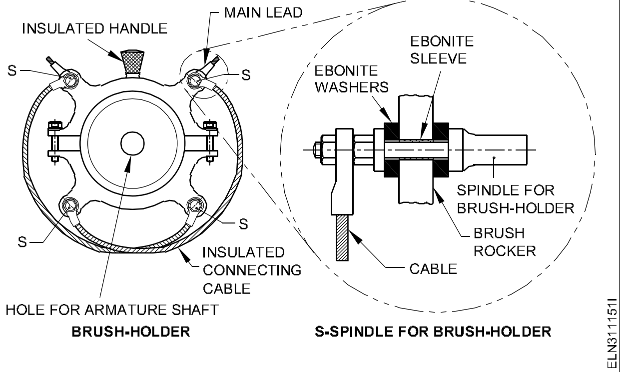
Fig 17



**Brush-rocker:** The spindle is used to have a number of brushes connected in a large machine. There may be only two brushes for a small machine. All the spindles are insulated and attached to the brush rocker.

The brush-rocker may either be supported by a bearing cover in a small machine or by brackets attached to the yoke as shown in Fig 18. The brush position to the neutral axis can be set by changing the position of the brush-rocker.

Fig 18



**Bearings** (Fig 19): Because of their reliability, half-bearings are frequently employed, though for heavy duties roller bearings are preferable. The ball and rollers are generally filled with hard oil for quieter operation and for reduced bearing wear. When sleeve bearings are used, these are lubricated by ring oilers fed from an oil reservoir in the bearing bracket.

**End plates** (Fig 20): The bearings are housed in these end plates, and they are fixed to the yoke. They help the armature for frictionless rotation and to position the armature in the air gap of the field poles.

Fig 19

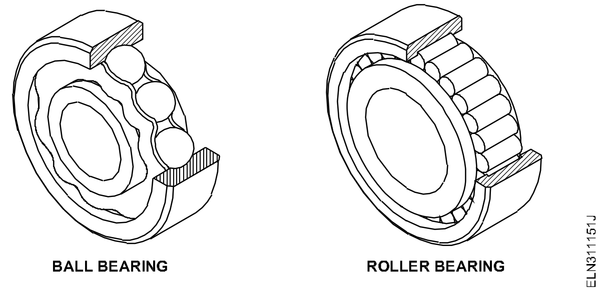
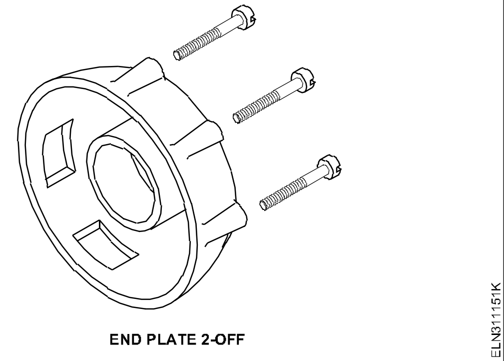


Fig 20

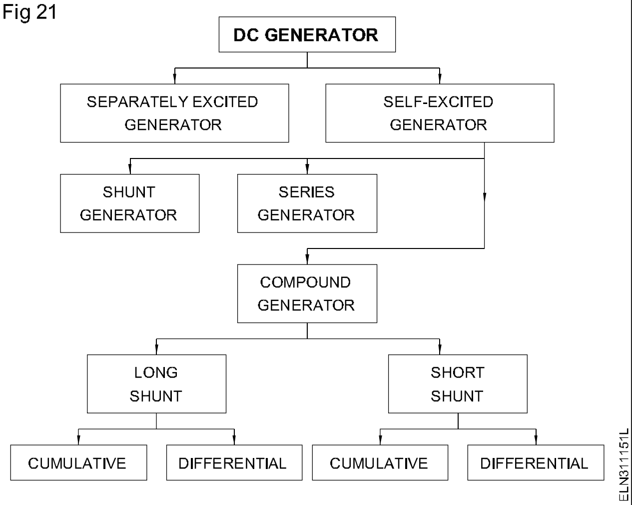


## Cooling fan

DC Machines are often selected based upon a particular work or load requirement. In most cases, heat dissipation is achieved through a cooling fan fitted on the DC Machine shaft. Another method to remove heat from DC machine is by providing forced air cooling. This is commonly done by providing an electric fan externally to blow air over the DC machine. Forced air cooling can reduce the amount of heat transferred into the machine structure and allow the machine to be operated at a higher load.

**Types of DC generators**: The type of a DC generator is determined by the manner in which the field excitation is provided. In general, the methods employed to connect the field and armature windings, fall into the following groups.(Fig 21)

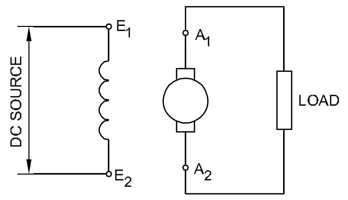
Fig 21



**Separately excited generator**: The field excitation for a separately excited generator, shown in Fig 22, is supplied from an independent source, such as storage battery, separate DC generator or rectified DC supply from an AC source.

The field excitation voltage may be the same as that of generated (armature) voltage or may differ. Generally, the excitation voltage will be of low voltage, say 24, 36 or 48V DC.

Fig 22

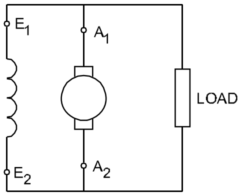


CONNECTION DIAGRAM OF SEPARATELY EXCITED DC GENERATOR

**Self-excited generator**: The field excitation is provided by its own armature. In this type of generators, initially the voltage is built up by residual magnetism retained in the field poles. Self-excited generators may be further classified as shunt, series and compound generators.

**Shunt generator:** The field winding is connected to the armature terminals as shown in Fig 23. (i.e. shunt field winding is connected in parallel with armature winding). The shunt field contains many turns of relatively fine wire and carries a comparatively small current only which is a small percentage of the rated current of the generator.

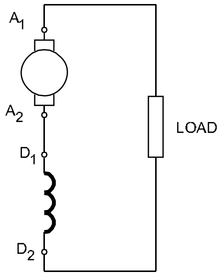
Fig 23



SHUNT GENERATOR

**Series generator:** The field winding is connected in series with the armature winding as shown in Fig 24. The series field winding has a few turns of heavy wire. Since it is in series with the armature it carries the load current.

Fig 24

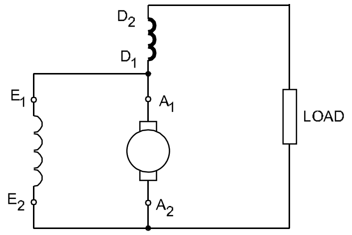


SERIES GENERATOR

**Compound generator:** The field excitation is provided by a combination of shunt and series field windings.

**Short-shunt compound generator:** This is a generator in which the shunt field is directly across the armature as shown in Fig 25.

