UNIT 2 D.C. MACHINES

DC machines have been widely used in Diesel Electric locomotives for their operating characteristics. These machines require frequent maintenance and attention to keep them in healthy state. It is important and necessary to be well informed about the construction, operating principle and probable areas of defects for a maintenance man so that they are confidant in maintaining these machines regularly. This block has been divided in five units to deal with the generator, motor, commutation, carbon brushes and flashover separately. The DC Generator has been discussed in Unit 2.1, DC Motor in Unit 2.2, commutation in Unit 2.3, carbon brush in Unit 2.4 and flashover in Unit2.5.

UNIT 2 D.C. MACHINES

UNIT 2.1 DC GENERATOR

OBJECTIVES

- After completing this unit, you will be able to:
- understand the working principle of DC generator
- appreciate the construction of DC generator
- define the EMF equation of a generator
- define and appreciate commutation of DC machine
- identify types of DC generators and their characteristics

STRUCTURE

1. Introduction
2. Constructional Details of DC generators
   2.1 Yoke
   2.2 Pole core or pole shoes
   2.3 Field coils
   2.4 Armature core
   2.5 Armature winding
      2.5.1 Lap winding
      2.5.2 Wave winding
   2.6 Commutator
   2.7 Brushes and bearings
3. EMF equation
4. Principle of operation
5. Commutation
6. Types of DC generators
7. Generator characteristic
   7,1 Open Circuit or no load Characteristic
   7.2 External or load Characteristic
   7.3 Internal or Total characteris tic
   7.4 Critical Resistance
8. Summary
9. Self-assessment exercises

1. INTRODUCTION

A machine, which converts mechanical energy into electrical energy, is called a Generator. This energy conversion is based on the dynamically induced emf. According to the Faraday's law of electromagnetic Induction, an induced emf is produced in the conductor which cuts the magnetic flux. This emf causes a current to flow in the conductor if its circuit is closed.
Hence the basic essentials for an electrical generator are: -
(i) Magnetic field;
(ii) Conductor or conductors and;
(iii) Relative motion between magnetic field and conductors.

2. CONSTRUCTIONAL DETAILS OF A DC GENERATOR

Here we are dealing with a DC generator. But there is a good similarity with a DC motor also as far as construction is concerned.
The following are the main parts of a DC generator:

- Yoke
- Pole core or pole shoes
- Field coils
- Armature core
- Armature winding
- Commutator
- Brushes and bearings

2.1 YOKE OR MAGNET FRAME

This is the outer part of the DC generator. It provides the mechanical supports for the poles and acts as a protecting cover for the whole machine. It carries the magnetic flux produced by the poles. Yokes are made out of cast iron or cast steel. The modern process of forming the yoke consists of rolling a steel slab round a cylindrical mandrel and then welding it at the bottom. The feet and the terminal box etc. are welded to the frame afterwards. Such yokes possess sufficient mechanical strength and have high permeability.

2.2 POLE CORE OR POLE SHOES

The field magnet consists of pole cores and pole shoes. The pole shoes serve two purposes.
(i) They spread out the flux in the air gap and also being the larger cross section reduced the reluctance of the magnetic path.
(ii) They support the exciting coils.

2.3 FIELD COILS

The field coils or pole coils, which consist of copper wire, are former-wound for the current dimension. Then the former is removed and the wound coil is put into place over the core.

2.4 THE ARMATURE CORE

It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. Its most important function is to provide a path of very low reluctance to the flux through the armature from North Pole to South Pole. It is laminated to reduce the loss due to eddy currents. Thinner the lamination, greater will be resistance offered to the induced emf and hence smaller the current. And thus the loss is also small.

2.5 ARMATURE WINDINGS

It is generally former wound. These are first wound in the form of flat rectangular coils and then are pulled into their proper shape in a coil puller.
Two types of windings are mainly used - namely lap winding & Wave winding.

2.5.1 Lap winding

In lap winding finish end of one coil is connected to a commutator segment and to the start end of the adjacent coil situated under the same pole and similarly all coils are connected. Since the successive coils overlap each other and hence the name (Ref. fig.1).

2.5.2 Wave winding

It is also called as series winding. In this winding, the coil side is not connected back but progresses forward to another coil sides. In this way the winding progresses, passing successively every N pole and S pole till it returns to coil side from where it was started. As the winding shape is wavy, the winding is, therefore, called wave winding (Ref. fig.2).

2.6 COMMUTATOR

The commutator, whose function is to facilitate the collection of current from the armature, is cylindrical in structure, built up of segments of high conductivity, hard drawn copper insulated from one another by mica sheets. It also converts alternating current into unidirectional current (DC).

2.7 BRUSHES&BEARINGS

The function of brushes is to collect current from the commutator. These are rectangular in shape, made of carbon normally. These brushes are housed in brush holder usually of the box type variety.
Generally ball bearings are employed due to their reliability but for heavy duty, roller bearings are also used. The balls and rollers are generally packed in hard oil for quieter operation. Sleeve bearings are also used where low wear is required.

3. E.M.F. EQUATION OF A GENERATOR

Generated E.M.F, E = $P\phi ZN/60A$ Volts

Where, P = No. of poles.

ϕ = Flux per pole in Wb (Weber)

Z =Total nos. of conductors.

N = r.p.m.
A = nos. of parallel paths in Armature.
(A = 2 for wave winding & A = P for lap winding)

4. PRINCIPLE OF OPERATION

The principle of electro-magnetic induction, discovered by Faraday, states that when a conductor is moved across a magnetic field so as to cut the lines of force, electro-motive force or E.M.F. measured in volts, is generated across the conductor. Thus, if an open loop or wire is made to rotate between the poles of a permanent magnet, as shown in fig.3 and fig.4, there will be a tendency for electricity to flow through the wire. The magnitude of this EMF or voltage, depends on the speed of rotation, and on the strength of the magnet, i.e. "the magnetic flux".

The direction of voltage generated in a conductor depends on the direction of the motion of the conductor across a magnetic field and the direction of the field itself. Since the magnet has two poles, two conductors can be connected together in series to form a loop and their voltages will be additive. Several loops can be joined together to form a coil having a number of turns, all the voltages being added together. For each half revolution, embracing one complete pole, the voltage will start from zero, rise to a maximum and fall to zero again. For the remaining half revolution a similar series of events will occur, but the direction of the voltage is reversed. This very simple form of alternating current (A.C.) generator is shown in fig.3.

To change this primitive machine into a direct current (D.C. generator) fig.4, it is necessary to introduce a commutator. In order to attain constancy of direction, the ends of the loop, instead of being connected to slip rings, are connected to a split metal ring, the two halves being insulated from each other. By placing the collecting brushes (C & D) on the commutator in such a position that the voltage induced in the loop is zero when the brushes change from one segment to the other voltage at the brushes will be uniform in direction, although it will still be alternating, commutator simply alters the connection of the loop to the external circuit at the instant when the induced electromotive force changes in direction.

