SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
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Department of Electrical and Electronics Engineering

Subject Name: Electrical Machines - I **Subject Code: EE T33**

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UNIT II

DC GENERATOR

Elementary concepts of rotating machines – mmf of distributed winding - DC Generator-Construction – Lap and wave winding – emf equation-excitation and types of generators-Characteristics - armature reaction-methods of improving commutation-testing power flow diagram Applications

Two Marks

1. **What is the principle of generator?**

   When the armature conductor cuts the magnetic flux emf is induced in the conductor.

2. **How will you find the direction of emf using Flemings right hand rule?**

   The thumb, forefinger & middle finger of right hand are held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of the lines of flux, thumb gives the direction of the relative motion of conductor and middle finger gives the direction of the emf induced.

3. **What is prime mover?**

   The basic source of mechanical power which drives the armature of the generator is called prime mover.

4. **What are the essential parts of a d.c generator**?

   1.Magnetic frame or yoke 2. Poles 3. Armature 4. Commutator, pole shoes, armature windings, interpoles 5. Brushes, bearings and shaft.

5. Give the materials used in machine manufacturing?

There are three main materials used in m/c manufacturing they are steel to conduct magnetic flux and copper to conduct electric current insulation.

6. What is the purpose of yoke in d.c machine?

1. It acts as a protecting cover for the whole machine and provides mechanical support for the poles.

2. It carries magnetic flux produced by the poles

7. What is the function of carbon brush used in dc generators?

The function of the carbon brush is to collect current from commutator and supply to external load circuit and to load.

8. Why the armature core in d.c machines is constructed with laminated steel sheets instead of solid steel sheets?

Lamination highly reduces the eddy current loss and steel sheets provide low reluctance path to magnetic field.

9. What are factors on which hysteresis loss?

It depends on magnetic flux density, frequency & volume of the material.

10. What is core loss? What is its significance in electric machines?

When a magnetic material undergoes cyclic magnetization, two kinds of power losses occur on it. Hysteresis and eddy current losses are called as core loss. It is important in determining heating, temperature rise, rating & efficiency of transformers, machines & other A.C run magnetic devices.

11. What is eddy current loss?

When a magnetic core carries a time varying flux, voltages are induced in all possible path enclosing flux. Resulting is the production of circulating flux in core. These circulating current do no useful work are known as eddy current and have power loss known as eddy current loss.

12. How hysteresis and eddy current losses are minimized?

Hysteresis loss can be minimized by selecting materials for core such as silicon steel & steel alloys with low hysteresis co-efficient and electrical resistivity. Eddy current losses are minimized by laminating the core.

13. Write down the emf equation for d.c.generator? April 2015

$E=(\Phi NZ/60)(P/A)$ Volts.

p -------- no of poles

Z --------Total no of conductor

Φ -------- flux per pole

N --------speed in rpm.

14. Differentiate lap winding and wave winding? April 2013

Sr. No.	Lap winding	Wave winding
1.	Number of parallel paths (A) = Poles (P)	Number of parallel paths (A) = 2 (always)
2.	Number of brush sets required is equal to number of poles.	Number of brush sets required is always equal to two.
3.	Preferable for high current, low voltage capacity generators.	Preferable for high voltage, low current capacity generators.
4.	Normally used for generators of capacity more than 500 A.	Preferred for generators of capacity less than 500 A.

15. Define armature reaction? April 2015, Nov‟2013, Nov‟2012

The effect of armature flux on the distribution of main flux is called armature reaction.

16. Define critical resistance April 2014

A tangent line is drawn to the linear portion of open circuit characteristics from origin. The slope of this tangent is called critical resistance.

17. What are applications of DC generators? April 2013

(i) Used for general lighting, charge batteries and giving excitation to the alternators

18. What is critical resistance of a DC shunt generator? April 2014

a) Under no load condition, the shunt field resistance should be less than the critical resistance.

b) Under load condition, the shunt field resistance should be more than the critical resistance.

19. What is the function of compensating windings in dc machines? April 2012

To neutralize the armature flux in the pole arc region this will otherwise cause severe distortion of main field flux.

20. What is short pitched coil? Nov‟2014

If the coil span is less than the pole pitch, then the winding is referred as short pitched coil.

21. What are the conditions are for buildup of voltage in a shunt generator? April 2014

- The residual magnetism must be present in the poles.
- The field winding must be properly connected with the armature.
- Under no load condition, the shunt field resistance should be less than the critical resistance.

- Under load condition, the shunt field resistance should be more than the critical resistance.

22. What is the importance of residual emf in a self excited DC generator? April 2012

The residual emf in a self excited dc generator is used to develop emf in an armature.

23. How can one differentiate between long shunt compound generator and short shunt compound generator? Nov‟2013

The series field winding won‟t carry any current under no load condition whereas in long shun motor series winding will carry no load current

24. Define distributed winding? Nov. 2014

When coil-sides belonging to each phase are housed or distributed in more than one slot under each pole region then the winding is called distributed winding

Examples of distributed winding are the armatures and D.C. machines.

25. Why commutator is employed in d.c.machines?

Conduct electricity between rotating armature and fixed brushes, convert alternating emf into unidirectional emf(mechanical rectifier).

26. Distinguish between shunt and series field coil construction?

Shunt field coils are wound with wires of small section and have more no of turns. Series field coils are wound with wires of larger cross section and have less no of turns.

27. Define the term commutation in dc machines?

The reversal of current is likely to take place in short interval when a coil is short circuited by a brush so that transfer of current from one direction to other is carried without any sparking. This process is called commutation.

28. What is mean by excitation?

The process of generating a magnetic field by means of an electric current is called excitation.

29. What is critical field resistance and critical speed?

Critical field resistance

If field resistance is more than critical resistance at start than induced emf fails to drive current through field circuit and generator fails to excite at given speed.

Critical speed

Critical speed of a generator is that speed for which the given field resistance will represent critical field resistance. Is the speed is below the critical speed the generator would fail to excite.

30. Under what circumstances does a dc shunt generator fails to generate?

Absence of residual flux, initial flux setup by field may be opposite in direction to residual flux, shunt field circuit resistance may be higher than its critical field resistance, load circuit resistance may be less than its critical load resistance.

31. How and why compensating winding in dc machine excited?

The compensating winding is excited by connecting in series with the armature and it is basically used to neutralize the armature flux in the pole arc region which will otherwise cause severe distortion of main field flux.

32. What are two unwanted effects of armature reactions?

Cross magnetizing effect & demagnetizing effect.

33. What is mean residual flux and residual voltage ?

Residual magnetism (or) residual flux

The magnetic field that remains in a magnetic material (a winding core) after the removal of electric power or the magnetizing force.

Residual voltage

The voltage which is induced due to residual flux (some flux stored inside the machine) is called residual voltage.

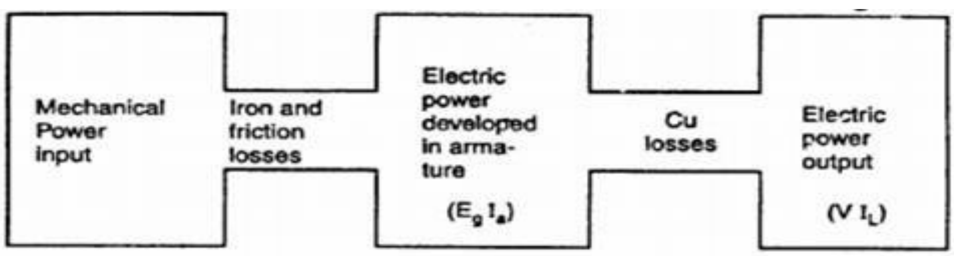
34. Why is the emf not zero when the field current is reduced to zero in dc generator?

Even after the field current is reduced to zero, the machine is left out with some flux as residue so emf is available due to residual flux.

35. On what occasion dc generator may not have residual flux?

The generator may be put for its operation after its construction, in previous operation, the generator would have been fully demagnetized.

36. Draw the power flow diagram of DC generator?



37. What are the constant losses in a DC machine?

The losses in a machine which remain constant at all loads are known as constant losses. The constant losses in a d.c. machine are:

(a) iron losses (b) mechanical losses (c) shunt field losses

11 Marks

1. **Explain the construction and working of DC generator in detail and Derive the emf equation of a generator.** **April 2013, Nov' 2014**
2. **Describe the working principle of DC generator with neat diagram** **April 2012**
3. **Explain the the constructional details of a DC machine with relevant diagrams.** **April 2015**

INTRODUCTION

An electrical machine which converts mechanical energy into an electrical energy is called an **electric generator.** While an electrical machine which converts an electrical energy into the mechanical energy is called an **electrical motor.**

Such electrical machines may be related to an electrical energy of an alternating type called **a.c. machines** or may be related to an electrical energy of direct type called **d.c. machines.**

The d.c. machines are classified as d.c. generators and d.c. motors. The construction of a d.c. machine basically remains same whether it is a generator or a motor.

GENERATOR PRINCIPLE

An electric generator is a machine that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming‟s right hand rule. Therefore, the essential components of a generator are:

(a) a magnetic field

(b) conductor or a group of conductors

(c) motion of conductor w.r.t. magnetic field.

The magnitude of the induced e.m.f. is given by,

$$E = B \times l \times v$$

Where l = Active length of conductor in m.

v = Relative velocity component of conductor in m/s in the direction perpendicular to direction of the flux.

Simple

Loop Generator

If angle between the plane of rotation and the plane of the flux is 'θ' as measured from the axis of the plane of flux then the induced e.m.f. is given by,

$$E = B\,l\,(v \sin\theta) \text{ volts}$$

Thefollowing fig.2.1 shows a single-turn rectangular copper coil rotating about its own axis in a magnetic field provided by either permanent magnets or electromagnets. As the loop rotates, the fluxlinking the coil sides AB and CD changes continuously.

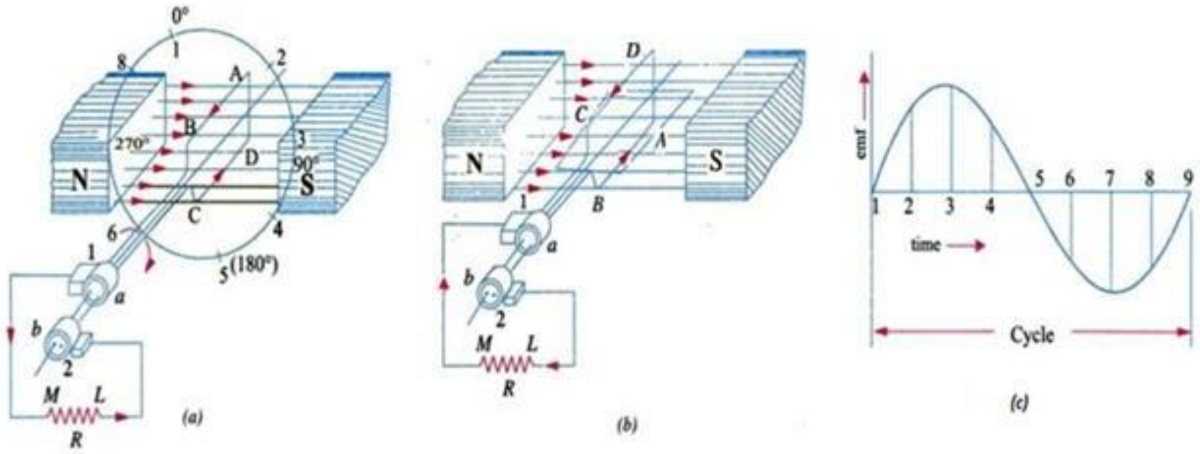


Fig.2.1

The two ends of the coil are joined to two slip -rings „a‟ and „b‟ which are insulated from each other and from the central shaft. Two collecting brushes (of carbon or copper) press against the slip-rings. Their function is to collect the current induced in the coil and to convey it to the external load resistance R. The rotating coil may be called „armature‟ and the magnets as „field magnets‟.

(i). When the loop is in position no. 1 [See Fig.2.1(a)], the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

(ii). When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 2 in Fig. (2.1(c)).

(iii). When the loop is in position no. 3, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum as indicated by point 3 in Fig. (2.1(c)).

(iv). At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle.

(v). At position 5, no magnetic lines are cut and hence induced e.m.f. is zero as indicated by point 5 in Fig. (2.1(c)). Hence, the direction of current flow in first half cycle is ABMLCD (Fig.2.1 (a)).

(vi). At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The maximum e.m.f. in this direction (i.e., reverse direction, See Fig. 2.1(c)) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil. Hence, the path of current flow is along DCLMBA (Fig.2.1 (a)).

Note that e.m.f. generated in the loop is alternating one. It is because any coil side, say AB has e.m.f. in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. If a load is connected across the ends of the loop, then alternating current will flow through the load. The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator or split rings (Fig.2.2(a)). The split rings are made out of a conducting cylinder which is cut into two segments insulated from each other by thin sheet of mica or some other insulating material (Fig.2.2(b)). We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

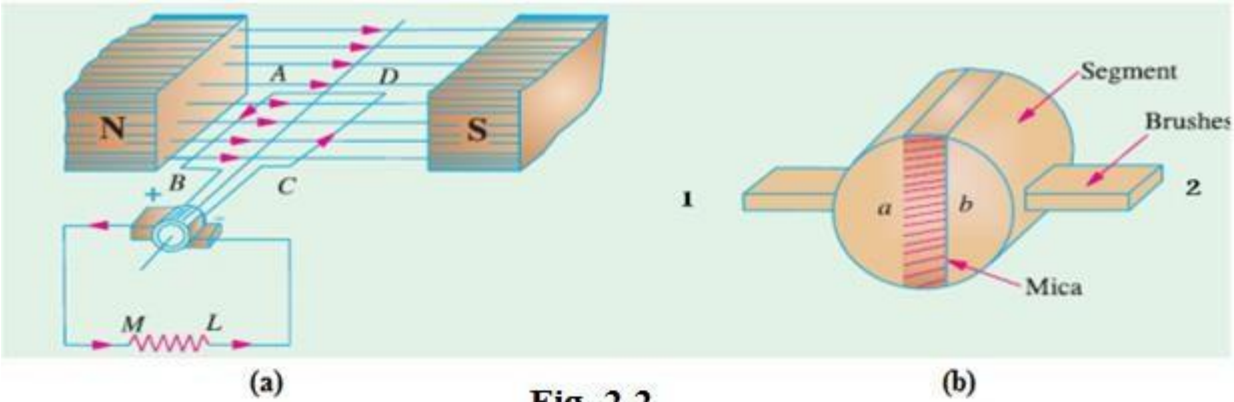


Fig. 2.2

It is seen (Fig.2.3(a)) that in the first half revolution current flows along (ABMLCD) i.e. the brush No.1 in contact with segment „a‟ acts as the positive end of the supply and „b‟ as the negative end. In the next half revolution (Fig.2.3(b)), the direction of the induced current in the coil has reversed. But at the same time, the positions of segments „a‟ and „b‟ have also reversed with the result that brush No.1 comes in touch with the segment which is positive i.e. segment „b‟ in this case. Hence, current in the load resistance again flows from M to L. The waveform of the current through the external circuit is as shown in (Fig.2.3(c)). This current is unidirectional but not continuous like pure direct current.