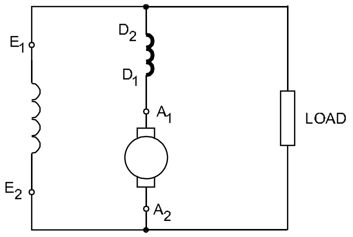
Fig 25



SHORT SHUNT COMPOUND GENERATOR

**Long-shunt compound generator:** This is a generator in which the shunt field is connected after the series field as shown in Fig 26.

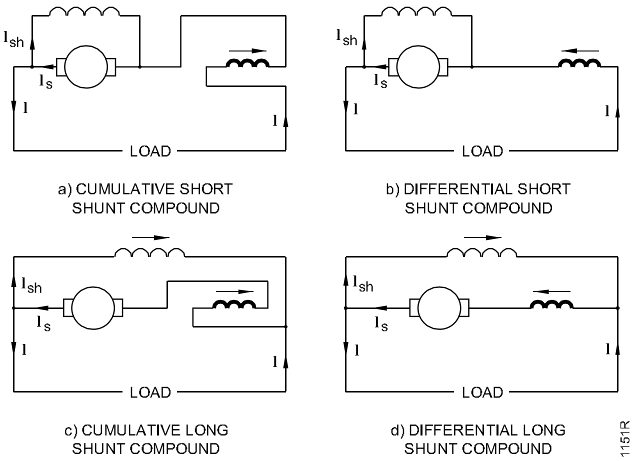
Fig 26



LONG SHUNT COMPOUND GENERATOR

**Differential and cumulative compound generator:** The compound generators can also be further classified as cumulative and differential. In cumulative compound generators the magnetising forces of the shunt and the series field ampere-turns are cumulative, i.e. they both tend to set up flux in the air gap in the same direction. However, in case the ampere turns of the shunt widning oppose those of the series winding, the machine is said to be differentially compound wound generator. Both the types are shown in Fig 27.

Fig 27



a) CUMULATIVE SHORT SHUNT COMPOUND

b) DIFFERENTIAL SHORT SHUNT COMPOUND

c) CUMULATIVE LONG SHUNT COMPOUND

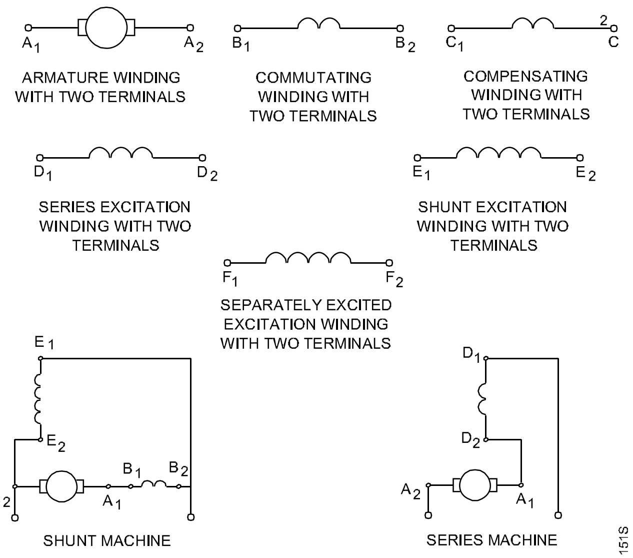
d) DIFFERENTIAL LONG SHUNT COMPOUND

TYPES OF DC COMPOUND GENERATORS

**Terminal markings** : As per BIS 4718-1975 the terminal markings for DC commutator machines shall be according to the marking principles stated below.

- Windings are distinguished by capital letters.
- End points and intermediate points of windings are distinguished by a numerical suffix.
- Winding letters for DC windings are chosen from the earlier part of the alphabet.(Fig 28)

Fig 28



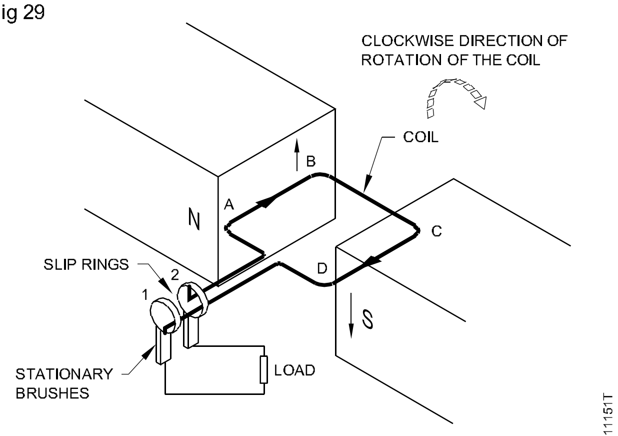
TERMINAL MARKING OF DC MACHINES AS PER BIS

**Commutator (Split rings)**

A generator produces electrical power with the help of the rotation of a group of conductors in a magnetic field. It uses the principle of electromagnetic induction to convert the input mechanical power into electrical power.

**Slip rings**: Let us consider a simple AC generator having a single loop of wire and rotated within a fixed magnetic field, as shown in Fig 29.

Fig 29



SIMPLE AC GENERATOR

Let each end of the single loop coil be connected to copper or brass rings called slip rings. These slip-rings are insulated from each other, insulated and mounted on the shaft. In a broader sense this rotating assembly (coil,shaft & slip-ring) is called armature. The wire loop (armature coil) is connected to an external circuit by means of two brushes which are positioned to rub against the slip-rings. As the armature is rotated at a uniform angular velocity, the generated voltage in the loop conductor will actually be of alternating voltage.

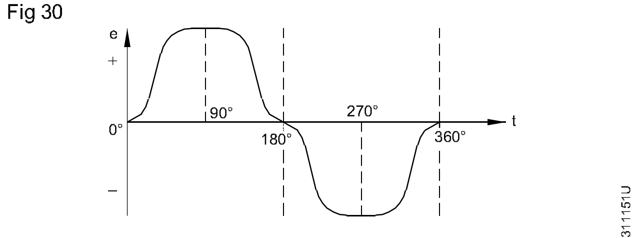
For the clockwise rotation indicated, the direction of generated voltage and the resulting current in the coil side under the north pole will be directed from A to B making the slip-ring 2 negative. This is readily confirmed by using Fleming's right hand rule. Similarly the direction of the induced voltage and the resulting current under the south pole is to be directed from C to D making the slip- ring 1 as positive. When the conductor AB moves from the north pole to the south pole, the direction of induced emf in it will reverse, so that the current will now flow from B to A making the slip-ring 2 positive. At the same time coil side CD has moved into the north pole region and its induced emf is reversed and current will flow from D to C making the slip-ring 1 negative.