If the loop of wire is closed by connecting the brushes (C&D) to an external resistance(R), which represents the 'load' imposed on the machine, electric current will flow through the loop and the resistance (R). In practice, the amount of current, which flows, is measured in amperes (amps). The magnitude of the current, which will flow through the circuit, depends on the voltage generated and on the value of the joint resistance of the loop of wire and the external resistance. Voltage, which the machine is capable of developing at the certain speed and with a magnet of the given strength, the current flow, measured in volts, divided by the total resistance of the circuit, measured in ohms.

If the loop of wire be rotated in one direction, the current will flow in the wire under the south pole (S), in the direction of the arrow, that is, away from the brush (C), and then in the wire under the north pole (N) towards the brush (D). From the brush (D), it will go to the external circuit and then back to the brush (C); thus completing the electric circuit. After rotating such that the position of the segments is reversed, it will be noticed that the picture remains identical and therefore the current flow will be in the same direction.

Although the primitive direct current generator, so far described, produces a uni-directional current flow, it is obvious that for each revolution of the coil the induced current will start from zero value, rise to a maximum value, fall to zero then rise to a maximum value again and finish at the zero point from which it started. However, by increasing the number of coils and spreading them out evenly, the flow of current can be made very nearly constant. This also means that there would be an increased number of segments in the commutator in proportion to the increased number of coils. In practice, a direct current generator has many coils consisting of insulated copper wire or strip, and in order to concentrate the magnetic flux where it is required, they are embedded in slots in a soft-iron laminated cylinder. This assembly is called the armature.

The permanent magnet of the original example is replaced by an electro-magnet having many poles wound with insulated copper wire; these are field coils and are referred to as the field system. The field strength, or excitation, depends upon the number of turns of wire on each pole and on the magnitude of current flowing through the wire.

From this it can be seen that there are two ready means of regulating the output of the generator; one by varying the speed of rotation of the armature and the other by altering the magnetic strength of the field system. The variation of speed of rotation is readily obtained by varying the governor setting on the diesel engine, which drives the armature, and by inserting variable resistance in the field system, the amount of current flowing through the coils of the Electro-magnets can be varied.

In a diesel locomotive, the driver of the locomotive makes these adjustments, as required, by moving his control handle, thereby simultaneously affecting engine speed and generator excitation. The main generator frame is coupled directly to the diesel engine flywheel casing. The armature is of the single bearing type, that is to say, one end of the shaft is coupled to the engine flywheel, and the other end is supported in a roller bearing, housed in an end plate bolted to the generator frame. The main generator is self ventilated, having its own fan which draws air through the machine so as to cool the windings and maintain them at a safe working temperature.

5. COMMUTATION

We have seen that current induced in the armature conductors of a DC generator is alternating and to make it unidirectional in the external circuit we use commutator. Also the flow of direction of current in the conductor envisages as the conductor's position changes from one pole to another i.e. as conductors pass out of the influence of a `N' pole and other that of a `S' pole the current in them is reversed. This reversal of current takes place along the Magnetic Neutral Axis (MNA).

Thus, commutation is a group of phenomena related to current reversal in the conductors of an armature winding when they place through the M.N.A. where they are short-circuited by the brushes placed on the commutator.

Commutation is said to be good if there is no sparking between the brushes and commutator when current reversal in the coil section takes place. Contrary to that, it is said to be poor if there is sparking at the brushes during current reversal in the coil section.

6. TYPES OF GENERATORS

In accordance with the method of excitation D.C. generators are divided into two categories -

1. Separately excited Generator
2. Self excited generators.

Since the separately excited generators have limited application we look forward for self-excited generators.

Generators with self-excitation can be divided according to the way of the field winding connection into following categories-

1. Shunt-excited generators
2. Series excited generators and,
3. Compound-wound generators

7. CHARACTERISTICS OF GENERATOR

There are 3 important characteristics of a DC generator.

1. Open circuit characteristic (O.C.C.)
2. External characteristic or load characteristics
3. Internal characteristic or total characteristic

7.1. O.C.C. or NOLOAD CHARACTERISTIC

It represents the relation between generated E.M.F. and field current. If it is practically the same for all types of generator whether they are self-excited or separately excited.

7.2. EXTERNAL OR LOAD CHARACTERISTIC

It is a curve representing the relation between the terminal voltage V and the load current I_L.

7.3. INTERNAL OR TOTAL CHARACTERISTIC

It is a curve, which represents the relation between the generated EMF.(Eg.) and armature current I_a.

7.4. CRITICAL RESISTANCE

The value of that resistance due to which field resistance line becomes tangent to the O.C.C. curve is called critical resistance.

8. SUMMARY

Necessary informations regarding operating principle, constructions, characteristic of DC generators have been given in this unit. These informations will help in maintaining the machines to ensure reliability and their trouble free functioning. Some informations have been given about commutation of DC machines, which would prove to be important to understand behavior of DC machines. Sketches and diagrams have been included in this unit to understand the block with more practical and systematic approach.

9. SELF-ASSESSMENT EXERCISES

1. Name different components of a dc generator and describe their functions.
2. State the EMF equation of a generator and mention detail names of different symbols.
3. Explain the commutation process of a dc machine with necessary diagrams.

UNIT 2.2 DC MOTORS

OBJECTIVES

After completion of this unit, you should be able to:

- understand the working principle of DC motor
- appreciate the construction of DC motor
- define the speed equation
- understand characteristics of DC motors
- appreciate brush grades and their selection criteria

STRUCTURE

1. Introduction
2. DC motor and its principle of operation
3. Back emf.
4. Types of DC motors
5. Speed equation
6. Speed control
7. Characteristic of DC motors
8. Constructional details of DC motor
9. Heating and cooling
10. Rating of DC motor
11. Summary
12. Self-assessment exercises

1. INTRODUCTION

A motor is a mechanism by which electrical energy is converted into mechanical energy. Its operating principle is the reverse of a DC generator. When a coil, carrying current, is placed in a magnetic field, it experiences forces, which turn it about in a direction perpendicular to both the field and current. Thus the motor armature placed inside the magnetic field gets motion, converting electrical energy to mechanical.

2. DC MOTORS – Principle of operation

A motor is a mechanism by which electrical energy is converted into mechanical energy. Both in principle and design, a DC motor is the reverse of a DC generator.

A steady current is passed through the armature coil from the commutator and the brushes are so arranged as to reverse the current every half revolution. When a coil, carrying a current, is placed in a magnetic field, it experiences forces, which turn it about in a direction perpendicular to both the field and the current. Due to the rotating torque the motion of rotation will not be continuous, unless the direction of the current is reversed each half revolution with the help of a split ring commutator (in a 2-pole machine).

The electric motor is fundamentally similar to the primitive form of D.C. generator described earlier and is based on the fact that, if a "loop of wire". If it is supplied, through its commutator, with electric current from a battery or any other source of direct current (D.C.) supply, the loop will rotate.