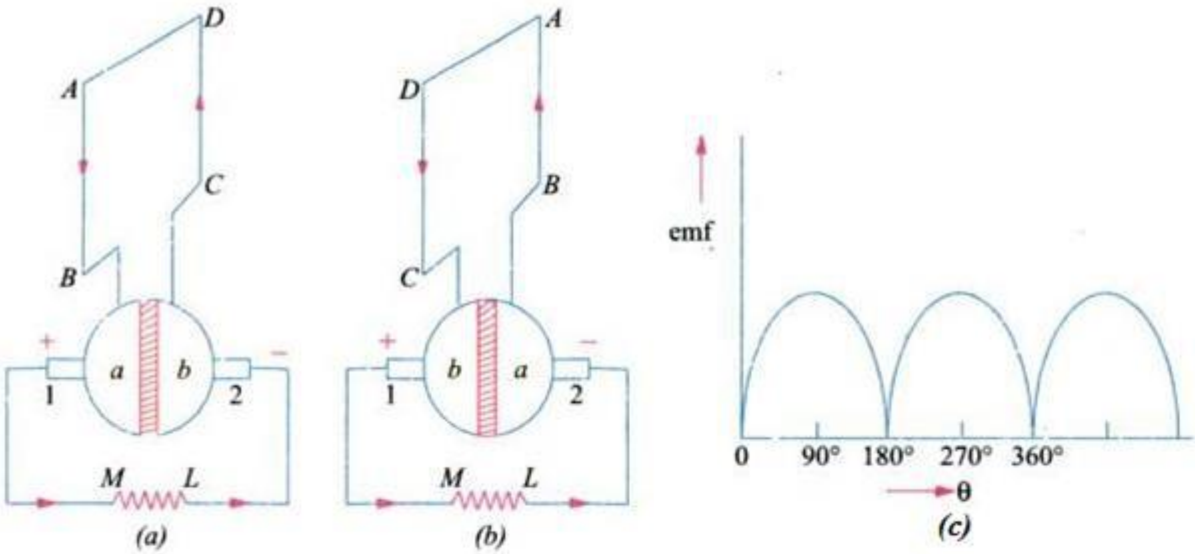


Fig.2.3

It should be noted that the position of brushes is so arranged that the change over of segments „a" and „b" from one brush to the other takes place when the plane of the rotating coil is at right angles to the plane of the lines of flux. It is so because in that position, then induced emf in the coil is zero.

The current induced in the coil sides is alternating as before. It is only due to the rectifying action of the split-rings (also called commutator) that it becomes unidirectional in the external circuit.

CONSTRUCTION OF A DC MACHINE

As stated earlier, whether a machine is d.c. generator or a motor the construction basically remains the same as shown in the Fig. 3.14.

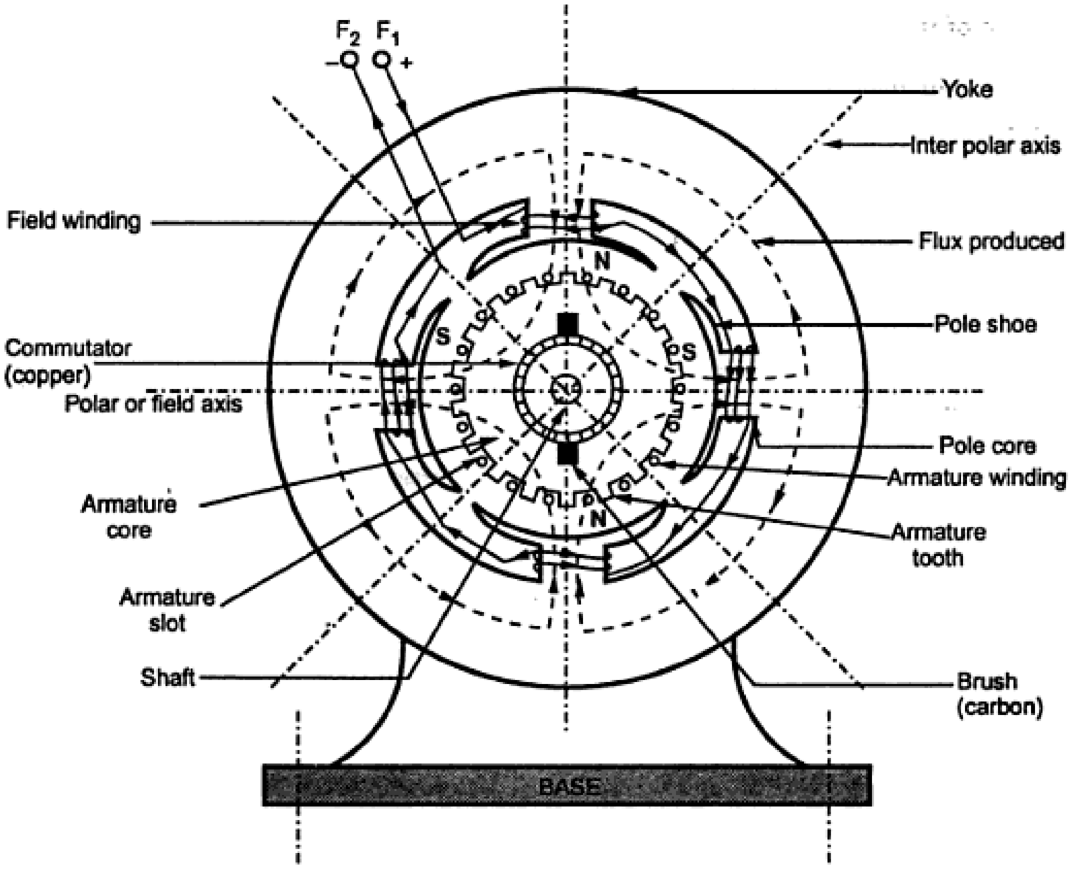


Fig. 3.14 A cross-section of typical d.c. machine

It consists of the following parts :

3.7.1 Yoke

a) Functions :

1. It serves the purpose of outermost cover of the d.c. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.
2. It provides mechanical support to the poles.

3. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. The low reluctance path is important to avoid wastage of power to provide same flux. Large current and hence the power is necessary if the path has high reluctance, to produce the same flux.

b) Choice of material : To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is cheapest. For large machines rolled steel, cast steel, silicon steel is used which provides high permeability i.e. low reluctance and gives good mechanical strength.

3.7.2 Poles

Each pole is divided into two parts namely, I) Pole core and II) Pole shoe

This is shown in the Fig. 3.15.

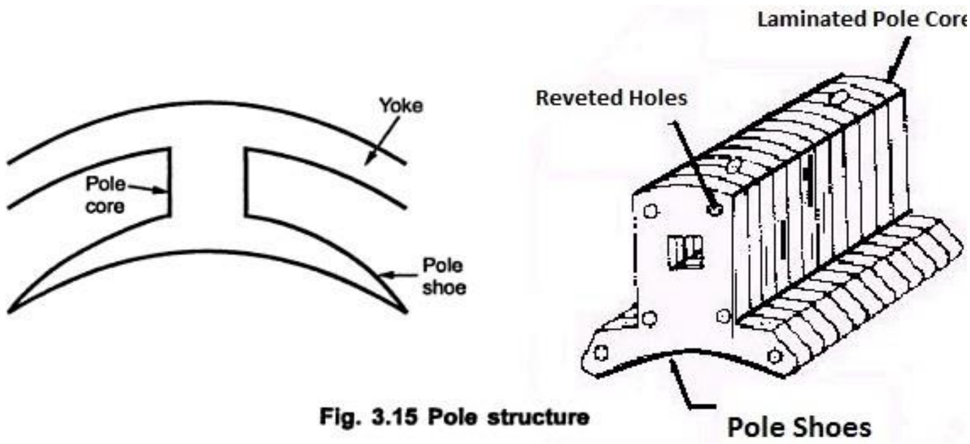


Fig. 3.15 Pole structure

a) Functions of pole core and pole shoe :

1. Pole core basically carries a field winding which is necessary to produce the flux.
2. It directs the flux produced through air gap to armature core, to the next pole.
3. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced e.m.f. To achieve this, pole shoe has been given a particular shape.

b) Choice of material : It is made up of magnetic material like cast iron or cast steel.

As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to the yoke.

3.7.3 Field Winding (F1 - F2)

The field winding is wound on the pole core with a definite direction.

a) Functions : To carry current due to which pole core, on which the field winding is placed behaves as an electromagnet, producing necessary flux.

As it helps in producing the magnetic field i.e. exciting the pole as an electromagnet it is called **Field winding or Exciting winding.**

b) Choice of material : It has to carry current hence obviously made up of some conducting material. So aluminium or copper is the choice. But field coils are required to take any type of shape and bend about pole core and copper has good pliability i.e. it can bend easily. So copper is the proper choice.

Key Point : *Field winding is divided into various coils called field coils. These are connected in series with each other and wound in such a direction around pole cores, such that alternate 'N' and 'S' poles are formed.*

By using right hand thumb rule for current carrying circular conductor, it can be easily determined that how a particular core is going to behave as 'N' or 'S' for a particular winding direction around it. The direction of winding and flux can be observed in the Fig. 3.14.

3.7.4 Armature

It is further divided into two parts namely,

I) Armature core and II) Armature winding

I) Armature core : Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

a) Functions :

1. Armature core provides house for armature winding i.e. armature conductors.
2. To provide a path of low reluctance to the magnetic flux produced by the field winding.

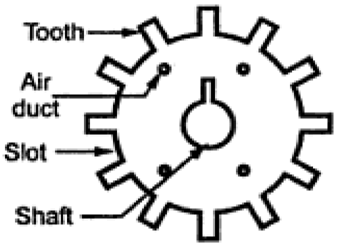


Fig. 3.16 Single circular lamination of armature core

b) Choice of material : As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.

It is made up of laminated construction to keep eddy current loss as low as possible. A single circular lamination used for the construction of the armature core is shown in the Fig. 3.16.

II) Armature winding : Armature winding is nothing but the interconnection of the armature conductors, placed in the slots provided on the armature core periphery. When the armature is rotated, in case of generator, magnetic flux gets cut by armature conductors and e.m.f. gets induced in them.

a) Functions :

1. Generation of e.m.f. takes place in the armature winding in case of generators.
2. To carry the current supplied in case of d.c. motors.
3. To do the useful work in the external circuit.

b) Choice of material : As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

Armature winding is generally former wound. The conductors are placed in the armature slots which are lined with though insulating material.

3.7.5 Commutator

We have seen earlier that the basic nature of e.m.f. induced in the armature conductors is alternating. This needs rectification in case of d.c. generator, which is possible by a device called commutator.

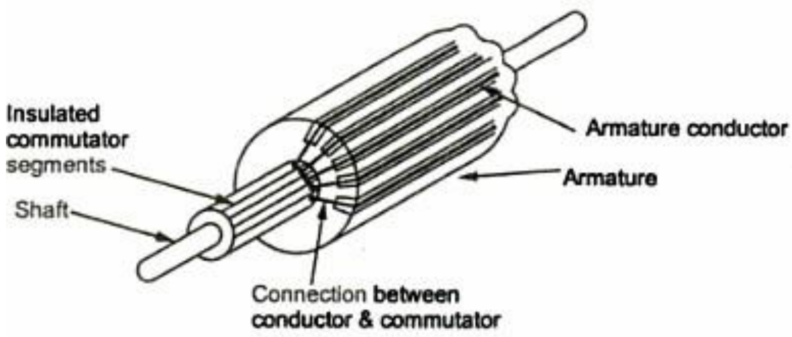


Fig. 3.17 Commutator

a) Functions :

1. To facilitate the collection of current from the armature conductors.
2. To convert internally developed alternating e.m.f. to unidirectional (d.c.) e.m.f.
3. To produce unidirectional torque in case of motors.

b) Choice of material : As it collects current from armature, it is also made up of copper segments.

It is cylindrical in shape and is made up of wedge shaped segments of hard drawn, high conductivity copper. These segments are insulated from each other by thin layer of mica. Each commutator segment is connected to the armature conductor by means of copper lug or strip. This connection is shown in the Fig. 3.17.

3.7.6 Brushes and Brush Gear

Brushes are stationary and resting on the surface of the commutator.

a) Function : To collect current from commutator and make it available to the stationary external circuit.

b) Choice of material : Brushes are normally made up of soft material like carbon.

Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called pig tail is used to connect the brush to the external circuit. To avoid wear and tear of commutator, the brushes are made up of soft material like carbon.

4. Explain the different types of DC generator

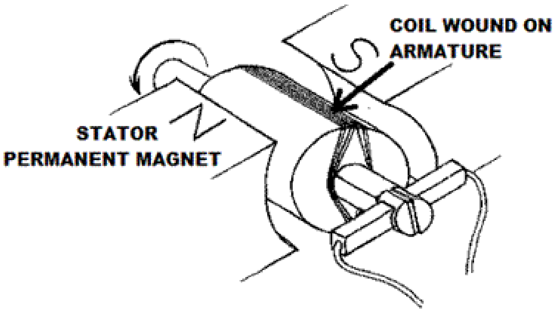
TYPES OF GENERATORS:

Permanent Magnet DC Generator:

When the flux in the magnetic circuit is established by the help of permanent magnets then it is known as Permanent magnet dc generator. It consists of an armature and one or several permanent magnets situated around the armature. This type of dc generators generates very low power. So, they are rarely found in industrial applications. They are normally used in small applications like dynamos in motor cycles.