Thus for one half of a revolution (for a two-pole generator) the emf is directed around the coils A to B & C to D. For the other half of the revolution the emf is directed around the coil D to C and B to A. The current in the externally connected load resistor via the stationary brushes in contact with the pair of slip rings `1'and `2' will be alternating (AC) in nature.

**Wave-shape of the induced voltage**: When the output voltage is plotted against electrical degrees we get the output wave-form.

The output wave-form obtained across the load, according to the pole shape shown in Fig 29, will not be of sinusoidal shape due to un-uniform magnetic field but of rectangular shape as shown in Fig 30.

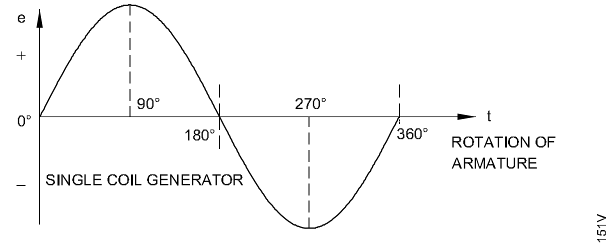
Fig 30



WAVE-FORM SHOWS COIL ROTATES UNDER UN-UNIFORM MAGNETIC FIELD

However, if the magnetic field is uniform, the output wave-form will be of sinusoidal shape as shown in Fig 31.

Fig 31



WAVE-FORM SHOWS COIL ROTATES UNDER UNIFORM MAGNETIC FIELD (SINE WAVE)

**Simple generator with split-rings**: A direct current generator is simply an AC generator provided with split rings instead of slip-rings.

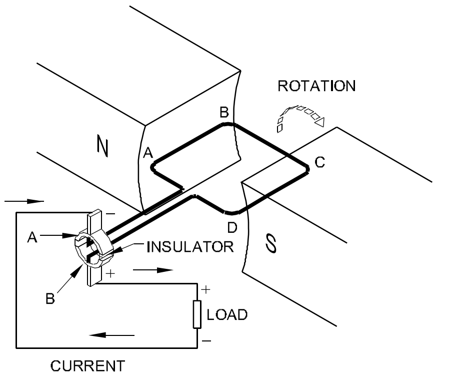
The split ring is a ring made up of hard drawn copper cut into two segments, insulated from each other and the shaft in which it is mounted. A commercial generator uses a number of split rings called commutators. The split ring is a device for reversing the brush contact with the armature coil terminals, every time the induced current in the coil reverses, so that the output current taken by the brushes remains always in the same direction.

As shown in Fig 32a, if the armature rotates clockwise the split ring rotates with it, and the brushes and the poles are stationary in their position. As shown in Fig 4a, when the moving coil is in the horizontal position, the induced current will flow through the coil from ABCD to the segment `B' via the positive brush and load to the negative brush and segment A. The direction of current flow in the external circuit is shown in Figures 32a and 32c.

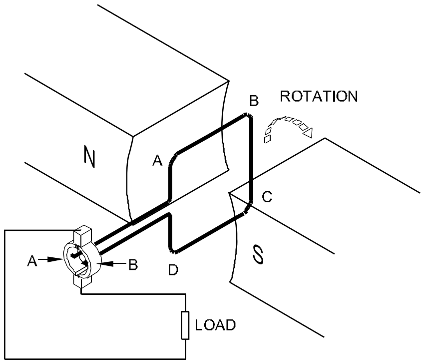
When the armature rotates so that the coil just assumes a vertical position as in Fig 32b, the brushes will short-circuit both the segments. The induced emf is zero and no current flows through the load circuit for a short moment.

When the armature rotates and the coil assumes the position as indicated in Fig 32c, the coil side AB will enter the south pole region and its induced emf will reverse, compared to the direction it had while moving under the north pole region as shown in Fig 32a.

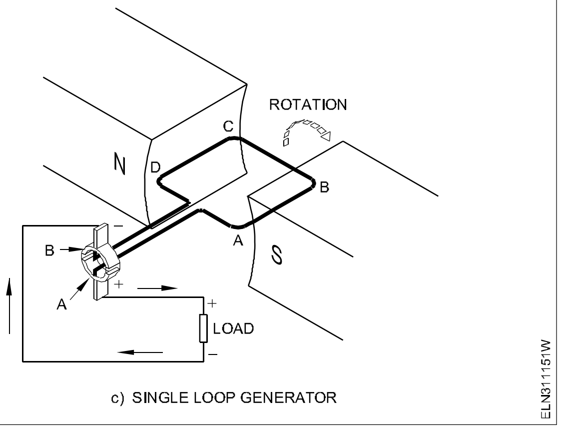
Fig 32



a) SINGLE LOOP GENERATOR



b) SINGLE LOOP GENERATOR



c) SINGLE LOOP GENERATOR

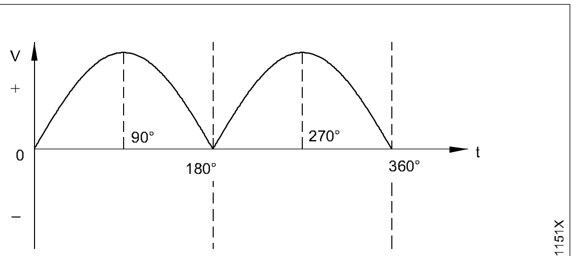
But when this happens the split ring segments `A' and `B' will also have exchanged their positions since they rotate along with the coil.

As the emfs in the coil sides AB and CD reverse their polarity, the split ring segments to which they are connected simultaneously change their positions under the stationary brushes. As a result, the polarity of the brushes remains fixed and the current direction through the load remains as shown in Fig 32c which is the same as shown in Fig 32a.

Figure 33 represents the generated voltage of a simple DC generator. The voltage is uni-directional due to the split ring action.

The induced emf by a single loop (one turn) coil is very small in magnitude and pulsating in nature as shown in Fig 33. Coils, having a number of turns in series, multiply the generated emf by the same number. However to get a steady (DC) current it is necessary to increase the pulses produced in the armature; thereby their average value is constant.

Fig 33



VOLTAGE PRODUCED IN A LOOP UNDER UNIFORM MAGNETIC FIELD

There are two ways to increase the number of pulses during each rotation of the armature.

- Increase the number of field poles.
- Increase the number of separate coils (multi-coil) in the armature.

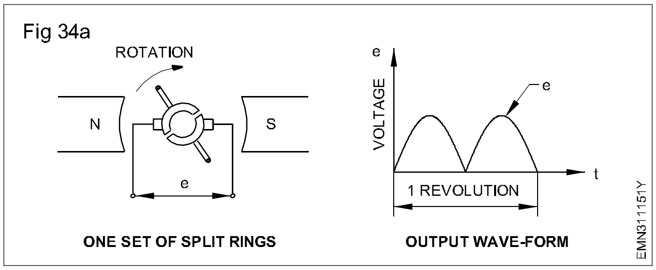
The multi-coils necessitate a multiple segment split-rings which is called a commutator.