If the brushes of the machine were connected to the terminals of a primary cell, instead of being connected to load R, the "loop of wire "would rotate. A greatly enhanced performance would be obtained by having an iron core on this loop, a further improvement would be to have many loops, another to have increased pole area, and a still further improvement would be obtained by having electromagnets instead of permanent magnets.

When used for traction, the direct current electric motor is usually of the series wound type, that is, the current, which passes through the armature also, passes through the field coils. The reason for this is that a motor having this particular type of winding has characteristics eminently desirable for traction work, its torque being proportional to the current flow, multiplied by the magnetic strength of the field system. The series wound motor is capable; therefore, of producing a high torque when the vehicle is started, and also has the advantage that as the load increases its speed drops.

The direct current traction motor can be considered as having the following major parts;

1. The electro-magnetic system consisting of the frame with pole pieces, the field windings and brush gear.
2. The reduction gears between the armature shaft and the road wheels, together with the gear case, which protects the gear wheels and holds the gear lubricant.
3. The axle bearing where the traction motor frame rests on the axle of the vehicle, this arrangement maintains a constant.
4. The nose suspension arrangement prevents the frame of the motor from rotating round the axle of the vehicle, The nose is spring borne on a bogie cross member.

3. BACK EMF

Due to the rotation of the armature coil (i.e. a conductor) in the magnetic field, the motor works as a DC generator and induced e.m.f acts in the circuit, which opposes the current. This induced e.m.f is called back e.m.f.

4. TYPES OF D.C.MOTORS

Like DC generators, DC motors are also of 3 types-
(i) Series wound motor,
(ii) Shunt wound motor and
(iii) Compound wound motor.

5. SPEED EQUATION

We know that back e.m.f. is produced by the generator action of the motor

Hence back e.m.f. E = $P\phi ZN/60A$, where symbols have their usual meanings.

Let V be the applied voltage and I_a and R_a is the armature circuit current and resistance respectively.

Then E = $V - I_a R_a$

$P\phi ZN/60A = V - I_a R_a$

Or N = $(V - I_a R_a) \times 60A/P\phi Z$

Or N $\propto (V - I_a R_a)/\phi$ since P Z & A are constants. for a particular motor.

Or N $\propto V/\phi$, Since I_a R_a drop is very small as compared to the applied voltage V.

Or N $\propto 1/\phi$, if applied voltage V is constant.

Hence speed is inversely proportional to flux / per pole if the applied voltage is constant.

6. SPEED CONTROL OF DC MOTOR

We know that, N = $(V-I_a R_a)/\phi$

From this formula it follows that the speed of a D.C. motor can be regulated by:
(i) varying the supply mains voltage V
(ii) Varying the voltage drop in the armature circuit I_a R_a
(iii) Varying the field flux

Methods

(ii) & (iii) are possible in any installation with constant supply voltage. But the first method is possible only in special installation; that permits the control of the supply voltage.

7. CHARACTERISICS OF D.C.MOTORS

There are three important characteristics of a D.C motor, which are given below: -
(Ref. Attached figures)

(i) Torque - Armature current characteristics

This shows the relation between mechanical torque developed and armature current.

(ii) Speed- Armature current characteristics

As the name indicates, it relates speed with armature current.

(iii) Speed - Torque characteristics

The characteristics curve gives the relation between speed and torque of a DC motor.

8. CONSTRUCTIONAL DETAILS OF DC MOTOR

8.1 INTER POLES

In addition to the main field coils of a motor being in series with the armature, there are also the coils of a smaller system of field magnets known as inter-poles. On generators with separately excited main fields, the inter-pole coils are in series with the armature.

The inter-poles are smaller than the main poles of either a generator or motor, but are the same length and positioned alternatively with the main poles. In a generator the polarity of an inter-pole is the same as the main pole ahead of it according to the rotational direction of the armature. The polarity of an inter-pole in a motor is the same as the main pole proceeding it. An electrical machine with no inter-poles would have some magnetically neutral regions between its pole-pieces. When a coil of the armature reaches a position during its rotation in the neutral region, its connections are short-circuited with the connection of the armature coil in advance, because in this position the commutator brushes will be in contact with both of their corresponding commutator segments. The purpose of the inter-poles, being situated in the neutral regions, is to induce a current in the short-circuited armature windings, which flows in the same direction as the current, which will flow when it has left the neutral region.
The use of inter-poles also serves to prevent the distortion of the main field of the generator by the reaction of the armature field, and thereby prevents the induction of Electro-motive forces into coil sides, which are being short- circuited by the brushes.

In small machines the need for inter-poles is not important but on large generators and motors the net effect of the inter-poles is to improve the commutation. Ideally there should be no sparking of the brushes on the commutator surface, although this is often difficult to achieve in practice.

9. HEATING AND COOLING

Every electrical machine is a power (or energy) conversion device. During these power conversion some of the energy is wasted. In electrical machines the loss in energy occurs in electrical circuits and in portions of magnetic circuits also. There are also frictional losses in the dynamic parts of the machines. These losses are converted in the form of heat energy, which increases, or tends to increase the temperature of iron and copper above that of the ambient temperature, which in turn effects the winding insulation. In addition to the effect it has on the insulation, an excessive temperature rise may also adversely influence the mechanical operating conditions of a given machine part. Thus, for example the original dimension of the commutator may change. Solder between the commutator and windings may get washed out. So to avoid all these, it is very essential to provide a cooling system on machines.

In most cases, the cooling is done by air currents. The cooling of machines by air streams is called ventilation. The ventilation employed depends on the environmental conditions of the place where the machine is to operate.

According to the method of ventilation employed, the following types of machines are distinguished: -

(i) Machines with natural ventilation.
(ii) Machines with internal self-ventilation.
(iii) Machines with external self-ventilation.
(iv) Machines with independent ventilation.

Enclosures have got the direct bearing with the ventilation. The following are the main types of enclosures: -

(i) Open pedestal

Rotor and stator windings are in free contact with the surroundings.

(ii) Open end Bracket

Rotors and stator windings are in contact with surrounding through openings.

(iii) Protected (formerly called semi-enclosed)

Openings in the frame are protected with wire, perforated covers etc.

(iv) Drip proof

Opening so constructed that no solid or liquid particles falling at an angle greater than 15*0* will enter the machine.

(v) Splash proof

Similar to drip proof but the angle of approach is 100^O from vertical.

(vi) Duct or pipe ventilated

Air for ventilation enters and emerges through a pipe through the openings.

(vii) Totally enclosed

Exchange of air throughout side and inside of the machine is prohibited.

(viii) Water proof

The machine is totally enclosed so as to exclude water applied as a stream as specified.

(ix) Flame proof

It is designed normally for mines.

(x) Resistant

Machine is so constructed, that it will not be harmed easily by moisture fume, alkali etc.

(XI) Submersible
So constructed that it will work when submerged in water under specified condition of pressure and time.

10. RATINGS

There are three types of ratings as specified.
(i) Continuous Rating: This is an output, which a machine delivers continuously without exceeding the permissible temperature. It can deliver 25% overload for two hours.
(ii)Continuous maximum Rating: This is similar to continuous rating but not allowing overload.
(iii) Short time ratings: This is an output which a machine can deliver for a specified period (say 1 hr 1/2 hr, 1/4 hr etc) without exceeding the maximum temperature rise limit.

11. SUMMARY

Informations regarding operating principle, construction, characteristic and selection of carbon brushes for DC motors have been given in this unit. These informations will help in maintaining the motors to ensure reliability and their trouble free functioning. Sketches and diagrams have been included in this unit to understand the unit with more practical and systematic approach.

13. SELF-ASSESSMENT EXERCISES

1. Describe and mention the speed equation of a dc motor.
2. What are the different types of cooling arrangements of DC motors?
3. What do you mean by rating of a motor? What are the types of ratings?

UNIT 2.3 COMMUTATION

OBJECTIVES

After completion of this unit you will be able to understand:

- cause of sparking in DC machines
- reactance voltage
- emf equation
- contribution of commutating poles
- reason for use of high resistance brushes

STRUCTURE

1. Introduction
2. Cause of sparking
3. Reactance voltage
4. Emf commutation
5. Commutating poles
6. Use of high resistance brush
7. Summary
8. Self Assessment Exercise

1. INTRODUCTION

Owing to the thinness of the insulation between the commutator segments, it is obvious that a brush may be in contact with two or more segments at the same instant. Hence, if an armature coil has its ends connected to two of these segments, the coil will be short-circuited by the brush, and as the armature rotates, each coil will, of necessity, be short-circuited. This period of short-circuit is the period during which the current is being delivered from the commutator segments concerned, to the brush, and it is, therefore, called the period of commutation.

By commutation we mean the changes that take place in an armature coil during the period that it is short-circuited by a brush. These changes are illustrated in figure 1, the winding being represented as a ring winding for simplicity. Currents of magnitude I amp are flowing to the brush through the armature from the right and left, the total current delivered by the brush, therefore, being 2I amps. In the first diagram the coil B is on the point of being short-circuited, and it is carrying, in a direction from left to right, half the current delivered by the armature to the brush. The second diagram shows the same coil in the middle of the short circuit period, from which it will be seen that it is possible for the current I flowing from right and left to reach the brush without passing through this coil. In the third diagram, the same coil B is shown immediately after short circuit, and in this position it is, or should be, carrying the full current in a direction from right to left. We thus see that during the short circuit period, the current in the short-circuited coil must be reversed and brought up to its full value in the reversed direction.

2. CAUSE OF SPARKING

If the current in coil B has not attained its full value in the position shown in the third diagram, then since the coil C is carrying the full current, and this current must reach the brush, the difference between the currents carried by coil B & C has to jump from the commutator bar to the brush in the form of a spark. Thus suppose that the armature conductors are carrying a current of 50 amps, but the current in coil B has only reached 40 amps, then by the end of short-circuit, the difference of 10 amps will have to jump to the brush in the form of a spark. The energy in these sparks may be very high, the result being a very high temperature rise of the commutator, and pitting and roughening of the segments in a very short time.

The cause of sparking at the commutator is, therefore, the failure of the current in the short-circuited coil to reach the full value in the reversed direction by the end of short-circuit. Suppose the current in each conductor is I amp, then what is required is that the current shall change from +I to -I during the time of short-circuit. This is represented in fig.2 in the form of a graph. "Curve I" shows what happened when the current does not reach the full value; "curve II" shows the ideal, a gradual change of current from +I to -I; "curve III" shows what may happen if one of the remedies for under commutation in overdone and the current in the reversed direction is forced up to a value greater than I.

3. REACTANCE VOLTAGE

The difficulty experienced by the current in attaining the full value in the reversed direction by the end of short-circuit, is due to the fact that the current in the short-circuited coil is changing. When the coil is carrying a steady current, this current produces a magnetic field of constant strength, and the number of lines of force linking with, or threading, the coil is constant. Under these conditions there is no change in number of lines of force and consequently there is no e.m.f. induced in the coil other than that produced by the rotation of the coil in the main field. But when the current changes in magnitude, or direction, or both, then there is a change in the number of lines of force linking with the coil, and in consequence an e.m.f. is induced. The production of this e.m.f is thus exactly similar to the production of an e.m.f in a coil by thrusting a magnet in to it, the only difference being that the necessary change in the number of lines of force linking with the coil is produced, not by the introduction of a magnet, but by a change in the current carried by the coil. Like all induced e.m.f., this induced e.m.f. is a back e.m.f., it tries to stop the change of current. Now the direction of current is from left to right in the first diagram of fig.1, and right to left in the third, and so the induced voltage acts in the original direction of the current, thereby preventing it from attaining its full value in the reversed direction by the end of short-circuit. This induced voltage is called the reactance voltage.

4. E.M.F. COMMUTATION

The cause of difficult commutation is the reactance voltage, and follows that if this voltage could be neutralized, spark-less commutation would be achieved. In order to neutralize the reactance voltage it is necessary to induce in the short-circuited coils another e.m.f which is opposite in direction to the reactance voltage, and, therefore, in same direction as the current when reversed. The old method of achieving this consisted in rocking the brushes forward until they were some way ahead of the magnetic neutral plane. The result of this was that the short-circuited coils were located ahead of the neutral plane, and were therefore, under the influence of the next pole further ahead. This pole induced an e.m.f in them in the required direction, because after commutation they would be entirely under its influence until they reached the next brush. There are two very serious objections to this method. The first is that with a changing load the position of the magnetic neutral plane is continually changing, thus necessitating the continual adjustment of the brush position. With modern dynamos it is invariably specified that they shall operate spark-less at any load between zero and full-load with a fixed brush position. The second objection is that the magnetic field which induces the commutating e.m.f. is the fringe of flux under the leading pole tip, and we have seen in a previous lesson that this flux is gradually wiped out as the load increases. With heavy leads it is, therefore, necessary to give the brushes a very large load, unless some other method of securing spark-less commutation is adopted.

5. COMMUTATING POLES

In order that a commutating e.m.f may be induced in the short-circuited coils it is necessary that these coils shall be situated in a magnetic field, called the commutating field. Instead of making use of the fringe of flux under the leading tips of the main poles, the modern method is to employ separate poles called commutating poles, or interpoles. These are narrow poles placed mid-way between the main poles and excited, so that each one has the same polarity as the next main pole further ahead, thereby giving a commutating field of the right kind. This is illustrated in fig.4. By the use of these poles the necessity for rocking the brushes forward with increasing load is done away with and, as a result, the machine can be worked with a fixed brush position. Now the reactance voltage is proportional to the change of current, which takes place in the short-circuited coil, and this in turn is proportional to the current delivered by the armature. The commutating e.m.f and the commutation magnetic field produced by the interpoles must therefore be proportional to the armature current. For this reason, the exciting current through the interpole windings must not be kept constant but must vary with the load. This is achieved by series excitation of the interpoles; that is, their exciting coils are connected in series with the armature, thereby carrying a current equal to the armature current. For small machines the exciting coils consist of insulated cable capable of carrying the full armature current, but with very large machines delivering very large currents the exciting coils consist of very heavy copper strips wound on edge. An interpole of this type is shown in fig.3. In extreme cases the coil may consist of a heavy copper casting. The next illustration (fig.5) shows a complete stator with main and commutating poles.

It will be readily understood that for a given armature current there is proper value of the commutating field, and that it is possible for this field to be too strong. In such a case the reversed current in the short-circuited coil is forced to too high a value by the end of short-circuit, and sparking at the commutator takes place in the reversed direction. This is called over-commutation and is represented graphically by "curve III" in fig.2.

6. USE OF HIGH RESISTANCE BRUSHES

A second method of obtaining good commutation is to use brushes having a high contact resistance when pressing on the commutator segment, since brushes of this kind help to force the current coming up to the brush from the leading side of the armature, through the short-circuited armature coils. This can be understood from Fig.6 in which the winding is again represented as a ring winding for simplicity. The total current collected by the brush from the armature is represented as 2I, and one-half of this, namely I amp comes from the left and I amp from the right. The current I coming from the left reaches the brush via commutator segment a and it has to traverse the contact resistance r1 between this segment and the brush. It has also an alternative path to the brush via the short-circuited coil and across the segment b, the resistance in this path being the contact resistance r2 between segment b and the brush. At the commencement of short-circuit the brush will be mainly in contact with segment b and will only just touch segment a, with the result that the resistance r1 will be very high (because of the very small area of contact) while r2 will be low. A large portion of the current coming from the left will, therefore, at this instant, take the lower resistance path through the short-circuited coil. As the commutator moves past the brush, the area of contact with segment a gradually increases, while that with segment b decreases and therefore, contact resistance r1 gradually decreases while r2 increases. There is thus a gradual tendency for that portion of the current I coming from the left and flowing through the short-circuited coil, to leave the coil and take the direct path to the brush across the segment a. This is as it should be, because the current coming from the left is not in the reversed direction and it is necessary to eliminate it from the short-circuited coil as quickly as possible. Now consider the current I coming up to the brush from the right. There are also two parallel paths open to this current as soon as it reaches the commutator segment b. The first is straight across the segment b to the brush and the second is round the short-circuited coil and then across the segment a. With brushes having a low contact resistance with the commutator there is no inducement for the current to take this second path. With carbon brushes, which have a high contact resistance, more and more of the current flowing to the brush from the right hand will be shunted round the short-circuited coil as the segment b passes the brush, because, as we have seen, the contact resistance r2 is gradually increasing, where-as the resistance r1 is gradually decreasing. Finally when the period of short circuit is almost ended, the brush will only just be touching segment b and r2 will be very high, becoming infinitely great when the segment has left the brush. The whole of the current I from the right will then be flowing through the short-circuited coil. Furthermore, this current is in the necessary reversed direction.

For the above reasons carbon brushes have almost entirely replaced the copper brushes which used to be used with older machines. The disadvantage of carbon brushes is that they can only be worked at a current density of about 40 to 50 amperes per sq. inch as compared with 150 to 200 for copper brushes. This necessitates a larger area of contact at the brush face and, therefore, a longer commutator.

The properties of a few grades of brush are shown in the following table: -

BRUSH TYPE	MAX. CURRENT DENSITY	MAX.CONTACT RESISTANCE	PRESSURE ON COMMUTATOR
	(amp/in.^{2})	(ohms/in.^{2})	(lb/in^2)
Copper Ordinary.	200	0.003	1.5
Carbon	40	0.04	2.0
Electro- graphite	60	0.02	2.0

For the same area of brush, (Contact resistance of carbon brush) / (Contact resistance of copper brush)= $^{0.04}\!/_{0.003}$ =13

But for the same current collected, the contact area of the carbon brush must be 200/40 = 5 times the area of the copper brush, because of its smaller working current density. Hence, since the contact resistance is inversely proportional to the contact area, we have, for the same current collected, (Contact resistance of carbon brush)/ (Contact resistance of copper brush)=13/5=2.6

This is sufficient to give improved commutation.

If a machine gives difficulty with commutation, it can often be cured by fitting new brushes having a higher contact resistance than the old ones. Brushes of high resistance often have a high coefficient of friction, and if such a change is made it is necessary to make sure that the armature temperature rise does not become too much high because of the increased brush friction. The specification for machines normally limits the temperature rise of the commutator to 45^{O}C.

7. SUMMARY

Information has been given about commutation of DC machines, use of high contact resistance type carbon brushes, cause of sparking and how to avoid it, which would prove to be important to understand behavior of DC machines. The contribution of commutating poles to improve commutation has been described so that their importance is appreciated.

8. SELF-ASSESSMENT EXERCISES

1. Justify the use of high contact resistance type carbon brush in traction machines for improving commutation.
2. What do you mean by emf commutation? How does it made proper by using commutating poles?
3. Why an Electro-graphite carbon brush is used in traction machines? Justify.

UNIT 2.4 CARBON BRUSHES

OBJECTIVES

On completion of this unit, you should be able to understand:

- Brush material
- Brush angles
- Types of brushes
- Electrical characteristics of brushes
- Selection of brush grades
- Service performance of brushes
- Analysis of commutation problems
- Technical data of brushes
- Carbon brushes for BHEL machines

STRUCTURE

1. Introduction
2. Brush material
3. Brush angles
4. Types of brushes
5. Electrical characteristics
6. Selection of brush grades
7. Service performance
8. Analysis of commutation problems
9. Technical data
10. Carbon brushes for BHEL machines

1. INTRODUCTION

Brushes provide connection between rotating armatures and external circuitry, and play a major role in satisfactory commutation of DC machines.

During commutation, in the armature coil under short circuit by the brush, the current reverses from +I to -I. Since the change of current takes place in a very short period, an emf is induced in the armature coil undergoing commutation. Commutating poles are provided to nullify this emf by creating an equal and opposite voltage in the same coil. However due to design limitations/manufacturing tolerances, it is not possible to totally balance out the induced emf (known as reactance voltage), and therefore the residual voltage in the coil causes a circulation of current, which appears in the form of sparking under the brushes. As the process of commutation became more apparent, it was realised that a brush of comparatively higher resistance could materially assist the commutation.

In the early experimentally period, before 1880, when DC motors were under development, copper brushes, in the form of brush and not as a solid block, were used. It was from the early period that the term brush emanated, and is still continuing. Copper brushes used to cause high commutator wear, heavy sparking, and even welding into the commutator surface. these problems and the fact that higher resistance of the brush assists commutation, led to the use of the carbon as a brush material.

The other reason for using carbon for brushes on electrical machines is that the wear of the carbon brush and electrical erosion, considerably exceeds that of commutator resulting in higher commutator life.

Charles Van Depoele, one of the early traction pioneers in America, was the first to try brushes made of carbon on traction motors after successful trials in 1884.

2. BRUSH MATERIALS

Carbon is used for the brush in the following forms:

1. Natural Graphite
2. Hard Carbon
3. Electro-graphite Carbon
4. Metalized Carbons and Graphite

These grades of carbon are obtained by varying the combination of raw materials, and the processes followed for mixing them. The following chart shows the cycle used for production of non-metallic carbon brush material. flow sheet for the production of non-metallic brush material

A few examples of processes and material variants and their usual effect on the performance are given below:

Raw materials

Graphite - decrease friction

Copper, Silver - decrease contact drop

Pressing

Pressing at higher pressures reduce the porosity, give greater strength, increased brush life and narrower blackened results.

Graphitisation

Reduces the hardness, friction and specific resistance.

Impregnation

- Oils and waxes generally improve friction, stability and increase contact drop slightly.
- Resins strengthen brush material so that it becomes more resistant to breaking and chipping.
- PTFE reduces friction under humid conditions.
- Barium floride reduces friction and wear at very low humidity.

In view of the above an exceedingly complex multivariant relationship exists between the various aspects of performance requirements, specifications of raw materials and processing. Therefore, stability of a particular make and grade of brushes can only be established after extensive tests and trials.

For traction machines, the Electro-graphite grades are most suitably used. Technical data on some of the most commonly used brush grades for traction machines is given in annexure.

3. BRUSH ANGLES

Brushes are often defined by the methods of applying them to the commutator. They are three main classes:

1. Reaction
2. Trailing
3. Radial

(No. 1 & 2 are used only on non-reversing machines.)

Reaction Brushes

The brushes are said to be `reaction' or `leading' when the commutator is rotated against the angle of tilt i.e. the brushes are inclined in a leading direction. The angle between the centre line of the brush and the normal lines between 30 to 40 degrees.

Trailing Brushes

The brushes are said to be `trailing' when the commutator is run in the same direction as the brushes are tilted. The tilt angle usually lies between 7 to 15 degrees.

Radial Brushes

Traction motors are invariably fitted with radial brushes i.e. their centre line is radial to the commutator, which permits operation under similar conditions for both direction of rotation.

4. BRUSH TYPES

Split Brushes

Commutator, howsoever well designed and manufactured, losses its truness in the long run of service and high/low spots are often formed on its surface. The unavoidable commutator eccentricity gives rise to radial forces, which tend to break commutator to brush contact.

The split brush arrangements gives some freedom to each piece of carbon to move independently so that the commutator surface is closely followed and electrical contact is maintained. The biggest advantage is the resistance between leading and trailing edge of the split brush tends to reduce circulating currents.

Rubber-Top Brushes

Apart from damping the radial forces, the rubber-tops prevent passage of current through the brush holder springs. The springs thus do not get over heated and loose their tensions.

5. ELECTRICAL CHARACTERISTICS

(BRUSH TO COMMUTATOR CONTACT)

It is perhaps surprising that very little is known even today regarding brush to commutator phenomenon.

Microscopic study has revealed that area of the contact initially is only of the order of 1/4000th of brush area. As the machine is started, due to very high current density at these contact points, the carbon gets heated up and a gaseous layer is formed between the brush and commutator, which helps in current conduction. The commutator losses its fresh copper colour, and initial high brush wear (due to initial high friction and high current density), gradually comes down. The colour of the film on commutator becomes stable after some hours, or in some cases after several days of running, depending on the operating conditions. If no mechanical/electrical or thermal disturbances occur, brush tracks present an uniform polished colour, varying from dark chocolet to mild black.

During the course of service, the first indications of any commutation problem due to internal or external factors are often revealed from the condition of the commutator film. It is therefore extremely necessary to have adequate familiarity of the different types of the commutator films. This information is usually given in the brush literature. IEC specification No. 276 gives illustrations of some typical films. Part 4. of IS-3003, also includes some of such specifications.

6. SELECTION OF BRUSH GRADES

Brush grade selection involves considerable tests both on the test bed and under actual service conditions. It is sometimes found that brushes which are considered satisfactory on the test bed do not operate satisfactorily in service. In view of this, the proper grade can only be selected after suitable service trials and evaluation.

Indian Standard Specification IS-3003 covers dimensions, requirements and test procedures for carbon brushes.

Divergence in the physical properties and dimensions of carbon brushes can cause considerable trouble in service. Verification of the properties involves exhaustive testing, and since the carbon brushes are required to be procured rather frequently, it is not practicable to carry out such a large amount of tests on each lot purchased. It is extremely important, therefore, to restrict the brush procurement from established and well proven sources only, even if the prices may be higher. Also, whenever a new supply source or a new brush grade is considered, detailed tests/service trials should be carriied out before approving the same for bulk use.

Some of the defects usually noticed on the carbon brushes are:

1. Dimensions not confirming to the drawing
2. Bowed/Curved and chipped carbons
3. Poor quality of pig tails, which results in their getting frayed/broken in service
4. Bad joints between pigtail and carbons, resulting in high unequal voltage drops across the same
5. Hair line, invisible cracks at pigtail to carbon joints
6. Physical properties not conforming to the grade

7. SERVICE PERFORMANCE

Howsoever good may be the design/manufacture of the machine, and the quality of the brushes, satisfactory performance cannot continue to be obtained without resorting to regular and proper maintenance of the brush-gear and commutator.

The importance of early detection of commutation troubles cannot be over emphasized. As such it is imperative that from the time the machines are commissioned, suitable statistical information should be collected on the basis of regular observations. Analysis of the data thus collected will help to avoid the possibility of any particular commutation problem assuming epidemic proportions.

Section II of BHEL's Workshop Manual covers the aspects which govern the satisfactory commutating performance of traction machines. In this section guidelines for operation, maintenance and trouble shooting are also covered.

8. ANALYSIS OF COMMUTATION PROBLEMS

The commutation problems are caused by several factors, some of which are enumerated here:

8.1 Carbon brushes

Poor quality of brushes, bad carbon to pigtail joints, wrong brush grades, mixing of grades on same machine, brushes too loose or tight in brush holders, improper bedding, brushes too thin or thick, brush angles not correct, etc.

8.2 Brush Gear

Brushes in incorrect positions, low or high spring tensions, unequal current sharing by brushes of the same arm, incorrect brush stagger, spring carrying current, excessive vibrations due to poor/defective mounting of brush holders, high brush box to commutator clearance, unequal pressure on parts of split brush, brush holders prone to flashover damages, poor accessibility for maintenance, etc.

8.3 Commutator

Eccentricity, ovality, high and low bars, flats on commutator, pround mica, oily or dirty surface, bridging of mica grooves, rough surface, high commutator temperatures, inadequate stability due to poor seasoning, etc.

8.4 Machine Faults

Compole strength and gaps not correct, clogged ventilation ducts, poor ventilation, defective armature bearings, dynamic unbalance, wrong connections of compole or main field windings, armature or field winding faults, inadequate equalization, commutating zone too narrow or unsymmetrical, poor commutation performance in general, saturated compoles, low field/armature ampere turns ratio, etc.

8.5 External Causes

Excessive vibrations due to defects in machine mounting or defective bogie designs or poor rail track, leakage from ventilation ducts, collapsed bellows, prolonged light load running, rapidly fluctuating or excessive loads, faults in control circuitry, mal-operation of line contactors, unequal load sharing by machines, excessive wheel slips or wheel locking, humid or corrosive atmosphere, towing of motors without lifting the brushes, oil/water/brake-shoe-dust coming with cooling air, high voltage transients, high ripple contents, poor maintenance, inadequate facilities in maintenance depots, etc.

Annexure-1

TECHNICAL DATA FOR CARBON BRUSHES

	EG0 (M)	EG236S (M)	EG14D (M)	EG225 (M)	EG59 (RE)	EG259 (M)	EG7097 (LC)	EG389 (LC)	EG6754 (LC)
Normal current density (Amp/cm2)	10	11	9.5	11.0	11.5	8.5	10	10	10
Contact drop at normal current (Volts)	1.0	1.4	1.25	1.15	1.25	1.65	2.5	2.5	2.5
Specific resistance (ohm-cm)	1100	2200	4200	4100	5100	5800	4100	1700	4000
Apparent density (gms/cm2)	1.15	1.6	1.72	1.48	1.65	1.73	1.62	1.46	1.72
Coef. of friction	11	. 11	. 11	. 14	.15	. 05	.15	. 15	.15
% porosity (Apparent)		20	13.2	27.0		13			
Shore hardness (Scleroscope)	36	65	77	34	65	65	70	30	86
Compr. strength (Kg/cm2)		410	840	230		750			
Transverse band strength (Kg/cm2)	210	180	250	130	210	300	320	270	390
Shear strength (Kg/cm2)		98	250	46		310			
Normal max. speed (M/sec)	20	50	45	50	50	50	50	45	45

Note: Most carbon materials are of a brittle granular structure, thus the physical properties can not be held within close tolerances. The figures quoted above therefore are typical values but considerable variability is to be expected between individual measurements.

Annexure-2

CARBON BRUSHES FOR BHEL TRACTION MACHINES

Sl.No.	Machine Type	Brush Grade	Size (TxWxL)	Drg. No.	Qty./Machine
1.	133AY / 133AX	EG14D Morgan	2(9.5X63.5X57)	D4775841	4
2.	253BW / 253AZ/ TM4601AZ/TM4603AZ	EG14D Morgan/ EG7097 Le Carbone	2(12.7X44.45X60)	D4775798	8
3.	TM4939AZ/165/165M	EG14D Morgan/ EG6754 Le Carbone	2(9.5X57.15X51)	D4775839	12
4.	AG15/AG2513	RE59 Ringsdroff	12.7X31.75X44.45	D4775293	8
5.	MG51 (GENERATOR)	RE59 Ringsdroff	12.5X31.75X43.2	D4775077	4
6.	MG51 (MOTOR)	EG225 Morgan	2(6.35X22.2X43.2)	D4775076	2

7.	TG10931/TG10919 EG389 Le Carbone	EG225 Morgan	2(11.1X31.75X64)	D4775851	60
8.	EC9005/2	EGO Morgan	9.5X9.5X25	B4900350	4
9.	TM2701AZ	EG14D Morgan	16X64X65	D4775847	2
10.	TM3603AZ	EG14D Morgan	2(11X40X60)	D4776200	8

9, SUMMARY

In DC-DC and AC-DC diesel locomotives, a large number of DC machines have been used. Carbon brushes play an important role in these machines. Understanding the characteristics and its working helps the maintainers/users to run the machines trouble free. The brush material, brush rigging, types of brushes and electrical characteristics help the users in selecting proper grade for a particular application. The service performance is recorded and monitored in order to decide the proper selection of brush grade too.
Commutation in DC machines is a critical phenomenon. Proper analysis of commutation problem helps in minimising the troubles. This unit also contains technical data of different carbon brushes, which are in use. A chart showing grades of brushes for specific application is given to help the reader .

11. SELF ASSESSMENT EXERCISE

1. Describe, How do you select a brush grade for an application.
2. Why is it necessary to monitor service performance of brush.
3. How do you analyse the commutation problem of a DC machine.
4. Why are the brushes placed at an angle in unidirectional machines.
5. Describe the process to obtain an Electro-graphite brush material.

UNIT 2.5 FLASHOVER

OBJECTIVES

On completion of this unit, you should be able to:

- Describe the cause of flashover.
- Detect a machine running with the risk of flashover.
- Suggest remedial actions.

STRUCTURES

1. Introduction
2. The trouble
   2.1 Dirt
   2.2 Loss of contact
   2.3 Sudden extreme load changing
3. The ultimate effect
4. Detection and remedy
5. Summary
6. Self-assessment exercises

1. INTRODUCTION

Flashovers are caused. They do not just happen. Something seems puzzling and mysterious only if it is not understood. With the gain of knowledge, the mystry disappears. If any one can find out what flashovers are and how are they caused, what to do to prevent them, that makes sense.

A generator flashover, seen for the first time, is truly awesome. The blast of fire, the smoke and noise are enough to make one jump as if it was a stroke of lightening. The traction motor flashover is also caused in the same way.

The commutator is the stage on which the flashover appears. Fig. 1 shows how the commutator is built up of copper segments separated from each other by thickness of mica. Each pair of segments has an armature coil connected between them. Electricity enters by way of one set of brushes, through the copper segments and into the winding. When it reaches the segment under the other set of brushes, it leaves. The mica insulation separates the copper segments and keeps the electricity flowing through the armature coil. If this insulation breaks down, electricity will short cut across the surface of the commutator. Almost instantly, the current jumps from one brush holder to other brush holder with explosive force forming an arc. This is known as flashover.

2. THE TROUBLE

The voltage between the segments of a machine is quite low and the thicker mica has an insulation capacity many times greater for the purpose. What then causes such relatively wide spaces to breakdown and permit the machine to flashover ? (Fig. 2 indicates the distribution of voltage.) Across the top of the mica, there is an air space. If dirt does collect at these spaces and packs between the segments, the current begings to leak through it. The space is made wide so that it will take longer to fill with dirt and be harden to bridge. If the space is not cleaned in time, insulation breaks down and flash over may result. These insulating space may also be bridged by copper fins or copper dust left over from stonning and resurfacing the commutator. Dirt and foreign materials are not the only cause of flashover. Air, being a good insulator is broken down into conductive gas by the action of intense heat. The change of air to a conductive gas is known as ionisation. It can be caused by flame or spark, by high voltage or by certain kinds of radiation.

Under certain operation conditions, motor or generator brushes will spark. The affect of this is not always serious. What happens depends upon how intense the sparking is and how long it lasts. Under some abnormal condition the spark at the brush may be so vicious and hot that it blasts a cloud of conductive gas and fiery particles across the commutator surface. These bridge the spaces between segments and electricity short cuts across the commutator surface. Every thing is then set for a flashover. The intense spark that sets off a flash over may occur when a brush bounches off the commutartor while the machine is carrying a load. It may also occur when there is a sudden extreme change in load, for greater than the machine can handle. The insulating spaces between the segments may be bridged by hot conducting gases generated by the intense heat resulting from :-

i) Dirt between segments which burns when current flows through it.
ii) Loss of contact of brushes from commutator which draws a hot spark.

iii) Intense sparking at the brushes caused by sudden extreme load changing.

2.1 DIRT

Dirt and foreign particles in the insulating space between commutator segments caused the majority of the flashovers. When enough dirts collects to bridge the space between segments, current begins to leak across (Fig. 5A) . The dirt heats and fuses into a better path. Current flow incfreases, specially as the oeprating voltage increases. The spot grows , and finally begins to glow (Fig.5B). As the commutartor turns, these glowing spot looks like a continuous ring of fire. Finally the spot gets white hot. Then it errupts conductive gases and incandescent particles (Fig.5C). As the commutator turns (Fig.6A), these form a fiery trail behind the spot. These breaks down the insulating air space between segments that may not be glowing and sets the stage for next act.

The current short cuts (Fig.6B) from the hot spot, across the segments bridged by the firery gases, back to the brush holder in a sizzling vicious spark. The intense heat and energy in these spark blast conductive gases acrosss the commutator circuit (Fig.6C) with explosive violence. The gas cloud races ahead of the glowing spot and breaks down the air resistance across the rest of the commutator from brush to brush, then full power of the machine jumps across (Fig.6D) in the final flashover.

2.2 LOSS OF CONTACT

Dirt may be the most frequent, but it is not the only cause of flashovers. Sometimes loss of brush contact will be to blame. These may be expected at high speed with a rough commutator surface or weak brush holder springs. It may also occur when brushes are jammed in the holders by muck or dirt so that they cannot follow the commutator surface quickly enough. Servere mechanical shock may jar the brush off the commutator.

If brush breaks contact with the commutator, it draws an electric arc (Fig.7). If these are severe enough, it will spray conductive gases over the commutator. If the fiery gas bridges enough segments, the collective voltage will cause the current to arc back to the brush (Fig.6B). The blast of conductive gas from these arc back may reach across the surface of the commutator to the next brush (Fig.6C). The full power of the machine then flashes over these short cut path (Fig.6D). Again, instead of doing useful work, the energy will be expanded in the terrifically hot, destructive blast of flashover.

2.3 SUDDEEN EXTREME LOAD CHANGING (The surprise attack)

Flashovers, that occur when the commutator is in perfect mechanical and electrical condition are most complexing. These are caused by sudden and extreme change in load, too great for machine to handle. Fig. 8A shows that, in a machine, current divides as it enters the winding. It remits and leaves through the out going brushes. Current flows in one direction when the coil is on one side of the brush and in the opposite direction when it gets to the other side. So the current must reverse in the split second it takes for the coil to pass under the brush, which is known as commutation.

If the current does not reverse in time the coil will come out from under the brush with the current still flowing in old direction. The meeting point with the current in other part, which is known as neutral point will no longer will be in the brush. This shifting of neutral point corwds the current to one edge of the brush. Then it breaks out over the surface of the commutator in a spark to reach in a shifted point (Fig.8B).

The greater the current, the harder it is to get it all completely reversed as the coil zips under the brush. Machines have interpoles or commutating poles , to speed up this current reversal and keeps the neutral point under the bursh. These are smaller poles located between the main poles in the machine frame. They help commutation only. The magentism of these poles builds up a voltage in the armature coil as they pass through the zone covered through the brush contact. This voltage speeds up the current reversal to get it done before the coil leaves the brush contact.

These poles are designed to do a good commutating job up to, and even beyond full load. When , however, a very overpowering current flows through the winding, the magnmetism in the iron cannot build up quickly enough. This means there is not enough voltage to reverse the current in time and sparking results. Moreover, as after saturation of the pole pieces no more magnetism can be expected , hence, there is a limit to the help the pole can give in reversing the current in the coil. When the current gets so heavy that this help is not enough then this sparking is the ultimate result.

When the machine is operating at full voltage, the jolt of sudden extreme overload causes vacious sparking at the brushes. Conductive gas bridges segments (Fig.8C). Current starts leak over the commutator surface (Fig,6B). The blast of fiery gas completes the short circuit between the brush holder (Fig.6 C&D).

Every day motors and generators demonstrate their ability Still the flashover occur if anything goes wrong. For instance, a contactor fails to operate momentarily, short circuiting generator.

A sudden surge of current occurs during high speed wheel slip. Taking a cross over at high speed may cause a brush of motor to bounce and flash a motor over. It is just like short circuiting of the generator because the current is no longer flowing through the motor winding, but short cutting across the commutator. So the current drawn from the generator reaches unreasonably high value. It knocks the generator off balance. The heavy sparking and flashover is the knock out blow.

3. THE ULTIMATE EFFECT

The space surrounding the commutator is filled with flame and conductive gases. These reach between brush holder and also over the frame part of the machine. Current can now flow from the brush holder to the frame and through the frame back to opposite bursh holder.

Flashover current can also strike from the commutator circuit through the fiery gases to the steel commutator cap. From here it finds its way to ground through shell, armature shaft and bearing. This is the cause of electric pitting of roller bearings and races.

When the confined space around the commutator is filled with ionised air and flame, the current can strike in many directions with destructive force (Fig.9). String bands are burnt, brush holders are flashover, bearings are damaged and if grease and dirt are present they may be set on fire. However, the current strikes the ground and it is detected by the ground relay.

4. DETECTION AND REMEDY

Detection of these types of defects can only be done visually. Insulation resistance between the segments cannot be taken with the help of a meter as they are connected to the windings. Megger readings and high pot tests are of no good because they check what is called resistance to ground.

Inspecting the defects visually, they can be rectified by cleaning, undercutting mica so that they look white or grey, air curing the machine or by blowing the commutator surface with compressed air. In case of improper or inadequate brush pressure, the brush gear can also be attended. Polishing, grinding or machining may also be required if the commutator surface is rough, having the defects of high bar etc. In some of the cases short circuited or open circuited winding may also cause flash over and can be detected by bar to bar milli-volt drop test or taking the micro ohm readings.

5. SUMMARY

Flashover of DC machines is a chronic disease. It is the prime cause of pre-mature failures of most of the DC machines. Moreover, it remains a mystery to the user that when the machine will fail and how an expert rectified the fault. This unit describes the causes of the flashover due to dirt deposition, loss of contact of carbon brushes and sudden extreme load changing, which are very common in case of traction machines.

Stage wise development of defects and ultimate effect on the machine has been elaborately described to help the maintainer to understand these defects and take remedial measures. Checking to judge the healthiness of the machine has also been described.

6. SELF ASSESSMENT EXERCISES

1. Describe how does the dirt deposition on the commutator surface lead to flashover.
2. Describe the reason of flashover due to loss of contact between the carbon brush and commutator.
3. Describe the process of detection and remedy of a machine suffered from flashover.