3.7.7 Bearings

Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.



PERMANENT MAGNET DC GENERATOR

Separately Excited DC Generator:

These are the generators whose field magnets are energized by some external dc source such as battery.
A circuit diagram of separately excited dc generator is shown in figure.

Where,

I_a = Armat

I_L = Load c

V = Terminal voltage

E_g = Generated emf

Voltage drop in the armature = $I_a \times R_a$ (Ra is the armature resistance)

Let, $I_a = I_L = I$ (say)

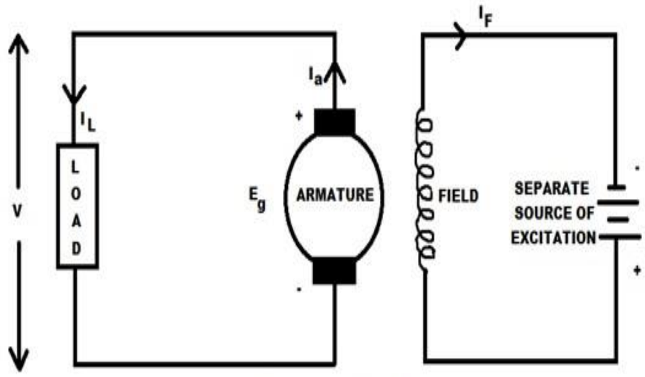
Then, voltage across the load, $V = IR_a$

Power generated, $P_g = E_g \times I$

Power delivered to the external load, $P_L = V \times I$.

Self-excited DC Generators:

These are the generators whose field magnets are energized by the current supplied by themselves. In these type of machines field coils are internally connected with the armature. Due to residual magnetism some flux is always present in the poles. When the armature is rotated some



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Separately excited DC generator

emf is induced. Hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux. As the pole flux strengthened, it will produce more armature emf, which cause further increase of current through the field. This increased field current further raises armature emf and this cumulative phenomenon continues until the excitation reaches to the rated value.

According to the position of the field coils the Self-excited DC generators may be classified as:

A. Series wound generators

B. Shunt wound generators

C. Compound wound generators

Series Wound Generator:

In these type of generators, the field windings are connected in series with armature conductors as shown in figure below. So, whole electric current flows through the field coils as well as the load. As series field winding carries full load current it is designed with relatively few turns of thick wire. The electrical resistance of series field winding is therefore very low (nearly 0.5Ω).

Let,

R_{sc} = Series winding resistance

I_{sc} = Current flowing through the series field

R_a = Armature resistance

I_a = Armature current

I_L = Load current

V = Terminal voltage

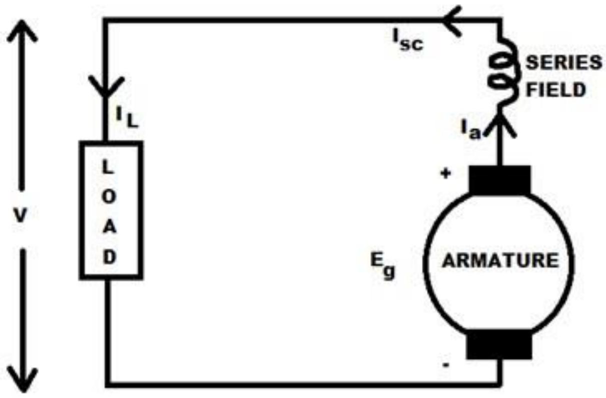
E_g = Generated emf

Then, $I_a = I_{sc} = I_L = I$ (say)

Voltage across the load, $V = E_g - I(I_a \times R_a)$

Power generated, $P_g = E_g \times I$

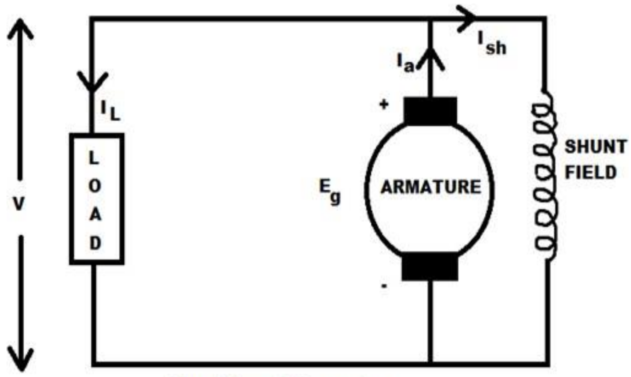
Power delivered to the load, $P_L = V \times I$



Series Wound Generator

Shunt Wound DC Generators:

In these type of DC generators the field windings are connected in parallel with armature conductors as shown in figure below. In shunt wound generators the voltage in the field winding is same as the voltage across the terminal.



Shunt Wound Generator

Let,

R_{sh} = Shunt winding resistance

I_{sh} = Current flowing through the shunt field

R_a = Armature resistance

I_a = Armature current

I_L = Load current

V = Terminal voltage

E_g = Generated emf

Here armature current I_a is dividing in two parts, one is shunt field current I_{sh} and another is load current I_L.

So, $I_a = I_{sh} + I_L$

The effective power across the load will be maximum when I_L will be maximum. So, it is required to keep shunt field current as small as possible. For this purpose the resistance of the shunt field winding generally kept high (100 Ω) and large no of turns are used for the desired emf.

Shunt field current, $I_{sh} = V/R_{sh}$

Voltage across the load, $V = E_g - I_a R_a$

Power generated, $P_g = E_g \times I_a$

Power delivered to the load, $P_L = V \times I_L$.

Compound Wound DC Generator:

In series wound generators, the output voltage is directly proportional with load current. In shunt wound generators, output voltage is inversely proportional with load current. A combination of these two types of generators can overcome the disadvantages of both. This combination of windings is called Compound Wound DC Generator.

Compound wound generators have both series field winding and shunt field winding. One winding is placed in series with the armature and the other is placed in parallel with the armature. This type of DC generators may be of two types- short shunt compound wound generator and long shunt compound wound generator.

Short Shunt Compound Wound DC Generator:

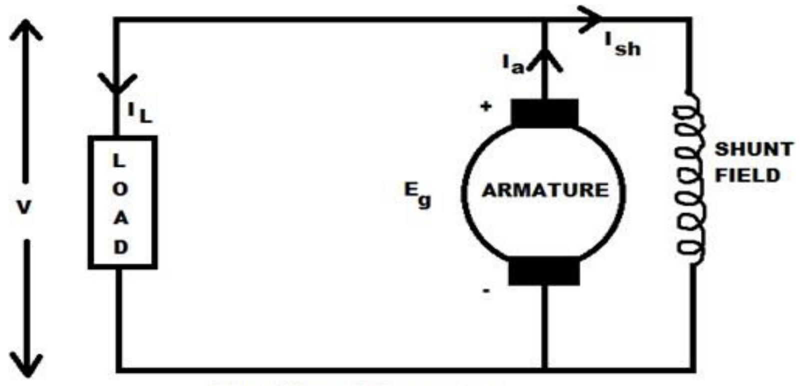
The generators in which only shunt field winding is in parallel with the armature winding as shown in fig.

Series field current, $I_{sc} = I_L$

Shunt field current, $I_{sh} = (V+I_{sc} R_{sc})/R_{sh}$

Armature current, $I_a = I_{sh} + I_L$

Voltage across the load, $V = E_g - I_a R_a - I_{sc} R_{sc}$



Shunt Wound Generator

Power generated, $P_g = E_g \times I_a$

Power delivered to the load, $P_L = V \times I_L$.

Long Shunt Compound Wound DC Generator:

The generators in which shunt field winding is in parallel with both series field and armature winding as shown in fig.

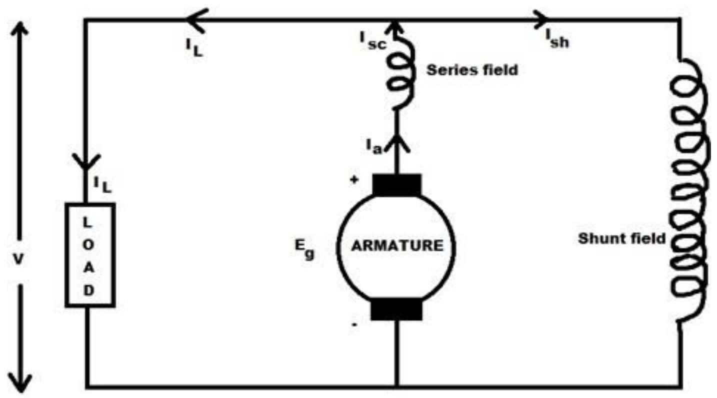
Shunt field current, $I_{sh}=V/R_{sh}$

Armature current, I_a= series field current, $I_{sc}= I_L+I_{sh}$

Voltage across the load, $V=E_g-I_a R_a-I_{sc} R_{sc}=E_g-I_a (R_a+R_{sc})$ [$\therefore I_a=I_{cs}$]

Power generated, $P_g= E_g\times I_a$

Power delivered to the load, $P_L=V\times I_L$



Long Shunt Compound Wound Generator

In a compound wound generator, the shunt field is stronger than the series field. When the series field assists the shunt field, generator is said to be commutatively compound wound. On the other hand if series field opposes the shunt field, the generator is said to be differentially compound wound.

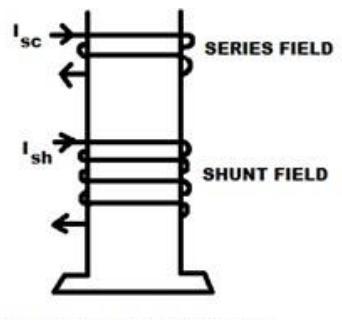
Fig 2.19 Current flow in field coils of Compound Wound DC Generator

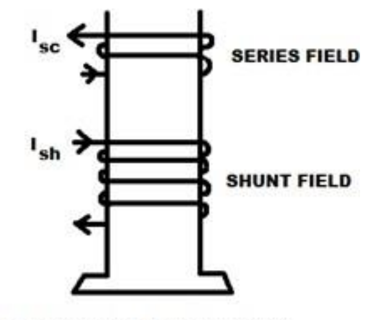
5. **Derive the expression for generated emf in a generator.** Nov‟2012
6. **Derive the emf equation of a generator.** April 2013, Nov‟ 2014

EMF equation of DC generator

Let

Φ = flux/pole in Weber


Isc
SERIES FIELD
Ish
SHUNT FIELD


Isc
SERIES FIELD
Ish
SHUNT FIELD

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

P = No. of generator poles

A = No. of parallel paths in armature

N = armature rotation in revolutions per minute (r.p.m.)

E = emf induced in any parallel path in armature

Generated emf (Eg) = emf generated in any one of the parallel paths (E).

Average emf generated/conductor = $\frac{d\Phi}{dt}$ volt

Now, flux cut/conductor in one revolution dΦ = ΦP Wb

No. of revolutions/second = N/60

Therefore, time for one revolution, dt = 60/N second

Hence, according to Faraday‟s Laws of Electromagnetic Induction,

EMF generated/conductor = $\frac{d\Phi}{dt} = \frac{\Phi \times P}{\frac{60}{N}} = \frac{\Phi P N}{60}$ volt

No. of conductors (in series) in one path = Z/A

For a simplex wave-wound generator: A=2

EMF generated/path = $\frac{\Phi P N}{60} \times \frac{Z}{2} = \frac{\Phi Z P N}{120}$ volt

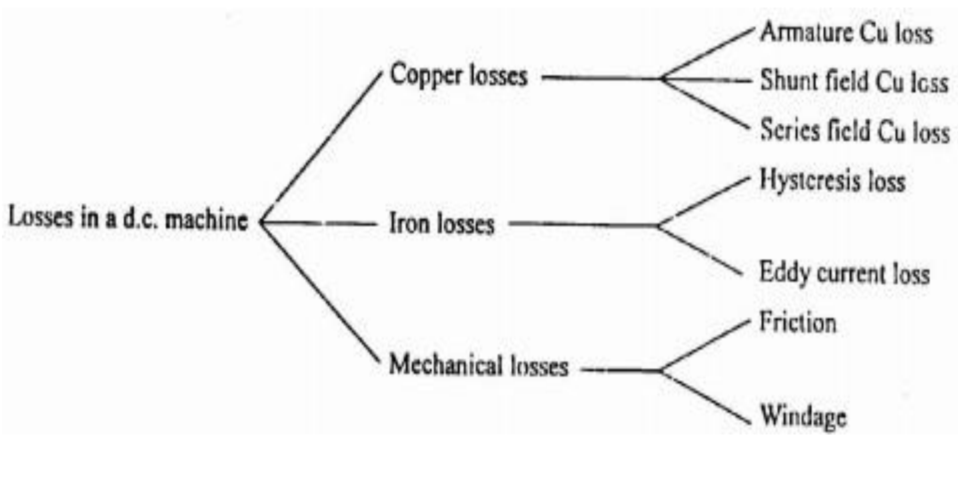
For a simplex lap-wound generator: A=P, No. of conductors (in series) in one path=Z/P

EMF generated/path = $\frac{\Phi P N}{60} \times \frac{Z}{P} = \frac{\Phi Z N}{60}$ volt

7. Explain the losses taking place in the DC generator

LOSSES IN DC GENERATORS:

Fig. 2.20


Losses in a d.c. machine
Copper losses
Armature Cu loss
Shunt field Cu loss
Series field Cu loss
Iron losses
Hysteresis loss
Eddy current loss
Mechanical losses
Friction
Windage

(a) Copper loss:

(i) Armature copper loss:

It is power loss in the armature circuit and equal to $I_a^2 R_a$. The value of armature current is decided by the load. This loss is about 30 to 40% of full -load losses.

Where,

R_a- Resistance of armature

I_a – Armature current

(ii) Field copper loss :

It is the loss in series or shunt field of generator. $I_{se}^2 R_{se}$ is the field copper loss in case of series generators, where R_{se} is the resistance of the series field winding. $I_{sh}^2 R_{sh}$ is the field copper loss in case of shunt generators. It is practically constant in case of shunt generators. This loss is about 20 to 30% of F.L losses.

(iii) The loss due to brush contact resistance. It is usually included in the armature copper loss.