Fig 34 represents the generated voltages and their wave shapes when the armature has different number of split rings, i.e. commutator segments. The practical generator will have more number of commutator segments as shown in Fig 34c, and the induced emf will be as shown in the adjoining graph.

### Armature circuit resistance and its relation with different types of windings and brush resistance

**Armature windings** ( Fig 35 Lap winding, Fig 36 wave winding): We have seen earlier, when a single loop conductor is rotated through a magnetic field, an alternating voltage is induced in it. This alternating voltage can be changed into direct voltage (rectified) by the commutator. In practice, there are several coils in the armature, each with a large number of turns laid in the slots of the armature core. This arrangement of the coil is called armature winding. The ends of the coils are soldered to the commutator raisers, depending on the kind of winding i.e. lap or wave, which decides the number of parallel paths in the armature.

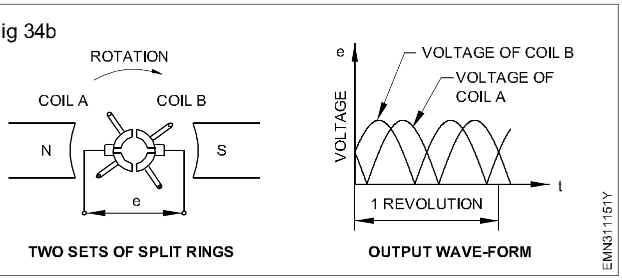
Fig 34a



ONE SET OF SPLIT RINGS

OUTPUT WAVE-FORM

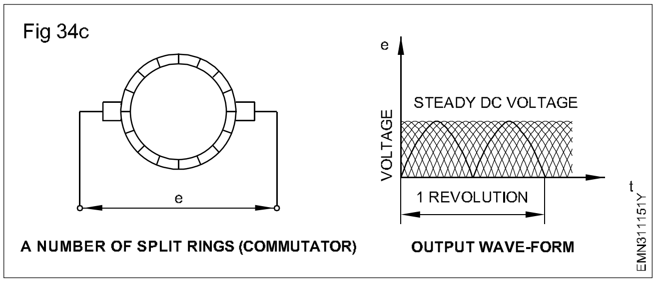
Fig 34b



TWO SETS OF SPLIT RINGS

OUTPUT WAVE-FORM

Fig 34c



A NUMBER OF SPLIT RINGS (COMMUTATOR)

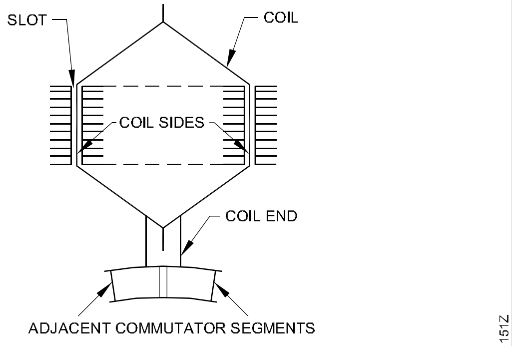
OUTPUT WAVE-FORM

i.e. lap or wave, which decides the numbers of parallel paths in the armature.

A preliminary knowledge about the different types of winding is essential to tackle problems related to the calculation of induced voltage in various types of generators.

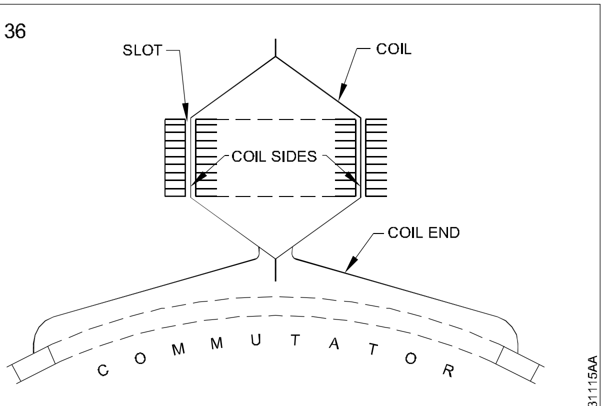
Lap and wave windings could readily be identified by the manner in which the coil ends are connected to the commutator bars. As shown in Fig 35, in a simplex lap winding, the ends of a coil are connected to adjacent commutator segments. Fig 36 shows the simplex wave winding in which the coil ends are connected to the commutator segments almost equal to the distance between poles of the same polarity.

Fig 35



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX LAP WINDING

Fig 36



COIL END CONNECTION TO THE COMMUTATOR OF A SIMPLEX WAVE WINDING

**Table 1 shows the main differences between lap and wave winding.**

Table 1

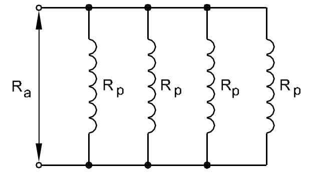
| Lap winding | Wave winding |
|---|---|
| The two ends of each armature coil are connected to adjacent commutator segments in the case of simplex, two segments apart in duplex and three segments apart in triplex. | The two ends of each coil connect to the commutator segments placed between adjacent poles of the same polarity. |
| There are many parallel paths for current as there are field poles in the case of lap winding | There are two parallel paths regardless of the number of field poles in the case of simplex wave winding. |
| No. of parallel paths = Number of poles x plex of the winding | Number of parallel paths in wave windings = 2 x plex of the winding where plex for-simplex is 1, duplex is 2 and triplex is 3. |
| The number of brush positions is equal to the number of poles. | Only two brush positions are required regardless of the number of field poles. |
| Used for machines having low voltage and high current capacity. | Used in machines having low current and high voltage capacity. |

**DC armature circuit - voltage drop and its importance**: One of the major reasons for the drop in voltage at the terminals of a loaded generator is due to armature voltage drop. This depends on the armature circuit resistance and the armature current. A thorough understanding of the armature resistance, apart from helping an electrician to calculate the efficiency of a DC machine, is of great help to check the correctness of the rewind armature without physically checking the number of turns and the size of the winding wire. This is done in all established factories, where a record is maintained to indicate voltage drop across the armature of each DC machine, at a specified armature current. Any variation from this recorded value to the value obtained from the rewind armature (having the same grade of brushes), clearly indicates either the size of the winding wire or the number of turns has changed, and the performance of the machine will not be the same as earlier. Normally armature circuit resistance will be in the order of one ohm or below.

**Voltage drop:** This could be calculated by finding the total resistance of the armature conductors in series per parallel path and dividing it by the number of parallel paths, but in actual practice it is calculated by the voltage drop method.

Refer to the circuit shown in Fig 37.

Fig 37



4-POLE SIMPLEX LAP-WOUND MACHINE WITH 4 PARALLEL PATHS

Let 'r' be the specific resistance of the armature conductors,

'a' be the area of the cross-section of the armature conductor in sq. cm.

'L' be the length of the conductor in cms.

'$R_a$' - armature resistance in ohms.

'$R_p$' - resistance per parallel path in ohms.

**Method of calculating the armature resistance**: Let P be the number of parallel paths in the armature,

Z be the total conductors in armature.

Then the number of conductors per parallel path = Z/P.

Resistance per parallel path $R_p = \frac{Z}{P} \times \frac{\rho L}{a}$

Armature resistance in ohms = $R_a$

$$R_a = \frac{R_P}{\text{No. of parallel paths}}$$

**Example**: In a DC 4-pole lap-wound machine the resistance of one conductor is 0.1 ohm; there are 48 conductors. Calculate the armature resistance.

Since it is lap-wound,

No. of parallel paths=No.of poles (assuming simplex winding).

Therefore, No. of parallel paths = 4.

Conductors per

$$\text{parallel path} = \frac{\text{Total No. of conductors}}{\text{No. of parallel paths}} = \frac{48}{4} = 12.$$

Resistance per parallel path = 12 x 0.1 = 1.2 ohms.

Therefore the total armature resistance for 4 parallel paths = 1.2/4 = 0.3 ohms.

In addition to this, the total armature circuit resistance includes brush resistance and brush contact resistance. Hence the value measured will be more than 0.3 ohms in the above example.

**Brushes:** The main function of the brushes is to transfer the energy present at the armature to the external circuit. Brushes are usually made from a compound of carbon and graphite. Graphite content provides a self-lubricating action as the brushes rub against the commutator.

The most important characteristics of brushes are specific resistance, friction coefficient, current-carrying capacity, maximum operating speed and abrasiveness.

Specific resistance is the resistivity of the brush material.

Friction coefficient is the ratio of the force on the surface to the force required to slide another surface over it, and is influenced by the brush temperature, pressure, current, atmospheric condition, mechanical condition, commutator material, surface films and speed. The resulting high brush friction often causes the brush to chatter and chip. Since friction serves no useful purpose, low brush friction is preferred. Low brush friction will have a friction coefficient in the order 0.22 or below whereas a high brush friction will have a friction coefficient above 0.4.

**Current-carrying capacity:** It depends on the brush material, operating conditions, type of ventilation and operating temperature. If the temperature is high due to high current density, the brush life will be shortened.

**Speed:** The allowable speed depends upon the characteristics of the brush material, spring pressure, current density, types of brush-holders, brush angle and the area of contact of the commutator.

**Abrasiveness:** The ability of the brush to prevent excessive build up of film usually caused by corrosive or oily atmosphere is called the abrasiveness or polishing action.

**Grade and types of brushes**: There are four major brush families classified according to the manufacturing process.

- Graphite
- Carbon and carbon graphite
- Electro-graphite
- Metal graphite

**Graphite:** Graphite brushes are usually made of natural or artificial graphite. Natural graphite contains impurities. Artificial graphite is usually pure. It is used in fractional HP machines.

**Carbon and carbon graphite:** It has high hardness, high mechanical strength, cleaning action and long brush life.

**Electro-graphite:** It consists of various forms of amorphous carbon. These brushes usually have higher current density, lower strength, lower hardness and lower specific resistance. They generally have good commutating characteristic but may not always be used because of the lesser requirement of high current, and the requirement of severe mechanical conditions.

**Metal graphite:** It is generally made from natural graphite, and finally divided into metal powders. Copper is the most common metal constituent, but silver, tin, lead and other metals are sometimes used. The metal content ranges from approximately 10 to 95% by weight. A high metal content provides greater current capacity, higher mechanical strength and also certain combined characteristics of contact drop and friction. It is used where high current and low voltages are involved. Its typical applications are for electroplating generators, battery chargers, welding generators and other high current equipment.

Whenever the brushes are to be changed, the same grade of brushes is to be procured and used to get the same performance characteristics from the machine.

As an accepted procedure, every electrician should identify the brush grade of each machine, either from service manuals or by visual inspection, and record it in the maintenance card of the machine for proper selection of replacement at a later date.

Brush contact resistance is the resistance offered between the brush and the commutator for the current flow. This resistance value depends upon the grade of brushes, material used for the commutator, contact area between the brush and commutator, and the brush tension. Normally the brush contact resistance is measured in terms of voltage drop at specific current ratings.

**Table 2 shows the different grades of brushes and their characteristics.**

Table 2

**Characteristics of brushes**

| Grade of carbon | Max. current density A/cm$^2$ | Max.contact resistance ohms/cm$^2$ | Pressure on commutator kg/cm$^2$ | Voltage drop in volts |
|---|---|---|---|---|
| Soft graphite | 9 to 9.5 A/cm$^2$ | – | 0.12 | 1.6 |
| Copper carbon | 15 to 16 A/cm$^2$ | 0.00000465 | 0.15-0.18 | 0.25-0.35 |
| Carbon | 5.5 to 6.5A/cm$^2$ | 0.000062 | 0.22-0.27 | 2 |
| Electro-graphite | 8.5 to 9 A/cm$^2$ | 0.000031 | 0.22 | 1.7-1.8 |

## EMF equation of DC generator

When the armature of a DC generator, containing a number of conductors in the form of a winding, rotates at a specific speed in the magnetic field, emf is induced in the armature winding and is available across the brushes. The equation and the numerical problems given as examples will help an electrician to better his understanding about the construction of a DC machine.

Induced emf in a DC generator can be calculated as explained below.

Figure 38 is given for your reference.

Let Ø = flux/pole in weber

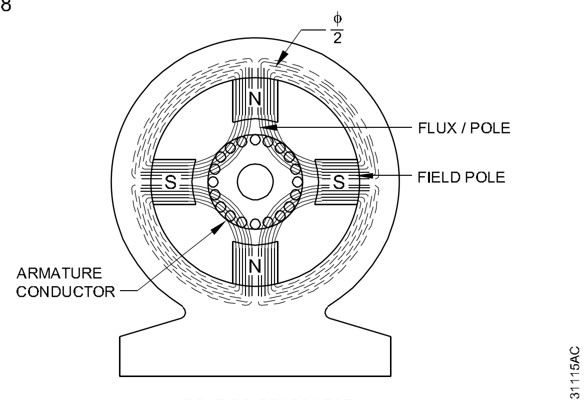
Z = total number of armature conductors = No. of slots x No.of conductors/slot

P = No. of poles in the generator

A = No. of parallel paths in armature

N = armature revolution per minute (r.p.m.)