(b) Magnetic Losses :(also known as iron or core losses)

Due to the rotation of armature in the magnetic field. There are some losses taking place continuously in the core and are known as iron losses or core losses. It consists of (i)eddy current loss and (ii)hysteresis loss

Hysteresis loss:

This loss is due to the reversal of magnetic flux in the armature core. Every portion of the rotating core passes under N and S pole alternately. There by alternating S and N polarity respectively. The core undergoes one complete cycle of magnetic reversal after passing under one pair of poles. If p is the number of poles and N, the armature speed in r.p.m. Then frequency of magnetic reversals is $f=\frac{PN}{120}$.

The loss depends upon the volume and grade of iron, maximum value of flux density B_{max} and frequency of magnetic reversals. For normal flux densities (i.e. upto 1.5 wb/m^2), hysteresis loss is given by steinmetz formula.

$$W_h = \eta B_m^{1.6} f v \quad \text{watts}$$

Where,

η – Steinmet hysteresis co-efficient.

B_m – Maximum flux density in Wb/m^2

f – Frequency of magnetic reversals. V – Volume of armature core.

Eddy current loss:

When the armature core rotates, it also cuts the magnetic flux; hence an e.m.f. is induced in the body of the core according to the laws of electromagnetic induction. This e.m.f. though small, sets up large current in the body of the core due to its small resistance, this current is known as eddy current. The power loss due to the flow of this current is known as eddy current loss. This loss would be considerable if solid iron core were used. In order to reduce this loss and the consequent heating of the core to a small value. The core is built up of thin laminations which are stacked and then riveted at right angles to the path of the eddy currents. These core laminations are insulated from each other by a thin coating of varnish.

It is found that eddy current loss is given by the following relation:

$$W_e = k_e B^2_{max} f^2 t^2 v \quad \text{Watts}$$

Where,

k_e = Constant

B_{max} = Maximum flux density in the core in Wb/m^2

t = Thickness of laminations.

V = Volume of core in m^3.

It is seen from the relation that this loss varies directly as the square or the thickness of laminations, hence it should be kept as small as possible. Another point to note is that $W_e = f^2$ but $W_h = f$. This fact makes it possible to separate the two losses experimentally if so desired.

These losses are constant for shunt and compound wound generators. Because in their case, field current is approximately constant. Both these losses total up to about 20% to 30% of full load losses.

(c) Mechanical losses:

These losses consists of

i. Friction loss at bearings and commutator.

ii. Air friction or windings loss of rotating armature.

These are about 10 to 20 % of full load losses.

(d) Stray losses:

The sum of the mechanical and magnetic losses are called stray losses. These are also known as rotational losses.

Constant and variable losses:

Constant losses are sum of the shunt field copper loss and stray losses. They do not vary with load current

Variable loss is nothing but armature copper loss because it varies with load current.

2.4 Applications of DC Generators:

(i). Separately Excited DC Generators

Because of their ability of giving wide range of voltage output, they are generally used for testing purpose in the laboratories.

Separately excited generators operate in a stable condition with any variation in field excitation. Because of this property they are used as supply source of DC motors, whose speeds are to be controlled for various applications. Example- Ward Leonard Systems of speed control.

(ii). Shunt Wound DC Generator:

They are used for general lighting.

- They are used to charge batteries because they can be made to give constant output voltage.
- They are used for giving the excitation to the alternators.
- They are also used for small power supply.

(iii). Series Wound DC Generators

- They are used for supplying field excitation current in DC locomotives for regenerative breaking.
- This types of generators are used as boosters to compensate the voltage drop in the feeder in various types of distribution systems such as railway service.
- In series arc lightening this type of generators are mainly used.

(iv). Compound Wound DC Generators

- Cumulative compound wound generators are generally used in lighting, power supply purpose
- Cumulative compound wound generators are also used for driving a motor.
- The differential compound wound generators are used for arc welding

At present time the applications of DC generators become very limited because of technical and economic reasons. Now a days the electric power is mainly generated in the form of alternating current with the help of various power electronics devices.

8. Describe OCC and load characteristics of shunt and separately excited DC generator. April 2013, Nov" 2012

CHARACTERISTICS OF DC GENERATOR:

The d.c. generators have following characteristics in general,

1) Magnetization characteristics

2) Load characteristics

1. Magnetization Characteristics

This characteristics is the graph of generated no load voltage E against the current If , when speed of generator is maintained constant. As it is plotted Without load with open output terminals it is also called No load characteristics or Open circuit characteristics

. E0 Vs If is magnetization characteristics

Where, E0 = No load induced e.m.f.

But for generator,

$$E = \frac{\Phi\, Z\, NP}{60A}$$

$$E \,\alpha\, \Phi \quad \text{with } \frac{Z\, NP}{60A} = \text{constant}$$

$$\text{Also } E \,\alpha\, I_f \qquad \text{as } \Phi \,\alpha\, I_f$$

2. Load Characteristics:

These are further divided into two categories

1) External characteristics
2) Internal characteristics

The external characteristics is the graph of the terminal voltage Vt against load current IL.

Key Point: While plotting both the characteristics the speed N of the generator is maintained constant.

In most of the cases, the shunt field current is very small as compared with load current IL. Hence in practice the internal characteristics shows the graph of induced e.m.f. E against load current IL instead of Ia, neglecting Ish.

Separately excited DC generator characteristics:

For a given dc generator it is clear that the induced emf is proportional to the flux and the speed. lf speed is kept constant, and the flux is varied, the induced emf also varies

Since $= \frac{\Phi Z NP}{60A}$

$E_g = \Phi N$

N = Constant

As increases , E_g also increases

The variation of flux with the induced emf is called the no-load magnetisation curve or saturation curve or open circuit characteristics (OCC) of the generator. Since the measurement of flux is difficult, the curve is plotted between field current (lf) and induced emf (Eg). Fig 2.20 shows circuit diagram for O.C.C of a separately excited generator. The prime mover gives the mechanical input to the d.c. generator.

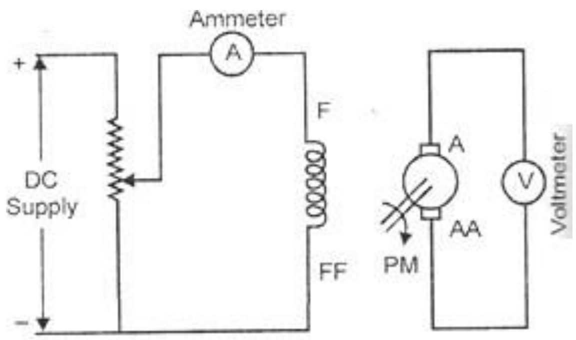


Fig.2.20

Fig below shows open circuit characteristics of a separately excited dc generator.

When the field current is zero, there is some flux due to residual magnetism and this causes a small induced emf. it is shown in figure above as OA.

As the field current is increased, the induced emf increases, increasing linearly from A to B. As the field current is further increased, the increase in flux is much smaller and hence the emf also increases slowly. At point D saturation has set in and any further increase in field current does not produce any increase in induced emf.

Φ

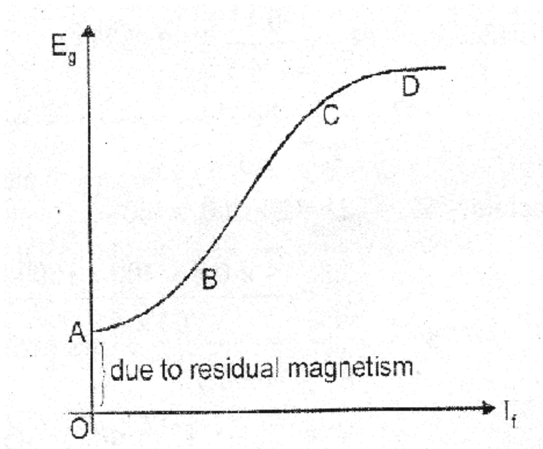


Fig.2.21

Internal and External Characteristics:

Fig.2.22 below shows internal and external characteristics.

The curve (l) can be drawn, armature current versus no load induced emf. It is for ideal dc generator only. There is no voltage drop in generator.

Internal Characteristics:

This curve is drawn between the emf E actually induced in the armature (after allowing for the demagnetizing effect of armature reaction) and armature current Ia. Here by increasing the armature current induced emf E will decrease due to armature reaction. This curve is called internal characteristics or total characteristics. This is curve (2), indicated in fig.2.22 below.

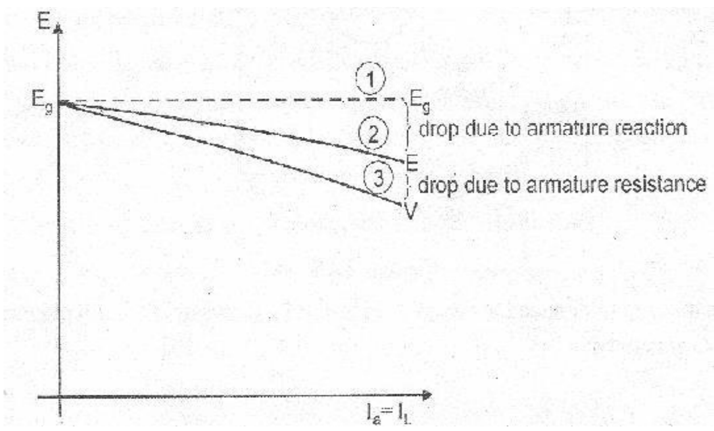


Fig.2.22

External Characteristics:

This curve is drawn between the terminal voltage (voltage across load) and armature current. Here by increasing armature current or load current, the induced emf again increases due to armature resistance. This curve is called external characteristics or voltage regulation curve. This is curve (3), indicated in above figure.

2.5.2. DC shunt generator characteristics:

In the discussion on OCC curve above, the field was connected to a separate d.c source. We may now ask, if d.c voltage is obtained from the armature of the generator can we use this voltage to supply the field, thus eliminating the need for a separate d.c source. The answer is yes, we may use this voltage for the field. The induced emf will depend the field current and at the same time the field current will depend on the induced emf. It is nothing but self excitation. Since the armature and field windings are connected in parallel it is called shunt excitation. Figure below shows dc shunt generator.

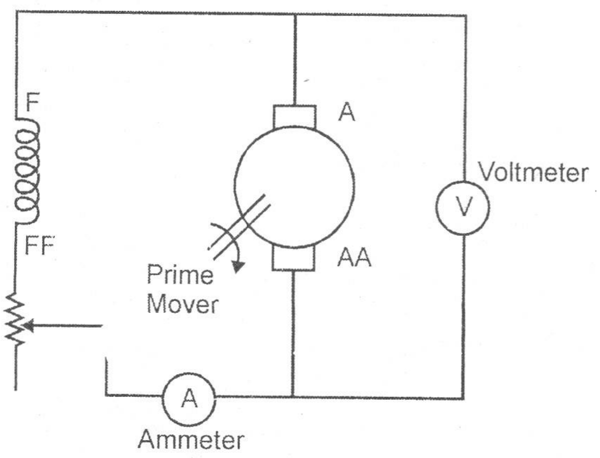


Fig.2.24

Here, the generator speed is constant. Fig. 2.24 below shows open circuit characteristics of a dc shunt generator.

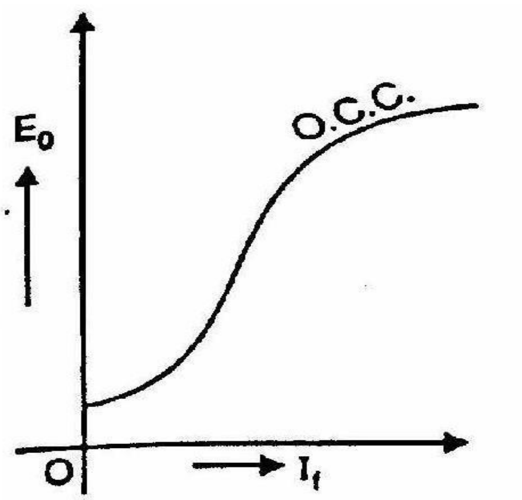


Fig.2.25

Initially the field current is zero, but emf is induced in the generator due residual magnetism. Due to this voltage field current increases and emf also increases.

The emf and field current progressively increase till it reaches point where field current is just sufficient to produce the voltage. There is no further increase in field current or induced emf. This curve can be drawn from field current and induced emf. This curve is open circuit characteristics.

Internal and External Characteristics (or) Load Characteristics:

Fig.2.25 below shows the connections for a d.c shunt generator. The field current Ish, the armature current Ia, and the load current IL are related by the equation.

$$I_a = I_{sh} + I_L$$

The armature has to supply both the load and field circuits.

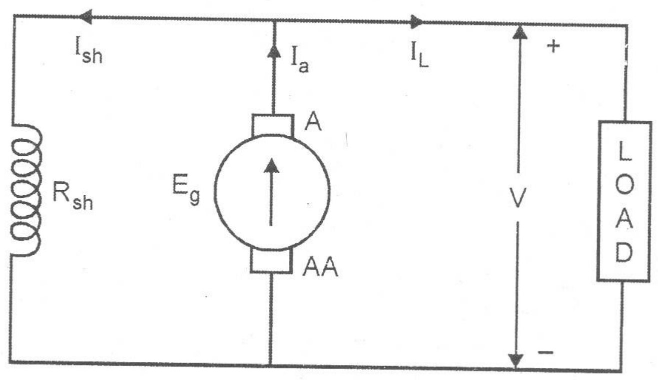


Fig.2.26

Once the generator has built up to the specified voltage on no load, it may be loaded. What happens as we increase the load on the generator? The load current IL increases and this implies that the generator current (armature current) also increases. It will also be found that while the induced emf Eg remains constant (if speed and field current are constant), the actual voltage available at the generator terminals for supplying the load reduces. This voltage is called terminal voltage and there are several reasons that cause its reduction.

i) As we start loading, Ia increases causing a drop of voltage in the resistance of the armature Ra.

ii) Drop in the brush contact resistance.

iii) Drop due to armature reaction. [When the load current flows in the armature conductors, a flux is produced. The armature is now under the influence of two fluxes. The main flux produced by the field and armature flux produced by the current flow].

The above three factors cause a decrease in the induced emf. The above discussion can be expressed by the following equation.

V = Eg - (Drop in armature resistance + Brush drop + Drop due to armature reaction)

Figure below shows internal and external characteristics of dc shunt generator.