Fig 38



4 - POLE DC GENERATOR

E = emf induced in the generator.

| | |
|---|---|
| Average emf generated per conductor in one revolution | = Rate of change of flux (Faraday's Laws of Electromagnetic induction |

$$\frac{d\varnothing}{dt} \text{ volt (since N = 1)}$$

Now, flux cut/conductor in one revolution, (d∅) = P∅ Wb

No. of revolutions/second = N/60

Time for one revolution, (dt) = 60/N second

According to Faraday's Laws of Electromagnetic Induction, we have emf generated/conductor/second

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing N}{60} \text{ volts}$$

emf generated in `Z'conductors in the armature assuming they are all in series $= \frac{P\varnothing ZN}{60}$ volts.

The emf generated in the armature of the DC generator when there are `A' parallel paths in the armature

$$= \frac{P\varnothing ZN}{60\ A} \text{ volts.}$$

Could be written as $= \frac{\varnothing ZN}{60} \text{x} \frac{P}{A}$ volts.

A = 2 - for simplex wave winding

= P - for simplex lap winding.

**Example**: A four-pole generator, having a simplex wave-wound armature has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine, when driven at 1500 r.p.m assuming the flux per pole to be 7.0 mWb?

**Solution:** $E = \frac{\varnothing ZN}{60} \text{x} \frac{P}{A}$ volts.

Here, $\varnothing = 7 \text{x}\ 10^{-3}$ Wb, Z = 51 x 20 = 1020, P=4, N = 1500 r.p.m.

A = 2 as the winding is simplex wave.

$$E = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60} \times \frac{4}{2} = 357\text{V.}$$

An 8-pole DC generator has 960 armature conductors and a flux per pole of 20mWb running at 500 r.p.m. Calculate the emf generated when the armature is connected as (i) a simplex lap-winding, (ii) a simplex wave winding.

**Solution**

(i) Simplex lap winding

$$E = \frac{\varnothing ZN}{60} \text{x} \frac{P}{A}$$

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{8} = 160\text{V.}$$

(ii) Simplex wave winding

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{2} = 640\text{V.}$$

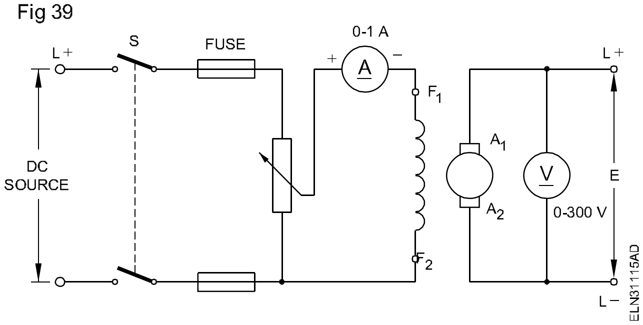
**Separately excited DC generator**

**Introduction**

A DC generator is the most commonly used separately excited generator, used for electroplating and battery charging. A separately excited generator is one in which the magnetic field is excited from an external DC source. The DC source may be a DC generator or a battery or a metal rectifier connected to an AC supply. Generally a potential divider is connected across the DC source, and the required DC voltage is supplied to the field as shown in Fig 39.

An ammeter is connected in the field circuit to measure the field current. The shaft of the generator is coupled to a prime mover. (Not shown in Fig 39)

Fig 39



**Magnetisation characteristic**: This characteristic gives the relation between the field flux and the induced voltage in a generator. However, it is difficult to measure the field flux, and, hence, the field current is taken instead of the field flux. The characteristic curve is drawn by keeping the field current in the `X' axis and the induced emf in the `Y' axis. To draw the characteristic curve, the connections are made as shown in Fig 39, and then, the prime mover is started and made to run at its rated speed, keeping the field switch `s' open. The terminal voltage which appears at the armature terminals is measured and recorded. This small voltage $E_r$ is known as residual voltage which is due to the residual magnetism available in the field cores.

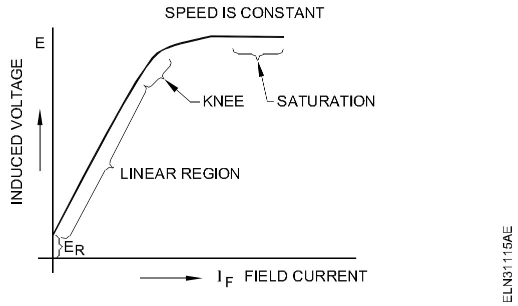
Throughout the experiment, the speed of the generator is held constant. Next, the field switch `S' is closed keeping the potential divider at its minimum position, and gradually the field current is increased in steps. For each step, the field current and the corresponding voltage at the armature terminals are noted. The readings are tabulated in Table 3.

Table 3

| Sl.No. | Field current | Terminal voltage |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

If a graph is plotted between the field current and the terminal voltage, the curve will be as shown in Fig 40. The field current is taken on the X-axis and the emf E on the Y-axis. The curve drawn is known as the magnetisation characteristic of a separately excited generator.

Fig 40



A study of the curve indicates that it starts just above the origin, travels straight in the linear region indicating that the emf induced is directly proportional to the field current $I_f$.

As the poles are in the process of saturation, the relation between the terminal voltage and the field current no longer stands in direct proportion as indicated by the knee portion of the curve.

Finally when the poles get fully saturated the induced emf ceases to increase even at the increased field current which is indicated by the last portion of the curve and named as saturation region.

**Reasons for not building up of voltage in a separately excited generator and their remedies**

Sometimes a separately excited generator may not build up voltage. The probable reasons and remedies thereof are given in Table 4.

**Load characteristic of a separately excited generator**: The load characteristic shows the relation between the load current and the terminal voltage. Through this characteristic curve, we can determine the behaviour of the generator on load.

Fig 41 shows the method of connecting the separately excited DC generator to obtain the load characteristic. The generator speed should be brought to the rated value with the help of the prime mover and the voltage is built up to its normal rated voltage. Then the load switch is closed. Gradually the load is increased in steps. Each time, the load current $\mathbf{I}_L$ in amps and the corresponding terminal voltage `V' in volts are noted. The readings are tabulated in Table 5.

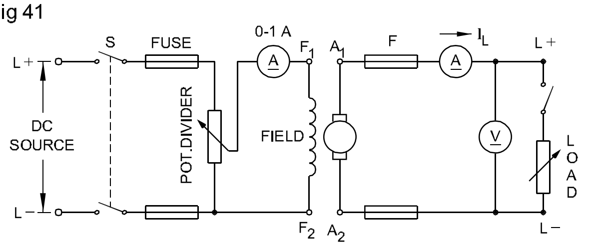
Table 4

| Reasons | Remedies |
|---|---|
| A break or opening in the armature or field circuit. | Test the field and armature circuits for open circuit. Locate the fault and rectify. |
| A short circuit in the armature or field. | Test the field and armature for short circuit. Locate the fault and rectify. |
| Loose brush connections or loose brush contact. | Tighten the brush connections. Check up the brush tension. Adjust, if necessary. If the brushes are worn out, replace them. |
| A dirty or severely pitted commutator. | Clean the commutator for dirt, dust and greasy material. Use trichloroethylene. If the segments are pitted, dress them up. |
| The speed is too low. | Increase the speed of the generator to its rated speed. |
| The DC supply for excitation is absent. | Check the DC supply across the field winding terminals. If the supply is not there, check the supply source and rectify the fault Where AC main supply is converted as DC supply through rectifiers, the fault may be located in the rectifier circuit. |

Table 5

| Sl.No. | Load current $I_L$ in amps | Terminal voltage in volts |
|---|---|---|
| | | |
| | | |
| | | |

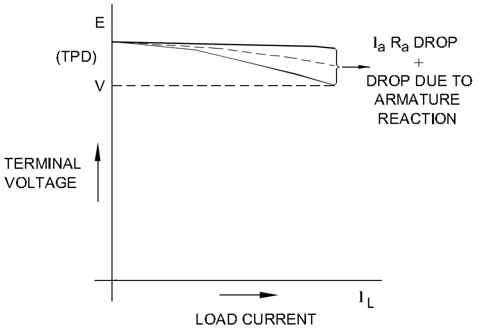
Fig 41



SEPARATELY EXCITED DC GENERATOR

The graph shown in Fig 42 is the load characteristic or external characteristic of a separately excited generator having load current in the X axis and terminal voltage in the Y axis.

Fig 42



EXTERNAL CHARACTERISTIC OF A SEPARATELY EXCITED DC GENERATOR

It is observed from the graph that a slight voltage drop occurs when the generator is loaded. This is due to the armature voltage drop ($I_aR_a$) and armature reaction.

If the voltage drop from no load to full load is very small, the separately excited DC generator can be regarded as a constant voltage generator.

## Advantages of a separately excited generator

The terminal voltage remains almost stable when compared to the self-excited generators because the field circuit is independent of the induced voltage.

As the field is independent, the $I_aR_a$ drop in the armature will not affect the field flux.

This generator can be used where a wide range of terminal voltage is required.

## Disadvantage

1. The disadvantage of a separately excited generator is the inconvenience of providing a separate DC source for excitation.
2. Besides it is expensive.

## Building up of a DC shunt generator

**Objectives:** At the end of this lesson you shall be able to
- **explain the conditions and method of building up of voltage in a DC shunt generator**
- **explain the method of creating residual magnetism in the poles of a DC generator**
- **determine the magnetization characteristic of a DC shunt generator**
- **estimate the value of field critical resistance in the DC shunt generator.**

**Condition for a self-excited DC generator to build up voltage**: For a self-excited DC generator to build up voltage, the following conditions should be fulfilled, assuming the generator is in sound condition.

- There must be residual magnetism in the field cores.
- The field resistance should be below the field critical resistance value.
- The generator should run at the rated speed.
- There must be a proper relation between the direction of rotation and the direction of field current. It could be explained as stated below.

The polarity of the induced voltage must be in such a direction as to produce the field current to assist the residual magnetism.

The polarity of the induced emf depends upon the direction of rotation and the polarity of the field poles depends upon the field current direction.

Even after fulfilling the above conditions, if the self-excited DC shunt generator fails to build up voltage, there may be other reasons as listed in Table 1.

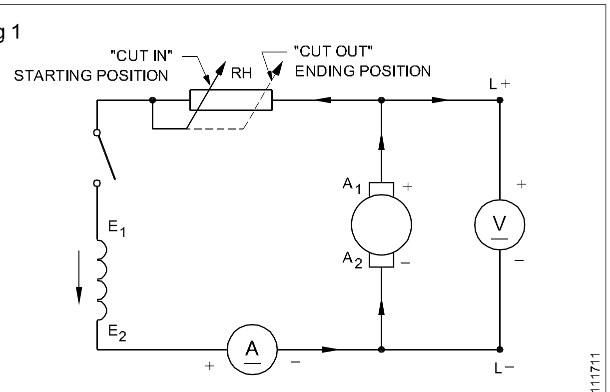
Table 1

| Sl.No. | Causes | Reasons | Remedies |
|---|---|---|---|
| 1 | A break or opening in the field or armature circuit. | Break or loose connection in the field or in the armature winding/circuit.<br>High resistance in the field circuit beyond the field critical resistance value. | Locate the open circuit and rectify.<br>Reduce the resistance of the field regulator. |
| 2 | Loose brush connections or contacts. | Improper brush contact/loose brush connections. | Check the brushes for excessive wear, and replace them, if necessary. Check the commutator for pitting. If necessary, turn down the commutator. Always clean the commutator when poor brush contact is discovered. Check the brush tension and readjust it, if necessary Tighten any loose connections. |
| 3 | A dirty or severely pitted commutator. | Severe sparking due to overload. | In this case, follow the same procedure as outlined above. |
| 4 | A short circuit in the armature or field | Overload or excess heating. | Do a resistance check, ascertain, locate and remove the fault. |

**Method of building up voltage in a DC shunt generator**: Fig 1 shows the circuit diagram for building up voltage in a DC shunt generator. When the generator is made to run at its rated speed initially, the voltmeter reads a small amount of voltage say, 4 to 10 volts. It is due to the residual magnetism. Since the field coils are connected across the armature terminals, this voltage causes a small amount of current to flow through the field coil. If the current flow in the field coils is in the correct direction, it will strengthen the residual magnetism and induce more voltage.

As such, the generated voltage will rise marginally. This rise in voltage, in turn, will further strengthen the increasing field current and induce more voltage. This rise in voltage, in turn, will further strengthen the increasing field current. This cumulative action will build up voltage until saturation is reached. After saturation, any increase in the field current will not increase the induced voltage. However, the whole procedure of building up of voltage takes a few seconds only.

Fig 1



DC SHUNT GENERATOR

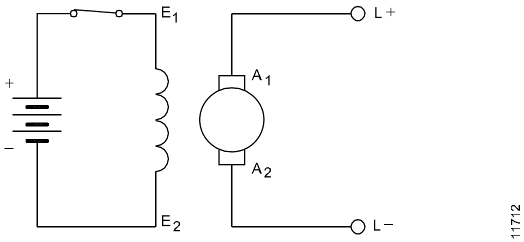
**Method of creating residual magnetism**: Without residual magnetism, a self-excited generator will not build up its voltage. A generator may lose its residual magnetism due to any one of the following reasons.

- The generator is kept idle for a long time.
- Heavy short circuit.
- Heavy overloading.
- The generator is subjected to too much heat.

When the generator loses its residual magnetism, it can be re-created as stated below.

**Flashing of field:** One of the methods to create residual magnetism is called the flashing of the `field'. This can be done by connecting the shunt field across a battery or any DC source for a few minutes as shown in Fig 2.