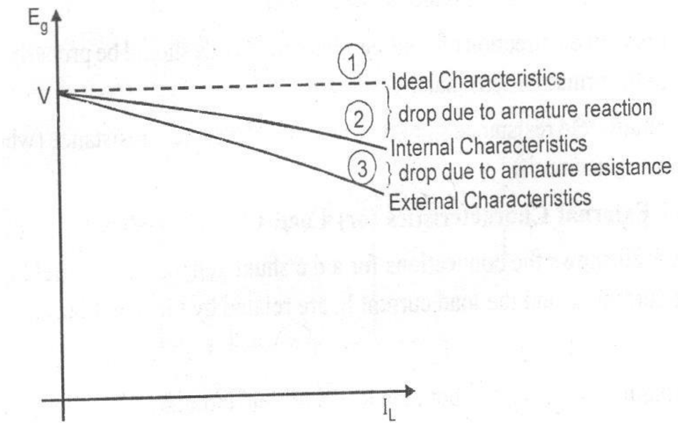


Fig.2.27

The curve (l) shows ideal dc generator i.e., by increasing load current the terminal voltage should be constant. There is no drop in the armature. i.e Eg = V. The curve (2) shows internal characteristics, here the drop is due to the armature reaction. The curve can be drawn for load current versus E. The cuwe (3) shows external characteristics. Here the drop is due to the armature resistance. By increasing the load current the terminal voltage decreases. It is shown in above figure.

$$V = E - I_a R_a$$

9. Describe OCC and load characteristics of series and compound DC generator.

3. DC Series Generator Characteristics

The connection for the dc series generator is shown in figure below.

In this case, it is easily seen that

$$I_a = I_{se} = I_L$$

Fig.2.27 below shows O.C.C, internal and external characteristics of series generator.

The curve (l) shows open circuit characteristics. This curve can be obtained by disconnecting the field winding from the machine and excited by separate d.c source. The curve (2) shows internal characteristics. Here the drop is due to armature reaction. By increasing the load current the induced emf E decreases. The curve (3) shows external characteristics. Here the drop is due to armature resistance and series field resistance. The terminal voltage decreases as

$$V = E - I_a(R_a + R_{se})$$

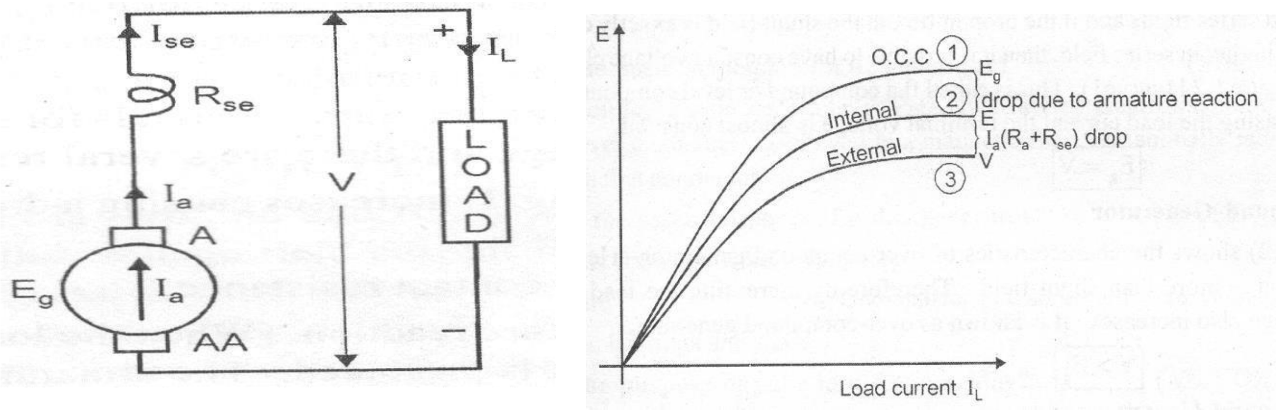


Fig.2.28

2.5.6 Compound Generator:

compound generator consists of series field and shunt field windings. Below shows external characteristics of compound generator.

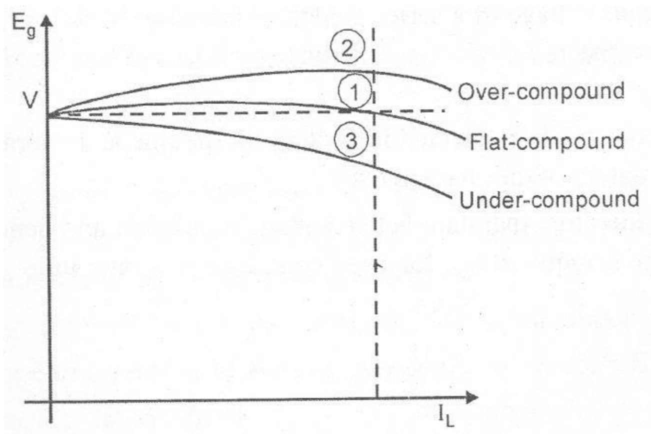


Fig.2.29

Flat Compound Generator:

In a shunt generator we have seen that the terminal voltage falls on loading, whereas in a series generator the terminal voltage increases with load. A compound generator has both shunt and series fields and if the drop in flux in the shunt field is exactly compensated for by the rise in flux in series field, then it is possible to have constant voltage characteristics as shown in figure above (curve l). This is called flat compound or level compound generator.

Here by increasing the load current the terminal voltage is almost constant.

$$Eg = V$$

Over Compound Generator:

Curve (2) shows the characteristics of over compound generator. Here the series field excitation is more than shunt field. Therefore by increasing the load current, the terminal voltage also increases. It is known as over-compound generator.

$$V > Eg$$

Under Compound Generator:

Curve (3) shows the characteristics of under compound generator. Here the series field excitation is less than the shunt field. Therefore by increasing the load current, the terminal voltage decreases. It is shown in figure. It is known as under-compound generator.

$$V<Eg$$

10. Explain the concepts of MMF distribution of AC windings

M.M.F. of Distributed A.C. Windings:

It is seen that the armature winding used for three phase alternators is distributed in nature. The efforts are made to place the coils in all the slots available per pole per phase. Such coils are then interconnected such that the magnetic field produced by armature after carrying current has same number of poles as that of field winding. Let us obtain the m.m.f space distribution of the current carrying armature by superimposing lime m.m.f. space waves of individual coils.

Consider single multiturn coil, carrying N turns and is a full pitch coil. It carries a current i such that the total ampere turns produced by the coil is (Ni). The direction of current i is as shown in the Fig. below and hence direction of flux lines around a and a" can be obtained by using right hand thumb rule.

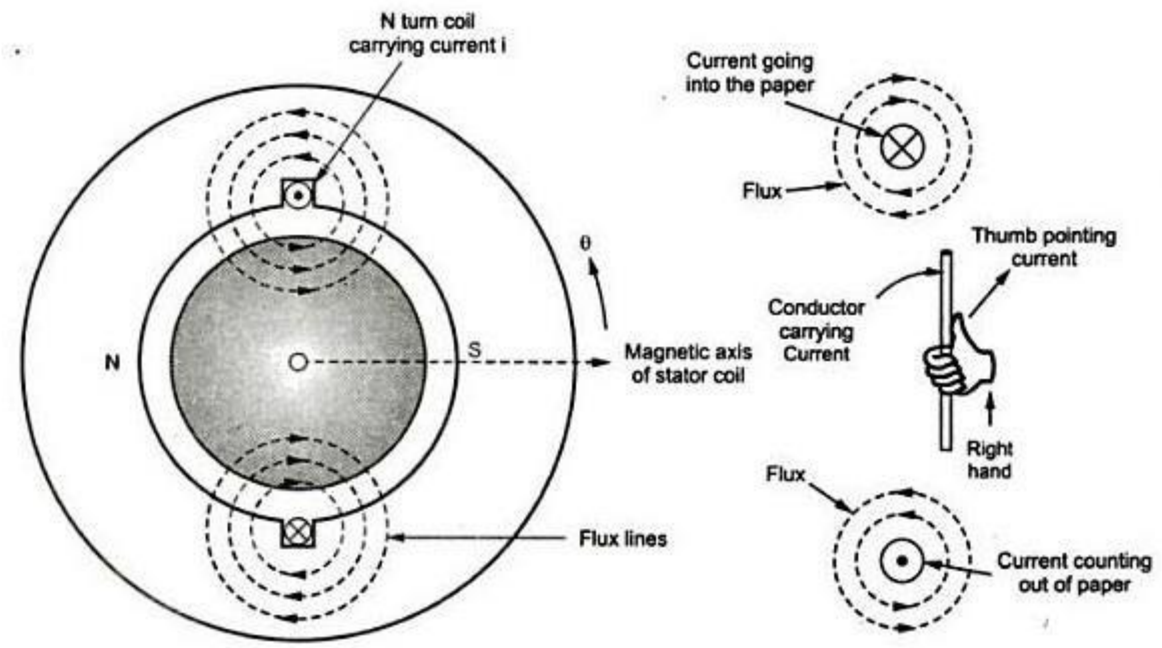


Fig.2.30 (a) Coil producing NI ampere-turns (b) Right hand thumb rule

The stator is wound for two poles same as the number of poles for which field winding is wound. Due to the flux lines produced by the coil, the North and South poles are induced on the stator periphery. The magnetic axis of the stator coil is from N pole to S pole as shown in the Fig.2.29 (a).

The assumptions to obtain M.M.F. space wave are,

l. It is cylindrical rotor machine.

2 The armature and rotor are made up of high grade magnetic material hence permeability of these parts is much higher than air. Hence reluctance is low so entire reluctance can be assumed to be due to two air gaps.

3. Thus if total m.m.f. is Ni then half the m.m.f. is required to create flux from rotor to stator in the air gap while half is required to create flux from stator to rotor in the air gap.

The flux lines radially crosses the air gap between rotor and stator twice. normal to the stator and tutor iron surfaces.

Consider a developed diagram of the coil shown in the Fig. 2. such that motor surface is over the stator which is laid down flat.

The m.m.f. and flux radially outwards from rotor to stator is assumed positive while that from stator to rotor is assumed negative. Thus m.m.f. distribution is stepwise giving a rectangular waveform. The m.m.f. - $\frac{Ni}{2}$ to + $\frac{Ni}{2}$; is used in setting flux from rotor to stator in the air gap. air gap. No m.m.f. required for iron path. Similarly the m.m.f. - $\frac{Ni}{2}$ is used in setting flux from stator to rotor in the air gap.

Thus m.m.f. changes suddenly from - $\frac{Ni}{2}$ to + $\frac{Ni}{2}$ at me slot while from + $\frac{Ni}{2}$ to − $\frac{Ni}{2}$ at other slot which is a pole pitch away. Total change in m.m.f. is abrupt and equal to Ni in crossing from one side to other of a coil.

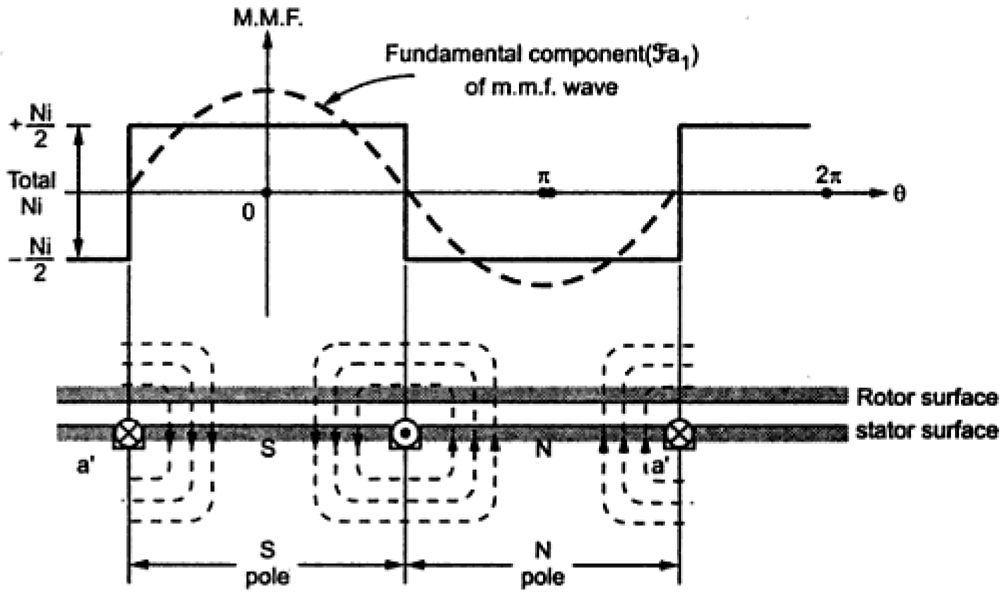


Fig. 2.31 M.M.F space wave of a single coil

M.M.F. change at any slot = Nl

The direction depends on the current direction.The rectangular m.m.f. space wave can be resolved into its Fourier series which includes its fundamental component and a series of odd harmonics, The fundamental component of m.m.f wave is given by,

…..(1)

Where, θ = Electrical angle measured from stator magnetic axis.

$$\mathcal{F}_{a1} = \frac{4}{\pi}\frac{Ni}{2}\cos\theta = F_{1p}\cos\theta$$

Key Point: This stator magnetic axis coincides with the positive peak of the mmf wave.

…..(2)

The odd harmonics are to be neglected.

Key Point: Equation (1) shows that the m.m.f. space wave is sinusoidal and when m.m.f. waves of individual phase group coils add, the odd harmonics get cancelled.

11. With neat diagram explain two types of armature windings.

2.7 Types of Armature Winding:

We have seen that there are number of armature conductors, which are connected in specific manner as per the requirement, which is called armature winding. According to the way of connecting the conductors. armature winding has basically two types namely,

a) Lap winding b) Wave winding.

2.7.1 Lap winding:

In this case, if connection is started from conductor in slot 1 then connections overlap each other as winding proceeds, till starting point is reached again.

Developed view of part of the armature winding in lap fashion is shown in the Fig. below

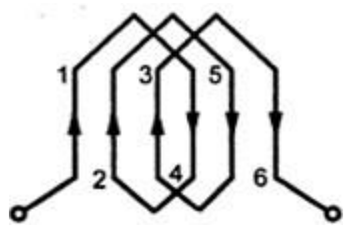


Fig.2.32 Lap winding

As seen from the Fig. 2., there is overlapping of coils while proceeding.

Key Point : Due to such connection, the total number of conductors get divided into 'P' number of parallel paths, where P = number of pole; in the machine. Large number of parallel paths indicate high current capacity of machine hence lap winding is preferred for high current rating generators.

2.7.2 Wave Winding:

In this type of connection, winding always travels ahead avoiding overlapping. It travels like a progressive wave hence called wave winding. To get an idea of wave winding a part of armature winding in wave fashion is shown in Fig..2..

$$\therefore \qquad \mathcal{F}_{a1}(\text{peak}) = F_p = \frac{4}{\pi}\frac{Ni}{2}$$

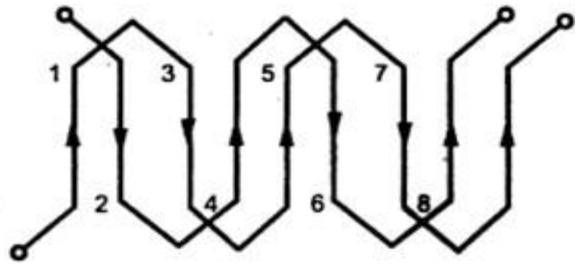


Fig. 2.33 Wave winding

Both coils starting from slot 1 and slot 2 are progressing in wave fashion.

Key point : Due to the type of connection, the total number of conductors get divided into two number of parallel path always, irrespective of number of poles of the machine: As number of parallel paths are less, it is preferable for low current, high voltage capacity generators.

The number of parallel paths in which armature conductors are divided due to lap or wave fashion of connection is denoted as A. So A=P for lap connection and A = 2 for wave connection.

2.7.3 Comparison of lap and wave type winding:

S.No	Lap Winding	Wave Winding
1.	Number of parallel paths (A) = Poles (P)	Number of parallel paths (A) = 2 (Always)
2.	Number of brush sets required is equal to number of poles.	Number of brush sets required is always equal to two
3.	Preferable for high current, low voltage capacity generators.	Preferable for high voltage, low current capacity generators.
4.	Normally used for generators of capacity more than 500A	Preferred for generators of capacity less than 500A

2.8 Right hand thumb rule:

It states that "Hold the current carrying conductor in the right hand such that the thumb is pointing in the direction of current and parallel to the conductor, then curled fingers point in the direction of the magnetic field or flux around it".

The Fig. 2. explains the rule.

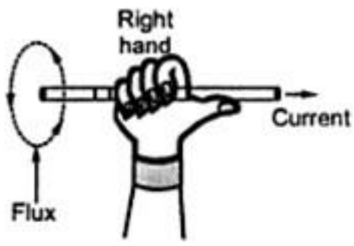


Fig. 2.34 Right hand thumb rule

Conventionally, such conductors are observed, assuming them to be placed perpendicular to the plane of the paper. So current moving away from the observer is denoted by a 'cross' while current coming towards the observer is denoted by a „dot". If now right hand is adjusted in such a way, that the thumb is pointing in the direction of current denoted as 'cross' i.e. going into the paper, then curled fingers indicate the direction of flux as clockwise, as shown in the Fig. 2.33. While if thumb of right hand is adjusted in the direction of current shown as 'dot' ie. coming out of paper, then curled fingers indicate the direction of flux as anticlockwise.

2.9 Methods of Excitation

The magnetic field required for the operation of a d.c. generator is produced by an electromagnet. This electromagnet carries a field winding which produces required magnetic flux when current is passed through it.

Key Point: The field winding is also called exciting winding and current carried by the field winding is called an exciting current.

Thus supplying current to the field winding is called excitation and the way of supplying the exciting current is called method of excitation.

The magnetic field in a d.c. generator is normally produced by electromagnets rather than permanent magnets. Generators are generally classified according to their methods of field excitation. On this basis, generators are divided into the following two classes:

(i) Separately excited d.c. generators

(ii) Self excited d.c. generators

The behaviour of a d.c. generator on load depends upon the method of field excitation adopted.

In separately excited generator, a separate external d.c. supply is used to provide exciting current through the field winding.

The d.c. generator produces d.c. voltage. If this generated voltage itself is used to excite the field winding of the same d.c. generator, it is called self excited generator.

2.10 Constant and Variable Losses:

The losses in a d.c. generator may be sub-divided into

(i)constant losses (ii) variable losses.

(i) Constant losses:

Those losses in a dc. generator which remain constant at all loads are known as constant losses. The constant losses in in d.c. generator are;

a) iron losses

b) mechanical losses

c) shunt field losses

(ii) Variable losses:

Those losses in a d.c. generator which vary with load are called variable

The variable losses in a d.c. generator are:

a) Copper loss in armature winding ($I_a^2 R_a$)

b) Copper loss in series field winding ($I_{se}^2 R_{se}$)

Total losses = Constant losses + Variable losses

Note. Field Cu loss is constant for shunt and compound generators.

2.11 Power Stages:

The various power stages in a d.c. generator are represented diagrammatically in Fig. 2.34.

A - B = Iron and friction loss

B – C = Copper losses

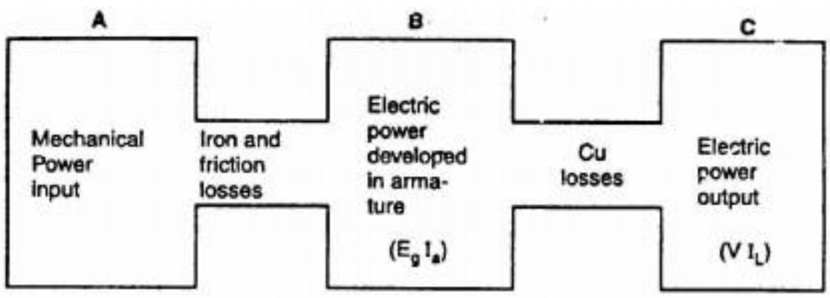


Fig. 2.35

(i) Mechanical efficiency

$$= \frac{B}{A} = \frac{E_g I_a}{\text{Mechanical power input}}$$

(ii) Electrical efficiency

$$= \frac{C}{B} = \frac{V I_L}{E_g I_a}$$

(iii) Commercial or overall efficiency

$$= \frac{C}{A} = \frac{V I_L}{\text{Mechanical power inpu}}$$

Clearly $\eta_C = \eta_m \times \eta_e$

$$= \frac{C}{A} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

(a) Explain the phenomenon of armature reaction in a DC machine Nov' 2014

1. Explain in detail about the armature reaction in a DC machine and discuss the effect of armature reaction can be neutralized. April 2015

2.12 Introduction to Armature Reaction

For the operation of any d.c. machine, presence of magnetic flux is essential. Whenever current flows through a field coil, it produces a flux which is called as field flux. Now suppose the d.c. machine is functioning as a generator, an e.m.f. will be induced in the armature when it is driven by a prime mover. If the generator is driving a load, the induced emf in the will cause current to flow through the load. Thus current will start flowing through the armature conductors. Now every current carrying conductor will set up its own magnetic field. All these armature conductors combine together to produce a flux which can be called armature flux.

Key Point : Thus the armature current will set up its own magnetic field. The effect of this armature flux on the distribution of main field flux is called armature reaction.

The armature reaction will try to make the main field flux to be weakened. Also it will distort the main flux.

Key Point: These two effects of armature reaction will reduce the generated voltage and may cause sparking at the brushes.

2.13 Concept of Armature Reaction:

To understand the concept of armature reaction, consider a two pole d.c. generator.

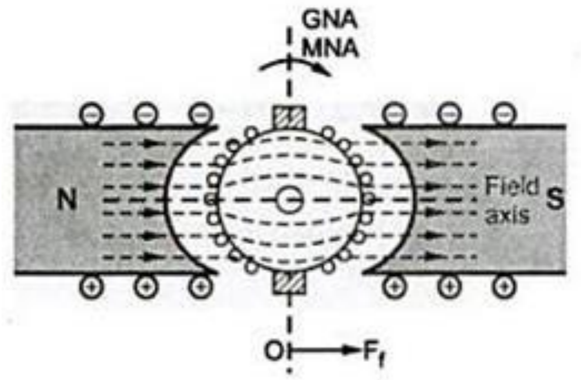


Fig. 2.36

For simplicity we will assume that the brushes are touching the armature conductors directly, although, they touch commutator segments in actual practice.

Assuming that the generator is not driving any load. So that there is no current in the armature conductors. The distribution of main field flux under this case is as shown in the Fig.2.13. The flux is symmetrically with respect to axis called polar axis which is line joining the centres of N and S poles. The direction of flux produced by field coil is from 1eft to right through an armature core and lines of force through the core are parallel to field axis.

The axis along which there is no e.m.f. induced in the armature conductors is called Magnetic Neutral Axis (MNA). From the Fig.2.13. it can be seen that magnetic neutral axis (MNA) and Geometric Neutral Axis (GNA) coincides with each other. The geometric neutral axis is nothing but the axis of symmetry between the poles. The brushes are always kept along MNA.

Key Point : Thus MNA can also be called 'axis of commutation' since reversal of current takes place along this axis.

As shown in the Fig.2.13, vector OFf represents the m.m.f. producing the main flux both in magnitude as well as in the direction. MNA is perpendicular to vector OFF

Now we will consider that the field coils are unexcited whereas the armature conductors are carrying current. Under this case the field set up by the armature conductors is as shown in the Fig.2.14.

The direction of current in armature conductors can be found by applying Fleming"s right hand rule. The current will flow in the same direction if the generator is driving load. Under N pole, the current is flowing in downward direction whereas under S pole, the current is flowing in upward direction.

The direction of the flux produced by current carrying conductors is vertically downwards in the armature core. This flux is symmetrical about a brush axis. In other words current carrying armature conductors try to magnetise the armature core along the brush axis.

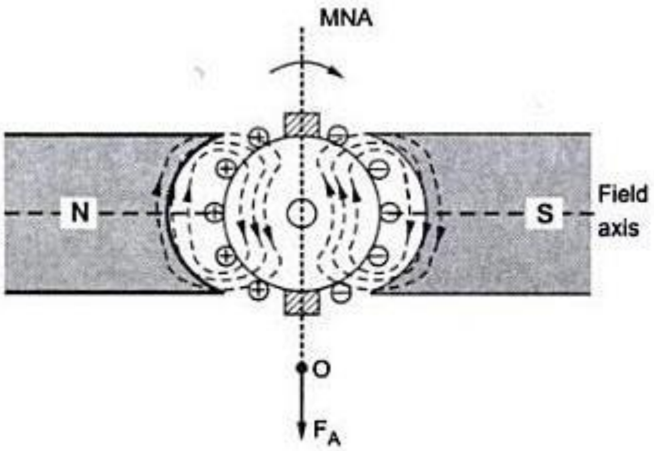


Fig. 2.37

The vector OFA shown in the Fig. 2.14 represents the armature m.m.f. both in magnitude and direction. This m.m.f. depends on the magnitude of the armature current.
Uptil now we have considered the main m.m.f. and armature m.m.f. separately as if they are existing independently.

Key Point: In practice the two mmfs exist simultaneously in the generator under load conditions.

Now the flux through the armature is not uniform and symmetrical. The flux gets distorted. Due to interaction of two fluxes, the resultant flux distribution is changed as Shown in the Fig.2.15.

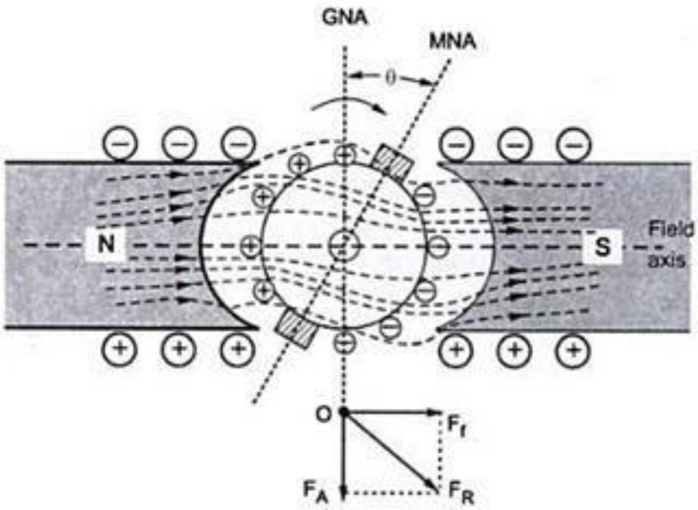


Fig. 2.38

The flux is crowded or concentrated at the trailing pole tips but weakened out at the pole tips.

Key Point : The pole tip which is met first during rotation by armature conductors is known leading pole tip and other is known as trailing pale tip.

The resultant m.m.f. OFR can be found by vectorially combining OF_F, and OF_A.

The new position of MNA is also shown which is perpendicular to the resultant m.m.f vector OFR. The MNA gets shifted through an angle θ so that brushes are also shifted and are along a new MNA.

Due to this brush shift, the armature conductors as well as armature current is redistributed. Some of the armature conductors which were earlier under the influence of S pole now come under N pole and vice versa.

This regrouping of armature conductors and armature current is as shown in the Fig. 7.24. It can also be seen that the brush shifts in the same direction as that of direction of rotation of armature.

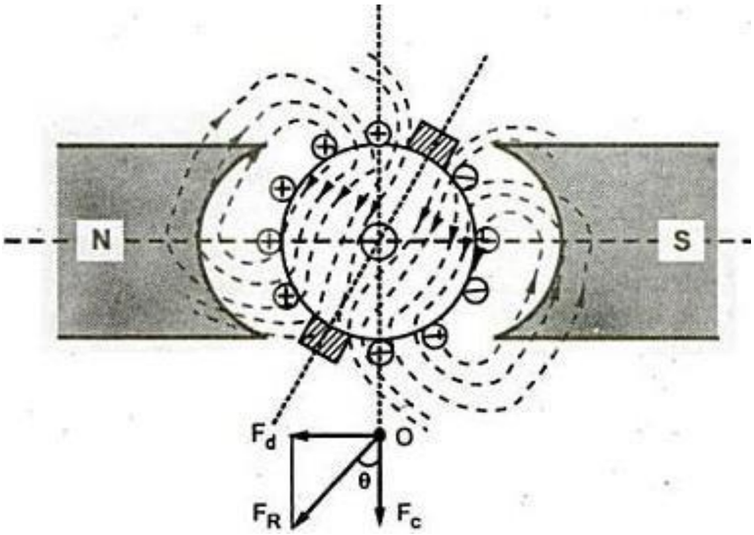


Fig. 2.39

The conductors on the left of new position of MNA carry current downwards and those to the right carry current upwards. The armature m.m.f. is now along new position of MNA represented by vector OFR in the Fig. 7.24. It is inclined at an angle θ to the left instead of being vertical.

The armature m.m.f. represented by vector OFR can be resolved into two components, OFd parallel to the polar axis and OFC perpendicular to the axis. The component OFd is in direct opposition with field m.m.f. vector OFf. This will tend to reduce the total flux.

Hence this component is called demagnetising component of the armature reaction whereas the other component OFC is at right angles to vector 0Ff. This will produce distortion in the main field. Hence this component is called cross magnetising component of the armature reaction.

It can be observed that both the components viz. demagnetising and cross magnetizing, will increase with increase in armature current.

3.17 Demagnetising and Cross Magnetising Conductors

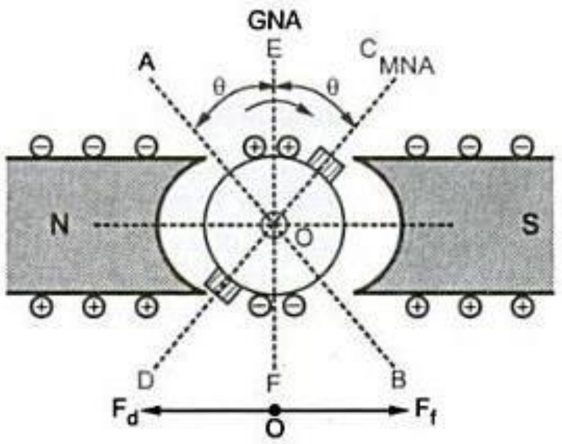


Fig. 3.30

The conductors which are responsible for producing demagnetising and distorting effects are shown in the Fig.3.30.

The brushes are lying along the new position of MNA which is at angle θ from GNA. The conductors in the region AOC = BOD = 2θ at the top and bottom of the armature are carrying current in such a direction as to send the flux in armature from right to left. Thus these conductors are in direct opposition to main field and called **demagnetising armature conductors.**

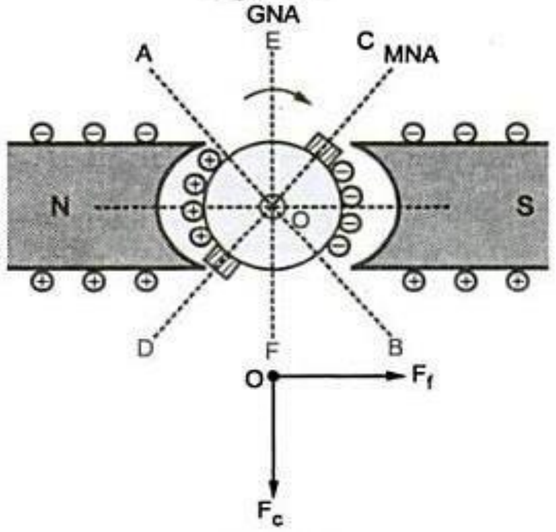


Fig. 3.31

The remaining armature conductors which are lying in the region AOD and BOC carry current in such a direction as to send the flux pointing vertically downwards i.e. at right angles to the main field flux. Hence these conductors are called **cross magnetising armature conductors** which will cause distortion in main field flux.

These conductors are shown in the Fig. 3.31.

3.18 Effects of Armature Reaction

The various effects of armature reaction can be summarised as,

1) The armature reaction always results in reduction of generated e.m.f. due to decrease in value of flux per pole.
2) The iron losses in the teeth and pole shoes are determined by the maximum value of flux density at which they work. Due to distortion in main field flux the maximum density at load increases above no load. Thus iron losses are observed to be more on load than on no load.
3) Due to armature reaction the maximum value of gap flux density increases. This will increase the maximum voltage between adjacent commutator segments at load. If this voltage exceeds beyond 30 V the sparking may take place between adjacent commutator segments.
4) The armature reaction shifts brush axis from GNA. Thus flux density in the interpolar axis is not zero but having some value. Thus there will be an induced e.m.f. in the coil undergoing commutation which will try to maintain the current in original direction. This will make commutation difficult and will cause delayed commutation.

3.19 Reduction of Effects of Armature Reaction

In order to reduce the effect of armature reaction following methods are used.

1) The armature reaction causes the distortion in main field flux. This can be reduced if the reluctance of the path of the cross-magnetising field is increased. The armature teeth and air gap at pole tips offer reluctance to armature flux. Thus by increasing length of air gap, the armature reaction effect is reduced.
2) If reluctance at pole tips is increased it will reduce distorting effect of armature reaction. By using special construction in which leading and trailing pole tip portions of laminations are alternately omitted.
3) The effect of armature reaction can be neutralized by use of compensating winding. It is always placed in series with armature winding. The armature ampere conductors under pole shoe must be equal to compensating winding ampere conductors which will compensate armature m.m.f. perfectly.
4) The armature reaction causes shifting the magnetic neutral axis. Therefore there will be some flux density at brush axis which produces e.m.f. in the coil undergoing commutation. This will lead to delayed commutation. Thus the armature reaction at brush axis must be neutralised. This requires another equal and opposite m.m.f. to that of armature m.m.f. This can be applied by interpoles which are placed at geometric neutral axis at midway between the main poles.

Out of the different methods mentioned above, used to reduce the effects of armature reaction, let us see the method of providing compensating winding in detail. This method is very popularly used in actual practice for d.c. machines.

3.19.1 Use of Compensating Winding

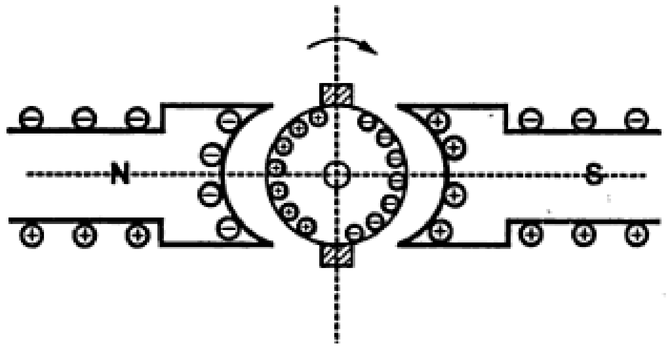


Fig. 3.32 Compensating winding

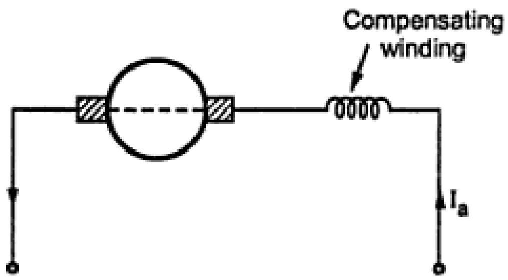


Fig. 3.33

The compensating windings are basically used to neutralise the armature flux in the pole arc region which will otherwise cause severe distortion of main field flux. These windings are of concentric type and are placed in axial slots in the pole faces as shown in the Fig. 3.32.

The symbolic representation of compensating winding is shown in the Fig. 3.33.

The armature reaction causes the displacement of main field flux. It affects the waveform of main field flux and makes it non-uniform. The effect of armature reaction depends upon armature current which inturn depends on the load on the machine.

In case of machines having large fluctuations in load such as rolling mill motors or turbogenerators, the armature reaction will cause sudden shift of flux in backward and forward direction depending on change in the load. This will cause statically induced e.m.f. in the armature coils whose magnitude depends upon how fast the load is changing and by what amount it is changing. There is dynamically induced e.m.f. in the armature coil also. Under worst conditions these two e.m.f.s may become additive. This will occur when load is increased on motor and decreased from generator. If this e.m.f. is more than the breakdown voltage across adjacent commutator segments, a sparkover may occur which can easily spread over as conditions near commutator are favourable for flashover. The maximum allowable voltage between the segment is 30 to 40 V. Thus there is always danger of short circuiting the whole armature if armature flux is not compensated.

This can be achieved by the use of compensating winding which will neutralize the effect of armature reaction. These windings are connected in series with the armature. The current in these windings flows in opposite direction to that in armature conductors below the pole shoes. This will counterbalance the cross magnetising effect of armature reaction which may cause flashover between the segments.

Key Point : *To have perfect neutralization of armature m.m.f. under the pole shoe, the ampere conductors of compensating winding must be equal to total armature ampere conductors under the pole shoe.*

Ampere turns per pole for compensating winding

$$= \frac{\text{Pole arc}}{\text{Pole pitch}} \times \text{Armature ampere turns per pole}$$

$$\text{Total ampere conductors per pole} = \frac{I_a}{A} \cdot \frac{Z}{P}$$

Since two conductors form one turn.

$$\text{Total ampere turns per pole in armature} = \frac{1}{2} \cdot \frac{I_a}{A} \cdot \frac{Z}{P}$$

$$\therefore \text{ Ampere turns per pole for compensating winding} = \frac{I_a . Z}{2AP} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

Since the distribution of armature m.m.f. and compensating winding m.m.f. is not identical the complete neutralization of armature m.m.f. can not be achieved by using compensating winding. The armature m.m.f. under the pole shoe is neutralized whereas there is incomplete neutralization in the interpolar region. There will be small flux density remaining unneutralized in GNA. This can be neutralized by using interpole windings.

Thus by using interpole as well as compensating windings, the armature reaction effect is completely neutralized over the entire armature periphery. The only flux present in the machine will be main field flux which will be an ideal situation.

Though compensating windings are very expensive they are provided in machines which carry heavy overloads or there is rapid change in the load. So that there will not be any possibility of flashover.

2. Define commutation. Explain methods of improving commutation in DC generator. April 2015, Nov" 2014

3.21 Practical Commutation

The e.m.f. induced in each coil of armature is alternating in nature. If load is connected, the current flowing will also be alternating. But the flow of current in a d.c. generator must be unidirectional. This can be achieved by the use of commutator. When the armature conductors are under the influence of one pole they carry current in one direction whereas the current is reversed when the conductors are under the influence of other pole. This reversal of current takes place along the magnetic neutral axis.

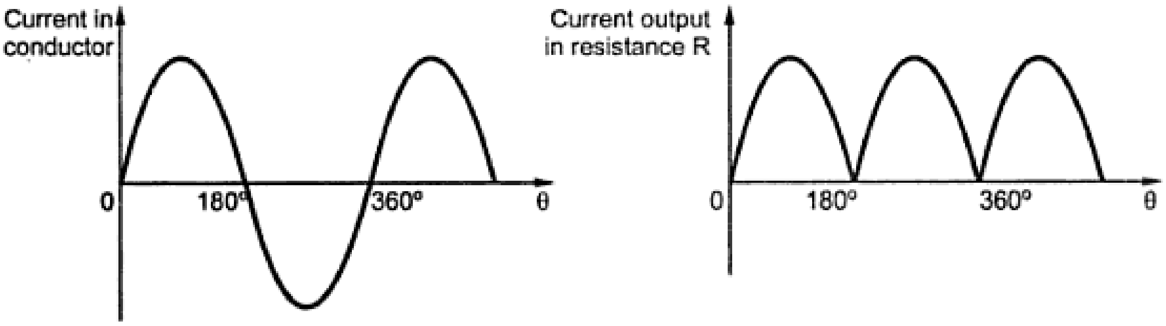


Fig. 3.37 Waveforms of current

Key Point : *The reversal of current is likely to take place in short interval when a coil is short circuited by a brush so that transfer of current from one direction to other is carried out without any sparking. This process is called* ***commutation****.*

Thus a process by which current in the short circuited coil is reversed while it crosses the MNA is called commutation. The time during which the coil remains short circuited is known as **commutation period**. This period is generally of the order of 0.0005 to 0.002 sec.

The commutation is said to be ideal when current changes from + I to zero and zero to – I within the commutation period. The sparking is produced between the commutator and brush if current is not reversed by that time. This will lead to damage of commutator as well as brush. Hence for satisfactory operation of d.c. machine proper commutation is required i.e. transfer of current must be without sparking and losses and heating of brushes and the commutator.

Now we will see the process of commutation in detail with the help of the figures. Let us assume that the armature winding is ring type and the width of brush is equal to the width of one commutator segment and one mica insulation. In this case only one coil is short circuited at a time at each of these brushes whereas in actual practice width of brush is more than that of commutator so that more than two coils are simultaneously short circuited at each brush.

As shown in the Fig. 3.38 (a), coil B is about to be short circuited. The brush is about to come in contact with commutator segment 'a'. Suppose that each coil is carrying current of 10 A so that total brush current is 20 A as every coil meeting at the brush supplies half the brush current independent of lap or wave wound armature.

Before coil B is short circuited, it is belonging to the group of coils lying left of the brush. It is carrying current 10 A from left to right.

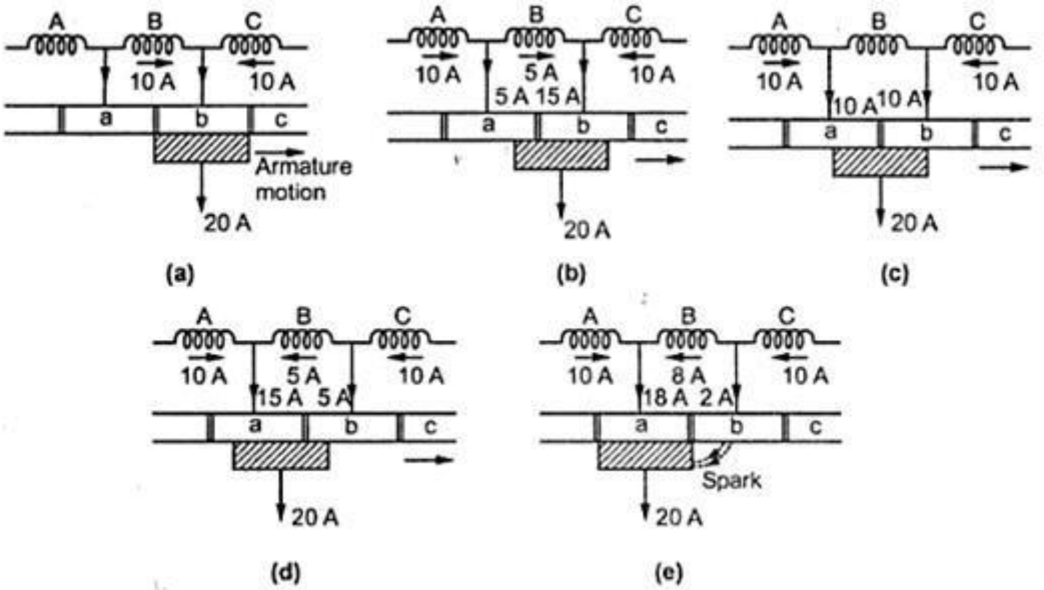


Fig. 3.38 Practical commutation

As seen from the Fig. 3.38 (b), coil B is entering short circuit period. The current in coil B has reduced from 10 A to 5 A as the other 5 A flows via segment 'a'. The total current is remaining same at 20 A. But area of contact of the brush is more with segment 'b' than with segment 'a'. Hence current of 15 A is from segment 'b' whereas 5 A from segment 'a'.

The coil B is in the middle of its short circuit period as shown in the Fig. 3.38 (c). The current in coil B is reduced to zero. The currents 10 A and 10 A pass to the brush directly from coils A and C. The total current is again 20 A and the contact area of brush with the segments 'a' and 'b' are equal.

As shown in the Fig. 3.38 (d), the coil B is now under group of coils to the right of brush. The contact area of brush with segment 'b' is decreasing whereas with segment 'a' is increasing. Coil B is now carrying 5 A in other direction. Thus current of 15 A is passed via. segment 'a' to the brush while the other 5 A is supplied by coil C and passes from segment 'b' to brush. Again the total current is 20 A.

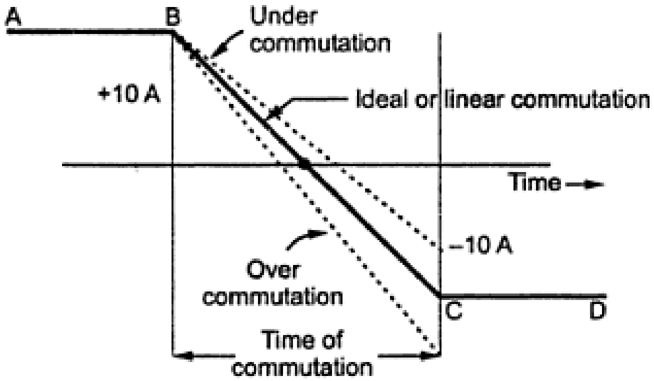


Fig. 3.39 Linear commutation

If case of ideal commutation is assumed then current through coil B will reverse at the end of commutation or short circuit period. But as shown in Fig. 3.38 (e) current flowing through coil B is only 8 A instead of 10 A. So the difference in coil currents i.e. 10 − 8 = 2 A jumps directly from segment 'b' to the brush through air and produces spark.

The variation in current during the process of commutation can be plotted with respect to time as shown in the Fig. 3.39.

The current in the coil B is 10 A till commutation begins represented by horizontal line AB. After finishing commutation the current is again 10 A but in reverse direction represented by horizontal line CD. Thus current changes from +10 A to 0 and then to –10 A. The way in which this current changes is important. If current varies uniformly represented by straight line BC the commutation is said to be linear commutation. But it is observed that the self induced e.m.f. in the coil will try to maintain the current in the same direction and will cause delay for commutation. The commutation in this case is said to be **retarded or under commutation.** This is shown by the dotted part in the Fig. 3.39. If reversal of current in the coil is faster than ideal or linear commutation then also sparking may occur. The commutation in this case is said to be **over commutation or accelerated commutation.**

Thus it can be seen that if reversal of current is retarded or accelerated then value of current in the short circuited coil after the commutation period is over is different than that when linear commutation occurs. This will cause sparking at the brushes. This will lead to excessive wear and tear of commutator and ultimately lead to burning of commutator. Hence it is desired that the commutation must be as sparkless as possible.

Now Let us see that why there is delayed or accelerated commutation. The main reason for non-linear commutation is the production of self induced e.m.f. in the coil undergoing commutation as the coil has significant amount of self inductance because it is embedded in the armature which is made up of high permeability material. This self induced e.m.f. though small in magnitude produces a large current through the coil whose resistance is small due to short circuit.

(b) Describe the methods of improving commutation in DC machine. Nov' 2014

3.22 Methods of Improving Commutation

There are two practical ways by which commutation may be improved. These methods are, 1. Resistance commutation and 2. E.M.F. commutation.

3.22.1 Resistance Commutation

In this method of improving commutation, the low resistance copper brushes are replaced by high resistance carbon brushes.

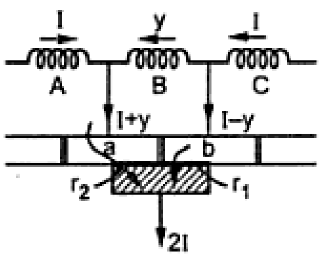


Fig. 3.40 Resistance commutation

From the Fig. 3.40 it can be seen that the current I from coil C when passing through commutator segment 'b' has two parallel paths. One is straight from 'b' to brush while the other is through short circuited coil B to segment 'a' and then to the brush. By using low resistance copper brush the current will not prefer second path as it will prefer first low resistance path.

When carbon brushes having comparatively high resistance are used then current I through coil C will select the second path as resistance r_1

Thus by increasing contact resistance between commutator segment and brushes, will limit short circuit current and reduce time constant (L/P) of the circuit which will help in quick reversal of current in the desired direction.

3.22.1.1 Advantages of Resistance Commutation

The advantages of resistance commutation are,

1) Upto some degree they are self lubricating and polish the commutator.
2) If sparking occurs, damage to commutator will be less as compared to when copper brushes are used.

3.22.1.2 Disadvantages of Resistance Communication

The disadvantages of resistance commutation are,

1) There is a loss of approximately 2 volts due to high contact resistance. Hence this is not used in small machines.
2) If carbon brushes are used the commutator is required to be made somewhat larger for heat dissipation without rise in temperature which is not necessary for copper brushes.
3) Larger brush holders are required due to lower current density (about 7-8 A/cm^2).

3.22.2 E.M.F. Commutation

The method in which reactance voltage produced is neutralized by the reversing e.m.f. in short circuited coil is called e.m.f. commutation. If the value of this reversing e.m.f. is made equal to reactance voltage, the effect of reactance voltage will be completely nullified so that there will be fast reversal of current which will give sparkless commutation. There are two ways of proving e.m.f. commutation.

a) By giving a forward lead to the brushes

b) By using interpoles.

3.22.2.1 Giving Brush Shift

If the brushes are shifted forward or backward depending on generator or motor, a little beyond to magnetic neutral axis, the short circuited coil will come under the influence of main pole of opposite polarity. This will partly neutralized the reactance voltage which will help in quick current reversal. This method is rarely used in practice as it will lead to many practical difficulties.

3.22.2.2 Interpoles

This method is more suitable and actually used in practice. In this method reversing e.m.f. required to neutralize reactance voltage is induced in the coil undergoing commutation by using small poles fixed to the yoke and placed in between the main poles i.e. along geometrical neutral axis. These poles are called **interpoles**. Practically interpoles are placed in between the main poles, as shown in the Fig. 3.41.

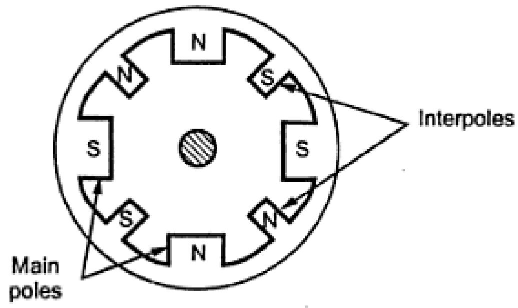


Fig. 3.41 Interpoles

On these interpoles few heavy gauge copper wire turns are wound and these are connected in series with the armature. The polarity of an interpole is same as the next main pole ahead in the direction of rotation and in case of motor it is same as main pole behind as shown in the Fig. 3.42. The brushes are kept along the GNA so that coil sides lie directly under the interpoles.

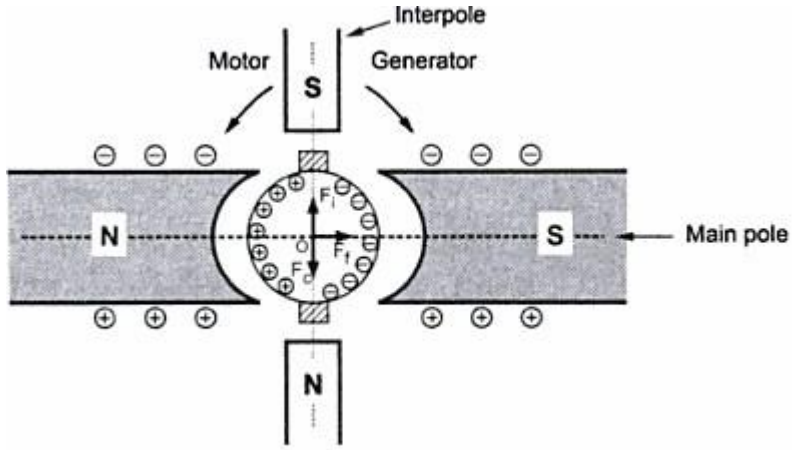


Fig. 3.42 Use of interpoles

The polarity of interpole is same as that of main pole ahead, the induced e.m.f. in them helps the quick reversal of current. The e.m.f. induced in the interpoles is called commutating or reversing e.m.f. which will neutralize the reactance voltage making sparkless commutation.

With interpoles sparkless commutation upto 20 to 30 percent overload with fixed brush position can be obtained. Hence sparking limit is at same value as that of heating limit. So for given output the machine can be made smaller and will be cheaper than non-interpolar machine.

Also by using interpoles automatic neutralization of reactance voltage at all loads is ensured since it is connected in series with armature and reactance and reversing e.m.f.s are proportional to armature current.

Although interpoles mainly provide reversing e.m.f. opposite to that of reactance voltage, the other advantage of using interpoles is that they help in neutralizing cross magnetising effect of armature reaction. As shown in the Fig. 3.42 OF_f represents m.m.f. due to main poles whereas OF_c represents cross magnetising m.m.f. due to armature. The m.m.f. due to interpoles represented by OF_i is in opposition to OF_c so they cancel each other. Thus shifting of brush from original position is not required. Also automatic neutralization at all loads is ensured since armature field and interpole are produced by same current.

But there is difference between compensating winding and interpoles. The two are connected in series and both will try to neutralize armature reaction effect. But interpoles in addition supply reversing e.m.f. to improve commutation. In addition to this, the action of interpoles is localized near the commutating area only. It has negligible effect on armature reaction occurring on the remaining part of the armature periphery.

Key Point : *So armature reaction effect can be completely neutralized by using interpoles as well as compensating winding.*

Write short notes on critical resistance.

3.37 Critical Field Resistance in D.C. Shunt Generator

Consider the magnetisation characteristics of a d.c. shunt generator shown in the Fig. 3.68.

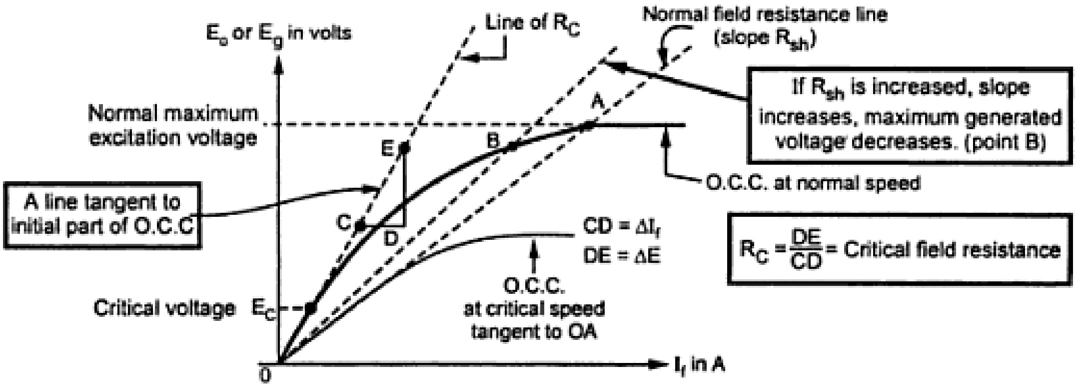


Fig. 3.68 Concept of critical resistance

The Fig. 3.68 shows that generator voltage builds in step till point A. This point is intersection of field resistance line with the open circuit characteristics (O.C.C.). The voltage corresponding to point A is the maximum voltage it can generate. If the slope of field resistance line is reduced by decreasing the field resistance, the maximum voltage generator can build will be higher than that corresponding to point A. Similarly if the slope of field resistance line is increased by increasing the field resistance, the maximum voltage generator can build will be less than that corresponding to point A i.e. corresponding to point B.

If now the slope of the field resistance line is increased in such a way that it becomes tangential to the lower part of the open circuit characteristics. The voltage corresponding to this point is E_C. This voltage is just sufficient to drive the current through field resistance so that cumulative process of building the voltage starts. This value of field resistance is called the **critical resistance** denoted as R_C, of the shunt field circuit at given speed.

Key Point : *If field circuit resistance is more than R_C at start then induced e.m.f. fail to drive current through field circuit and generator fails to excite at given speed.*

Thus we can define critical resistance as that resistance of the field circuit at a given speed at which generator just excites and starts voltage building while beyond this value generator fails to excite.

The critical resistance is the slope of the critical resistance line.

$$\therefore \quad R_C = \frac{\Delta E}{\Delta I_f} = \frac{DE}{CD} = \tan\theta$$

Similar to the critical resistance there is a concept of critical speed N_C. We know that $E \propto N$. As speed decreases the induced e.m.f. decreases and we get O.C.C. below the O.C.C. at normal speed. If we go on reducing the speed, at a particular speed we will get O.C.C. just tangential to normal field resistance line.

Key Point : *This speed at which the machine just excites for the given field circuit resistance is called the* ***critical speed*** *of a shunt generator denoted as N_C.*

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