Fig 2



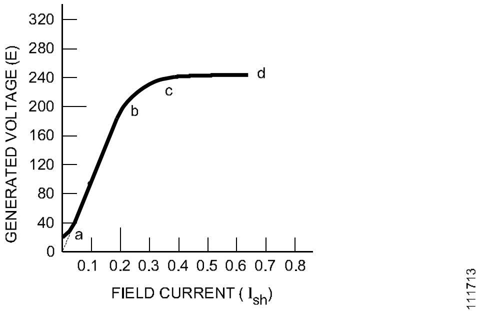
FLASHING OF THE FIELD

While flashing the field, the polarity of the magnetic field, now created, should be the same as that of the residual magnetic field it lost earlier.

In practice, this checking may not be possible. Alternatively note the polarity of the DC supply used for flashing the field and the corresponding field terminals. Run the generator in the specified direction at its rated speed. Measure the residual voltage induced and its polarity. Check whether the polarity of the residual voltage is the same as that of the DC generator. If found reversed, flash the field again by connecting the supply voltage in reverse polarity.

**Magnetisation characteristic of a DC shunt generator:** The magnetisation characteristic curve shown in Fig 3 gives the relation between the field current and the induced voltage. Referring to the emf equation, the induced emf in a generator is proportional to the flux per pole and the revolutions per minute of the generator. At a constant speed, the generated emf becomes directly proportional to the field flux. In a given machine, the flux depends upon the field current. The graph (Fig 3) illustrates this feature. Because of the residual magnetism, the curved part below point `a' does not start at zero. Between the points `ab', the curve is in almost a straight line indicating that the voltage in the area is proportional to the field current. Between points `b' and `c' a large increase in field current causes only a slight increase in the voltage. It indicates that the field cores are reaching saturation and this part of the curve is called the `knee' of the curve. Between points `c' and `d', the curve is flat indicating that the increased field current is not able to increase the induced voltage. This is due to saturation of the field cores. Because of saturation, the field flux becomes constant, and the induced voltage will not be in a position to increase further. This curve is also called a no-load or open-circuit characteristic curve.

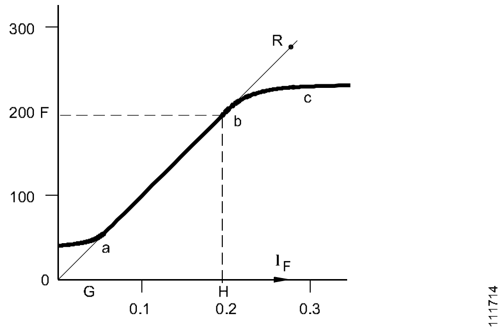
Fig 3



MAGNETISATON CHARACTERISTIC OF A DC SHUNT GENERATOR

**Critical resistance:** If the shunt field circuit resistance is too large, it does not allow sufficient current to flow into the field to build up its voltage. In other words, it acts like an open field. Therefore, the field circuit resistance should be smaller than a value called critical field resistance. Critical field resistance is the highest value of resistance of the shunt field circuit with which a DC shunt generator can build up voltage. Beyond this value of resistance, the generator fails to build up voltage. The value of the critical resistance can be determined by drawing a tangential line to the open circuit characteristic curve as shown in Fig 4.

Fig 4



FIELD CRITICAL RESISTANCE

For example, by drawing the tangent on the open-circuit characteristic curve as shown by line OR of Fig 4, we find the tangent is parting at point `b' from the curve. By drawing ordinates from point `b' to x and y axis, the value of critical resistance ($R_c$) can be determined as below.

$R_c$ = Field critical resistance

$$= \frac{\text{voltage represented by the tangent}}{\text{current represented by the tangent}}$$

$$= \frac{OF}{OH} = \frac{200\ V}{0.2\ A} = 1000 \text{ ohms.}$$

Field circuit resistance is the sum of the field resistance and field rheostat resistance. This value should be less than, say 1000 ohms (field circuit resistance) to enable the generator to build up voltage, if the generator is intended to self-excite. Normally this happens when the field regulator resistance is set at a high value.

# Test a DC machine for continuity and insulation resistance

**Objectives:** At the end of this lesson you shall be able to
- **state the necessity of measuring the insulation resistance of an electrical machine**
- **state the frequency of tests**
- **state the required conditions for the tests**
- **state the reasons for the low value of insulation resistance in the machines**
- **state the method of improving the insulation resistance of DC machines.**

**Necessity of measuring insulation resistance**: The most important aspect in the maintenance of DC machines is taking care of the insulation. Electrical insulation of DC machine windings is designed for the satisfactory operation at the specified voltage, temperature and to retain the electrical and mechanical strength and the dimensional stability over many years of operation. The insulation resistance of DC machines in service should be checked periodically, preferably every month. The possibility of reduction in the value of insulation resistance is due to the continuous working of the machine under full load condition, the heat generated in the winding and local atmospheric moisture, dust and dirt. If they are not checked in time, the insulation becomes weak and the winding will loose its dielectric property, and will ultimately lead to failure of the machine. Periodical checks and measurement of insulation resistance and improvement thereof to the required level will ensure prevention of failure of insulation, and thereby, the breakdown of the machine.

A common device for measuring insulation resistance is a direct indicating insulation tester or Megger. The measurements are made at voltages 500/1000 volt DC depending upon the voltage rating of the machine.

**Measurement of insulation resistance**: Insulation resistance shall be measured between the winding and frame (earth), and between windings.

For low and medium voltage rated machines, the insulation resistance, when the high voltage test is applied, shall not be less than one megohm as per B.I.S. 9320 - 1979. The insulation resistance shall be measured with a DC voltage of about 500 V applied for a sufficient time for the reading of the indicator to become practically steady, such voltage being taken from an independent source or generated in the measuring instrument.

**When it is required to dry out windings at site to obtain the minimum value of insulation resistance, it is recommended that the procedure for drying out as specified in IS:900-1965 may be followed.**

**Frequency of test**: Periodical checks or tests are predetermined in preventive maintenance programmes with a forethought. The planning of the preventive maintenance (PM) schedule should be based on the past experience of maintenance personnel, and the recommendations made by the machine manufacturer. Usually the measurement of insulation resistance is a must during the period of overhauls. The duration of overhaul will be once in 6 months, ideal for DC machines where they are working continuously. Overhauling is done once a year, for such of those machines as are not working continuously. The overhauling is done during plant shut-down periods.

However in DC machines where the overhaul interval is too long, or delayed, it is advisable to have constant vigil and check the insulation resistance at least once a month regularly, and maintain a record of the values of the insulation resistance tests as shown in Table 1.

Table 1

**Insulation resistance test**

| Date | Time | Weather condition | Duty cycle | Test between terminals | Insulation resistance | Remarks |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |