LECTURER NOTES

ON

ELECTRICAL MACHINE

FOR 4th SEMESTER (E&TC)

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Unit-1: ELECTRICAL MATERIAL:

1.1 Properties & uses of different conducting material.

1.2 Properties & use of various insulating materials used electrical engineering.

1.3 Various magnetic materials & their uses.

1.1: PROPERTIES AND USES OF CONDUCTING MATERIALS:

Conducting Materials:

Materials used for conducting electricity are known as **conducting materials**. These materials play a vital role in Electrical Engineering. It is interesting to know the applications of these materials in the field of Electrical Engineering, like the type of materials used in Transmission lines, Electrical Machines, Starters, and Rheostats, etc., along with different conducting materials, we will also go through their alloys.

Conducting materials can be classified into **Low resistivity** materials and **High resistivity** materials.

Before going into details, first of all, will see what resistivity here is

What is the resistivity of conducting materials?

Every material opposes the flow of electrons through it. The resistivity of a material is the resistance between opposite faces of a portion of a material having unit length and unit cross-sectional area.

Factors affecting resistivity:

- **Alloying**:

Metals in their pure form possess the lowest resistivity when they are alloyed with other metals their resistivity increases.

Alloying decreases the rate of increase of resistance.

- **Temperature**:

Resistivity of a metallic conductor increases with the rise in temperature and vice versa

- **Mechanical stress:**

Stresses are developed in metals due to mechanical forces and their crystal structure gets distorted. Due to these mechanical stresses metals conductivity decreases hence resistivity increases.

Low Resistivity Conducting Materials:

They should have a low voltage drop, small power loss. Also, these materials have a low-temperature coefficient of resistance and high mechanical strength.

Applications of Low resistivity Materials:

- House wiring
- Transmission and Distribution
- Knife switches
- Current carrying springs

- Sliding contacts
- ACSR conductor is used for transmission and distribution purpose as it has less sag.

Low resistivity conducting materials are as following.

- Copper and its alloys like Cadmium copper, Chromium copper, Brass, Bronze, and its alloys like Phosphorus Bronze, Berrilium Bronze, etc.
- Aluminium and its alloys like Duraluminium, Hindaluminium, Magnaluminium.

1. Copper:

Copper is available in 2 forms

1. The Annealed Copper:

Annealed copper is obtained by heating at a specific temperature and then cooling.

This is chemically the same as hard drawn copper but has different mechanical strength due to the different processes used for making them.

Applications: This is used at places where flexibility is required e.g. Wiring of binding, Winding wires of electrical machines, and transformers. Braided copper flexible links used in spot welding machines and busbars.

Braided Copper Flexible Links

2. Hard Drawn Copper:

This is obtained by drawing copper bars or rods in cold conditions. Hard drawn copper is chemically the same as annealed copper but has different mechanical strength due to the heat treatment process used in making them.

Applications: This is used at places where high tensile strength is required even though the conductivity is less e.g. transmission and distribution lines.

2. Alloys of Copper:

- **Cadmium Copper:**

Cadmium of 0.55-1.04% is added to Copper to increase the tensile strength. It appears in white color. It is a corrosion-resistant material. With an increase in cadmium content, the conductivity decreases.

Applications: Used for flexible telephone cords, trolley wires, electrodes, switchgear contacts, commutator segments, etc.

- **Chromium Copper:**

Chromium is mixed with Copper to increase hardness. It has excellent conductivity and hardness also.

Applications: Used for resistance welding electrodes, seam welding wheels, switchgear, cable connectors, **circuit breaker** parts, and electrical and thermal conductors that require strength.

3. Brass:

Brass is an alloy of Copper-60% and Zinc-40%. It does not get oxidized when exposed to the atmosphere. It is fairly resistant to corrosion. And it has high tensile strength but conductivity is lower than Copper.

Applications: Used in current-carrying and structural material in socket outlets, fuse holders, lamp holders, switches, knife switches, sliding contacts for starters, and rheostats.

- **Muntz Metal:**

When alloy contains 57 to 63% Cu and 43 to 37% of Zinc it is called as Muntz metal. This metal is malleable, ductile, and anti-corrosive.

Applications: It is used for bolts, nuts, rods and tubes, welding rods, condensers, springs, bases, and caps of valves.

4. Bronze:

It is an alloy of Copper-90% and Tin-10%. It is chemically very stable and does not react with most of the gases and liquids. Its corrosion resistance is better than Brass. It has good conductivity but less than Copper.

5. Alloys of Bronze:

- **Phosphorus Bronze:**

It contains 10 to 15% Tin and up to 0.5% Phosphorous.

Phosphorus bronze has high tensile strength, elasticity, and low conductivity and is used for making current-carrying springs, brush holders, knife switches, blades, etc.

- **Berrilium Bronze:**

It consists of Copper, Tin and Berrilium.

Berrilium bronze's mechanical strength is higher than Cadmium bronze. It is used to making sliding contacts, knife switches, blades, etc.

- **Silicon Bronze:**

It contains 90 to 96% Copper, 3 to 5% Silicon, 0.5 to 2% Manganese or Zinc.

Silicon Bronze is a restraint to corrosion and certain chemicals also. It has more electrical conductivity and has good tensile strength. It is used for boiler parts, aerial wires, and spring materials.

- **Aluminium Bronze:**

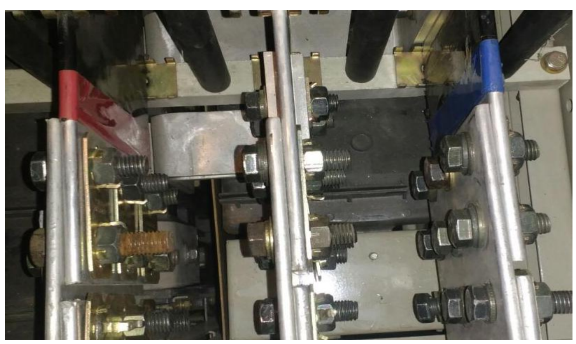
It is an alloy of 80-90% Copper, 6-7% Aluminium, 2% Iron, and 0.5% Tin.

Aluminium bronze is light in weight, strong, and resistant to oxygen and chemical actions. It is tough, ductile, and shockproof. It is used for gear drives, sliding parts, brush holder frames, die-castings, parts coming in touch with saline water.

6. Aluminium:

Aluminium's electrical conductivity is next to Copper. It is malleable and ductile and can be drawn into wires. Al offers high resistance to corrosion due to the oxide layer formed on its surface when exposed to the atmosphere. It is a good conductor of heat and electricity. It is much lighter than copper for the same mass.

Applications: It is used in overhead transmission lines, domestic wiring, flexible wires, busbars, and rotor bars of squirrel cage induction motor.



Aluminium Busbars

7. Alloys of Aluminium:

Pure aluminium does not have good machining properties and has poor strength and is mechanically weak. It is alloyed to improve these properties while retaining its corrosion resistance.

- **Duraluminium:**

It is an alloy of 4.22% Cu, 0.65% Mg, 0.22% Si, 0.42% Fe and rest of it Al.

It has better tensile strength and good machinability than Al and is most suitable for making sheets, tubes, and bars in the automobile and aeronautical industry.

- **Hindaluminium:**

It is an alloy of Al, Hg, Mn, Cr and Si.

Components made from Hindaluminium are strong, hard and are low in cost.

- **Magnaluminium:**

It is an alloy of consisting of 0 to 2.5% Cu, 1 to 55% Mg, 0 to 1.2% Li, 0 to 3% Si, 0 to 0.9% Fe, 0 to 0.03% Mn, and 85 to 95% Al.

Magnaluminium is a brittle alloy with poor castability and has lightweight. It can be welded and machined. It is mostly used in the aircraft and automobile industries. E.g. Vehicle door handles.

High Resistivity Conducting Materials:

High resistivity materials are the materials used in such applications where a high value of resistance is required. These materials have properties like the low-temperature coefficient of resistance, high melting point, and no tendency for oxidation. They must be ductile and should have high mechanical strength.

Applications of High resistivity Materials:

- Starter resistance
- Heating elements
- Precision resistance
- Loading resistance
- Incandescent Lamp filament

High resistivity conducting materials are as following.

- High resistivity materials consist of Manganin, Constantan or Eureka, Platinum, Nichrome, Tungsten, Carbon, and Mercury.

1. Manganin:

Manganin is an alloy of 86% copper, 12% manganese, and 2% nickel. It can be easily drawn into thin wires. It possesses a very low value of the temperature coefficient of resistance.

Applications: It is used in making wire-wound precision resistance for measuring instruments, Shunts for electrical measuring instruments, and Resistance boxes.

2. Constantan or Eureka:

Constantan or Eureka is an alloy of 60% copper and 40% nickel. It is a very stable alloy with very high working temperatures. It does not corrode due to air, heat, and moisture.

Applications:

1. It is used in making resistance elements in resistance boxes and thermo-couples for temperature measurements.
2. Used for resistance elements in field regulators used for regulating the generated voltage of a generator.
3. Used as supporting wires for electric filaments.

3. Platinum:

Platinum has a high melting point of 1770oC, it is rustproof and chemically inert. And it is a malleable and ductile metal.

Applications: It is used as heating elements in laboratory ovens and furnaces. Platinum Rhodium thermocouples are used for measurement for temperature up to 1600°C.

4. Nichrome:

Nichrome is an alloy of nickel 75-78%, chromium 20-30%, manganese 1.5%, and balance is iron. It can withstand high temperatures up to 1100°C for a long time without melting and oxidizing.

Applications: Used in making heating elements for electric heaters, electric irons, and furnaces.

5. Tungsten:

Tungsten is a hard metal and does not become brittle at high temperatures. It has a very high tensile strength. It oxidizes very quickly in the presence of oxygen even at temperatures of a few hundred degrees centigrade. In the atmosphere of inert gasses like Argon or in a vacuum it can easily work up to 2000°C.

It does not exhibit magnetic properties when pure but when alloyed with steel called Tungsten Steel it becomes magnetic material of top quality.

Applications: It is commonly used as filaments in incandescent lamps and in heaters in electron tubes. In the form of an alloy of Tungsten steel, it is used for making permanent magnets.

6. Carbon:

Carbon is mostly available as graphite which contains about 90% of carbon. To increase the conductivity of carbon products, different kinds of additives like copper as bronze powder are mixed with the carbon moulding compounds.

Carbon is resistant to moisture and it does not get oxide. It has low surface friction, it can withstand arcing and it is not affected by moisture, acids, and bases.

Applications: Used extensively as brushes as it possesses mirror-smooth surface. Used as an electrode in arc lamps and arc welding. Carbon also finds application in carbon resistors.

7. Mercury:

Mercury is the only metal that is liquid at room temperature. Its expansion and contraction is uniform over a wide range of temperature changes.

Applications: It is used in mercury vapor lamps. Used in arc rectifiers to convert AC to DC. It is used for making and breaking contact in Bucchholz relay and thermometers.

1.2: PROPERTIES AND USES OF INSULATING MATERIALS:

1. Mechanical properties
The mechanical properties considered are the tensile strength, elongation, tensile modulus, compressive modulus, impact strength etc.

2. Thermal properties
Include temperature and time of exposure. In this, the important consideration is that at what temperature one can operate the device for its required lifetime. The insulating materials used must be stable within the allowable temperatures. Some of the thermal properties checked for certain insulating materials are melting point, flash point, volatility, thermal conductivity, thermal expansion and heat resistance.

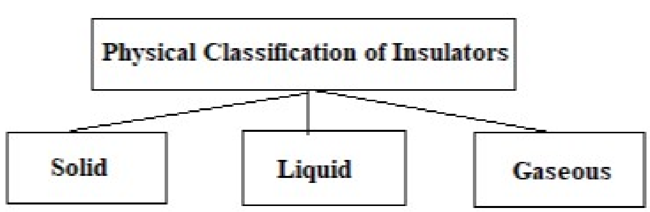
3. Environmental properties including chemical
The environment includes the effect of air (Oxidation), effect of light, ultraviolet rays, acid and alkali fumes, and humidity.

4. Electrical properties
From the electrical function point of view, the most important is the dielectric strength of insulation. Dielectric strength is that value of voltage which causes the electrical_rupture of an insulating material in practical use. Another important property is the dielectric constant, which determines the share of the electric stress which is absorbed by the material. For insulating materials, the loss tangent and resistivity (volume and surface) are also important properties.

5. Economic
Economic may or may not be an important factor for a given application. Types of insulating materials

Physical Classification of Insulating Material

The physical classification of insulating material is classified into three types they are solid, liquid, and gaseous. The physical classification of insulators is shown in the below figure.



Physical Classification of Insulating Materials

The solid insulating materials are fibrous, ceramic, mica, glass, rubber, and resinous. The liquid insulating materials are mineral oils, synthetic oils, transformer oils, and miscellaneous oils. The gaseous insulating materials are air, hydrogen, nitrogen, and Sulphur hexafluoride.

Structural Classification

The structural classification of insulating material is classified into two types they are cellulose and fibrous.

Chemical Classification

The chemical classification of insulating material is classified into two types they are organic and inorganic.

Process of Manufacture

The process of manufacture is classified into two types they are natural and synthetic.

Some of the insulating materials are fiberglass, mineral wool, cellulose, natural fibers, polystyrene, polyisocyanurate, polyurethane, insulation facings, phenolic foam, urea-formaldehyde foam, etc.

Applications of Insulating Material

The applications of insulating material are

- Cable and transmission lines
- Electronic systems
- Power systems
- Domestic portable appliances
- Electrical cable insulating tape
- Personal protective equipment
- Electrical rubber mats

1.3: VARIOUS MAGNETIC MATERIALS AND THEIR USES:

All substances show some kind of magnetic behaviour. After all, they are made up of charged particles: electrons and protons. It is the way in which electron clouds arrange themselves in atoms and how groups of these atoms behave that determines the magnetic properties of the material. The atom (or group of atoms) in effect becomes a magnetic dipole or a mini bar magnet that can align according to the magnetic field applied. The net effect of all these dipoles determines the magnetic properties of the magnetic materials.

Types of Magnetic Materials

To study magnetic properties of magnetic materials, the material is usually placed in a uniform magnetic field and then the magnetic field is varied. There are three major kinds of magnetic behaviour:

- **Diamagnetic materials:**

These materials are barely magnetised when placed in a magnetic field. Magnetic dipoles in these substances tend to align in opposition to the applied field. In effect, they produce an internal magnetic field that opposes the applied field and the substance tends to repel the external field around it.

This opposing field disappears as soon as the external field is removed.
Ex: Gold, water, mercury and even animals!

- **Paramagnetic materials:**

In these materials, the magnetic dipoles in the magnetic materials tend to align along the applied magnetic field and thus reinforcing the applied magnetic field. Such substances are attracted by a magnet if it applies a sufficiently strong field. It must be noted that such materials are still feeble magnetised and the magnetisation disappears as soon as the external field is removed. The magnetisation (**M**) of such materials was discovered by Madam Curie and is dependent on the external magnetic field (**B**) and temperature T as:

$$\vec{M} = C\frac{\vec{B}}{T}$$

Where C= Curie Constant
Ex: Liquid oxygen, sodium, platinum, salts of iron and nickel.

- **Ferromagnetic materials:**

We are most familiar with these materials as they exhibit the strongest magnetic behaviour. Magnetic dipoles in these materials are arranged into domains where the arrangements of individual magnetic dipoles are essentially perfect that can produce strong magnetic fields. Normally, these domains are usually randomly arranged and thus the magnetic field of each domain is cancelled by another and the entire material does not show any magnetic behaviour.

However, when an external field is applied, the domains reorient themselves to reinforce the external field and produce a strong internal magnetic field that is along the external field. Upon removal of the external field, most of the domains stay put and continue to be aligned in the direction of the (erstwhile) magnetic field. Thus, the magnetic field of the magnetic materials persists even when the external field disappears. This property is used to produce Permanent magnets that we use every day. Iron, cobalt, nickel, neodymium and their alloys are usually highly ferromagnetic and are used to make permanent magnets.

List of magnetic materials:

Now, to summarise the different types of magnetic materials, here we have given a list of magnetic materials.

Diamagnetic	Paramagnetic	Ferromagnetic
Gold	Liquid Oxygen	Iron
Water	Sodium	Cobalt
Mercury	Platinum	Neodymium
Salts of Iron and Nickel	Nickel	

Unit-2: DC GENERATOR:

2.1 Construction, Principle & application of DC Generator.

2.2 Classify DC generator including voltage equation.

2.3 Derive EMF equation & simple problems.

2.4 Parallel operation of DC generators.

2.1 Construction, Principle & application of DC Generator:

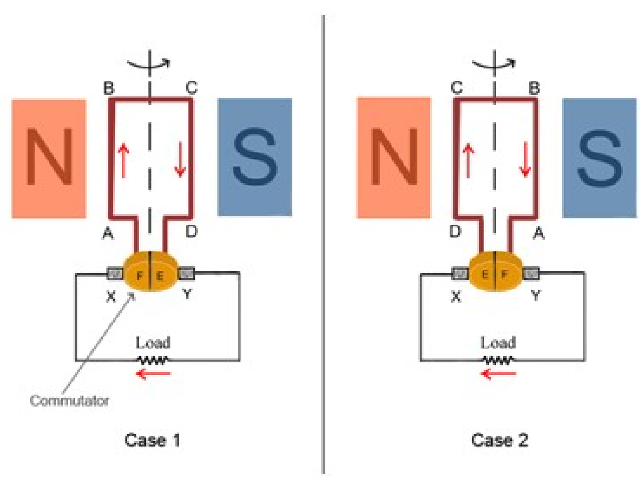
Electrical generators are standalone machines that provide electricity when power from the local grid is unavailable. These generators supply backup power to businesses and homes during power outages. Generators do not create electrical energy, but they convert mechanical or chemical energy into electrical energy. Based on the output, generators are classified into two types as AC generators and DC generators. In this article, we will be discussing DC generators in detail. You can check out our article on the AC generator to understand its working principle, construction and more.

What is a DC Generator?

A DC generator is an electrical machine whose main function is to convert mechanical energy into electricity. The working principle of DC generators is based on Faraday's laws of electromagnetic induction. When a current caring conductor rotates in a magnetic field it slashes magnetic flux, an emf will be generated. This electromotive force can cause a flow of current when the conductor circuit is closed.

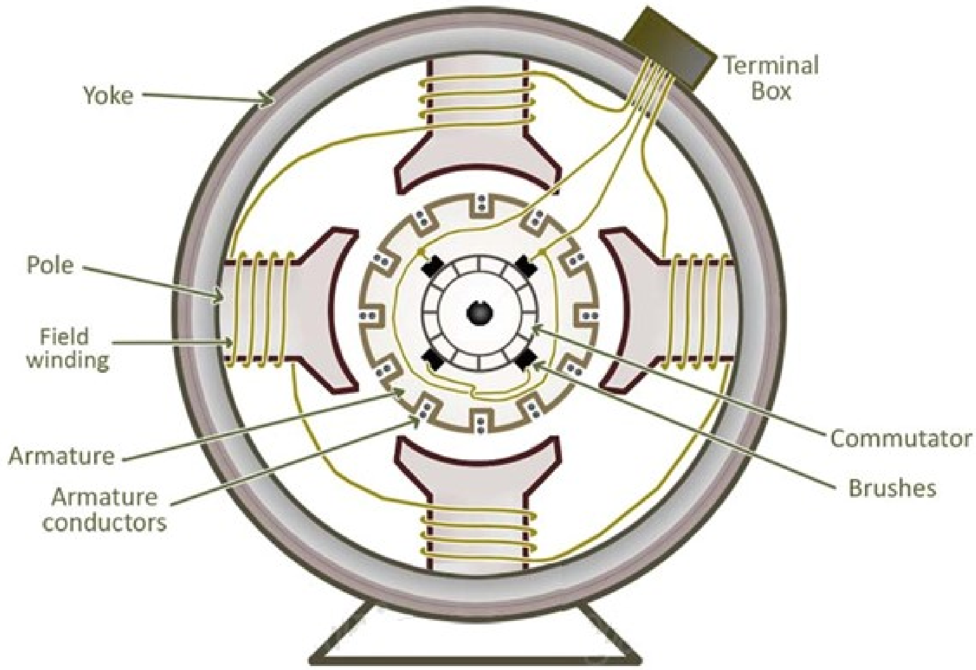
Working Principle of A DC Generator:

According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor. The magnitude of induced emf can be calculated from the emf equation of dc generator. If the conductor is provided with a closed path, the induced current will circulate within the path. In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field. Thus, an electromagnetically induced emf is generated in the armature conductors. The direction of induced current is given by Fleming's right hand rule.



According to Fleming's right hand rule, the direction of induced current changes whenever the direction of motion of the conductor changes. Let's consider an armature rotating clockwise and a conductor at the left is moving upward. When the armature completes a half rotation, the direction of motion of that particular conductor will be reversed to downward. Hence, the direction of current in every armature conductor will be alternating. If you look at the above figure, you will know how the direction of the induced current is alternating in an armature conductor. But with a split ring commutator, connections of the armature conductors also get reversed when the current reversal occurs. And therefore, we get unidirectional current at the terminals.

Basic Construction Of A DC Generator:



The above figure shows constructional details of a simple **4-pole DC machine**. A DC machine consists of two basic parts; **stator and rotor**.

Basic constructional parts of a DC machine are described below.

1. **<u>Yoke</u>:** The outer frame of a dc machine is called as yoke. It is made up of cast iron or steel. It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding.

2. **<u>Poles and pole shoes</u>:** Poles are joined to the yoke with the help of bolts or welding. They carry field winding and pole shoes are fastened to them. Pole shoes serve two purposes; (i) they support field coils and (ii) spread out the flux in air gap uniformly.

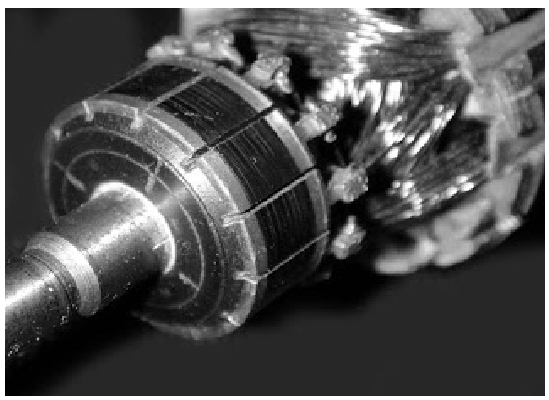
3. **<u>Field winding</u>:** They are usually made of copper. Field coils are former wound and placed on each pole and are connected in series. They are wound in such a way that, when energized, they form alternate North and South poles.

Armature core (rotor)

4. **Armature core:** Armature core is the rotor of a dc machine. It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses. It may be provided with air ducts for the axial air flow for cooling purposes. Armature is keyed to the shaft.

5. **Armature winding:** It is usually a former wound copper coil which rests in armature slots. The armature conductors are insulated from each other and also from the armature core. Armature winding can be wound by one of the two methods; lap winding or wave winding. Double layer lap or wave windings are generally used. A double layer winding means that each armature slot will carry two different coils.

6. **Commutator and brushes:** Physical connection to the armature winding is made through a commutator-brush arrangement. The function of a commutator, in a dc generator, is to collect the current generated in armature conductors. Whereas, in case of a dc motor, commutator helps in providing current to the armature conductors. A commutator consists of a set of copper segments which are insulated from each other. The number of segments is equal to the number of armature coils. Each segment is connected to an armature coil and the commutator is keyed to the shaft. Brushes are usually made from carbon or graphite. They rest on commutator segments and slide on the segments when the commutator rotates keeping the physical contact to collect or supply the current.



Commutator

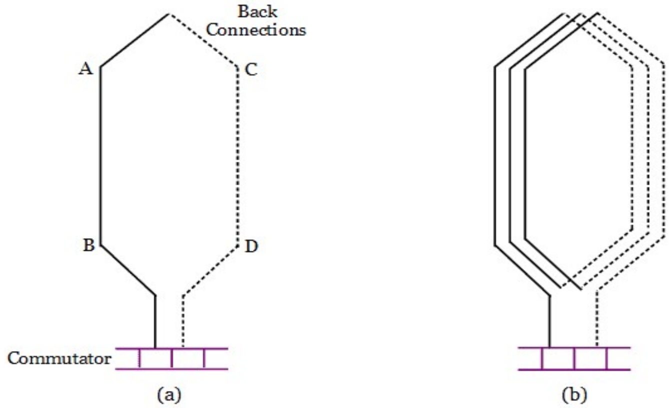
Armature winding

Armature winding is one of the most important parts of the DC Generator. In armature winding, you have to be clear with several terms like coil sides, coil pitch, pole pitch, front pitch, back pitch, commutator pitch, etc. Without a proper understanding of these terms, it is not possible to efficiently design the winding.

Terms used in the armature winding:
The following terms are used in connection with the armature winding.

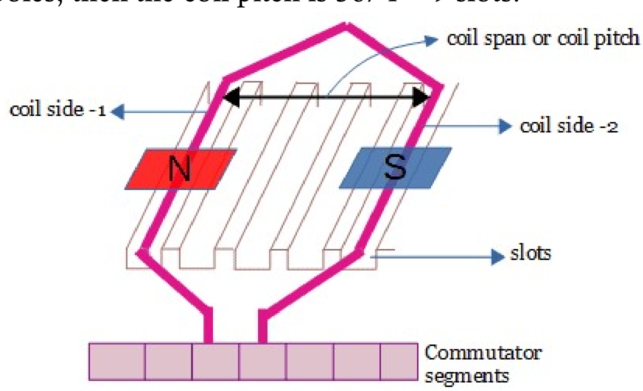
Conductor:
The conductor is an individual wire lying in the magnetic field. By relative motion of the conductor, the field induces an emf in it. It may have one or two or more parallel strands. In the following figure, AB and CD are the conductors.

Turn:
A turn has two conductors in series lying in the magnetic field. In other words, a conductor in one slot is connected to a conductor in another slot, it forms a turn.
Coil:
The above said two conductors AB and CD along with their end connections constitute a coil or winding. It may be a single turn coil or multi-turn coil. Single turn coils have only two conductors. Whereas the multi-turn coil will have many conductors. The figure below (b) shows 3 turn coil, which has 3 conductors on each coil side.
Coil Side:
Each coil, either single turn or multi-turn, has two sides called the coil sides. A conductor can also be called a coil side. AB and CD are said to be the two coil side of the coil. A **coil group** may have one or more single coils. The number of coils are arranged in coil groups called the **winding**.



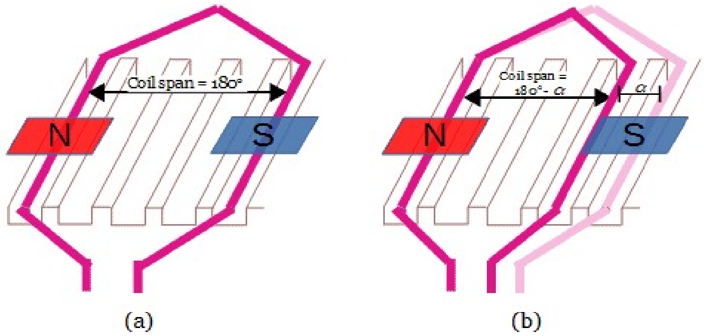
Coil sides in (a) single turn winding (b) 3 turn coil

Front end and Back end connector:
A wire that connects the end of a coil to a commutator segment is called a front end connector. The back end connector is a wire that connects one coil side to the other side of the coil. Back connections are opposite to that of the commutator.
Pole Pitch:
Pole pitch is nothing but the peripheral distance between two adjacent poles. It is measured in terms of armature slots or armature conductors. It can also be defined as the number of armature slots(or armature conductors) per pole. Let there be 48 conductors and 4 poles in a dc generator, then the pole pitch is 48/4 = 12.
Coil Pitch or Coil span:
It is the angular distance between two sides of a coil, measured in terms of armature slots. For example, if there are 36 slots and 4 poles, then the coil pitch is 36/4 = 9 slots.



Coil span or coil pitch

If the coil pitch is equal to the pole pitch, then it is called a **full pitch coil**. For a full pitch coil, each coil side lies under the opposite pole as shown in the figure below. It means the coil span is 180 electrical degrees. If the coil pitch is less than the pole pitch, it is said to be **short pitch coil or fractional pitch coil**.



(a) Full pitch coil (b) short pitch coil

Pitch of a winding or winding pitch:

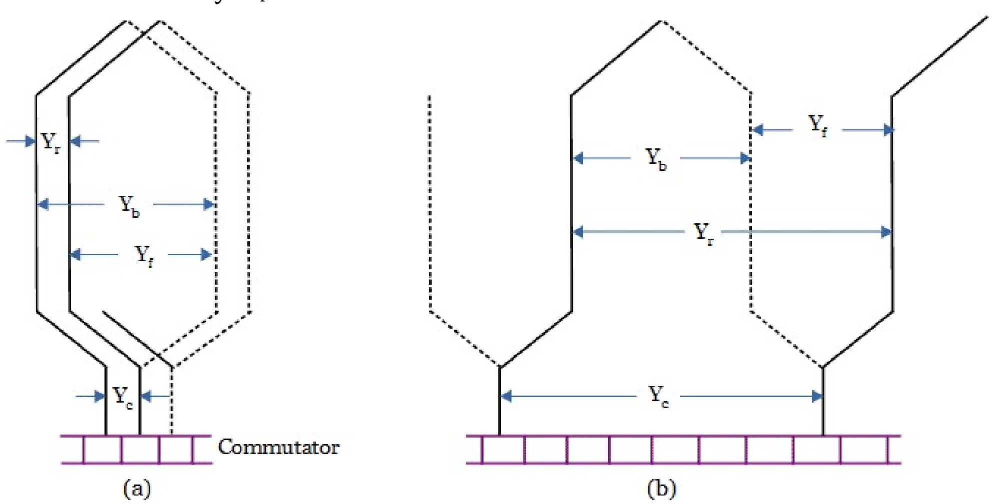
Winding pitch is defined as the distance between two successive conductors which are directly connected together around the armature. It is the beginning of two successive coil sides and is denoted by Y. For lap winding, $Y = Y_b - Y_f$ and for wave winding, $Y = Y_b + Y_f$.

Back Pitch:

The distance at which a coil advances on the back of the armature is called back pitch, denoted by Y_b. It can also be defined as the distance between the first and the last conductors of a coil. It is the same as coil span and is shown in the below figure (a) and (b).

Front Pitch:

It is the distance between the second conductor of one coil and the first conductor of the next coil. Both the coils should be connected to the same commutator segments on the front, as shown in the figure (a) and (b) below. It is denoted by Y_f.



Pitch in (a) Lap winding (b) Wave winding

Resultant Pitch:

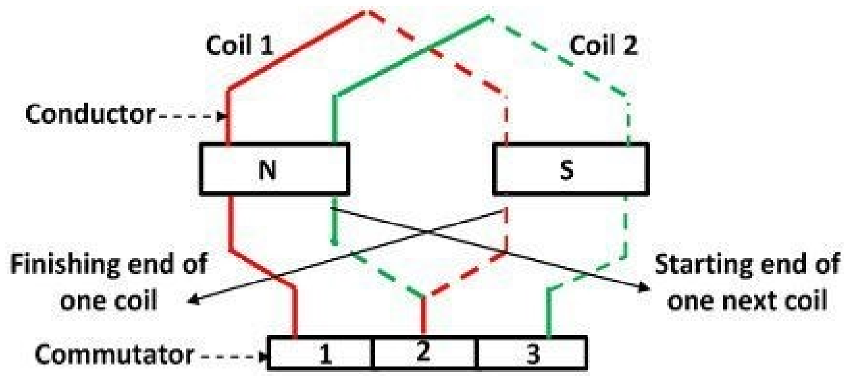
It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected. It is illustrated in the above figure (a) and (b), denoted by Y_r.

Commutator Pitch:

It is the distance between the Commutator segments to which the two ends of a coil are connected. From the figure, you can observe, for lap winding, Commutator pitch (Y_c) is the difference of back pitch(Y_b) and front pitch(Y_f). For wave winding, it is the sum of the back pitch and front pitch.

Lap Winding:

When the winding is connected in such a manner that the end of the one coil is connected to the starting end of other coils (adjacent coil) of the same pole and so on then the winding is known as lap winding.



Lap Winding

Lap winding can be of three type's simplex, duplex, and triplex. In simplex lap winding, there are as many parallel paths as there are a number of field poles. The multiplex (duplex or triplex) lap windings are used where heavy currents at low voltage are necessary. The duplex lap winding is obtained by placing two similar windings on the same armature and connecting the even-numbered commutator bars to one winding and the odd-numbered ones to the second winding.

Important Points Regarding Lap Winding:

i. The back and front pitches Y_b and Y_c should be odd and approximately equal to pole pitch = Z / P. Where,

- Z = number of conductors on the armature
- P = number of (field) poles

ii. Y_b should be either greater or less than Y_f by 2m. Where,

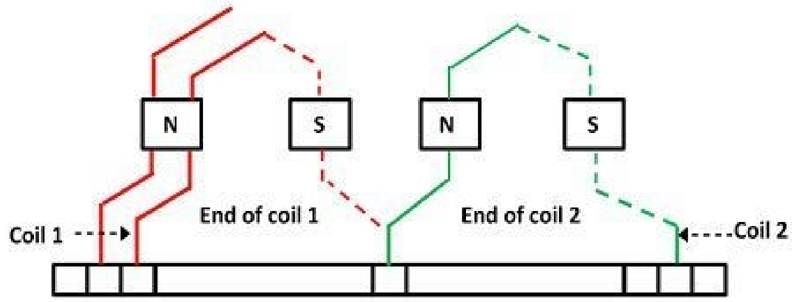
- m = multiplicity of the winding.

$$Y_B = Y_F \pm \frac{Y_B + Y_F}{60} 2M$$

Where,

- m = 1 for simplex winding
- m = 2 for duplex winding
- m = 3 for triplex winding

Wave Winding:



Wave Winding

In wave winding, the coil side is not connected back but progresses forward to another coil side. In this way, the winding progresses passing successively every N-pole, S-pole till it returns to the coil side from where it was started. Because the winding progresses in one direction around the armature in a series of ' waves ', hence it is known as wave winding or series winding.

Important Points Regarding Wave Winding:

i. Both Pitches Y_b and Y_f should be odd and of the same sign.

ii. Back and front pitches must be nearly equal to the pole pitch and maybe equal or differ by 2 in which case, they will be one more or one less than the average pitch.

iii. Commutator Pitch,

$$Y_c = \text{Average Pitch } Y_a$$

iv. Resultant Pitch,

$$Y_a = Y_f + Y_b$$

v. The average Pitch, which must be an even integer is given by,

$$Y_A = Z \pm 2 / P$$

Where,

- Z = number of conductors
- P = number of poles

The +ve sign in the above formula will give progressive winding and the -ve sign a retrogressive winding.

vi. For an even number of pairs of poles i.e., for 2, 4, 6, or 8 pair pole machines :

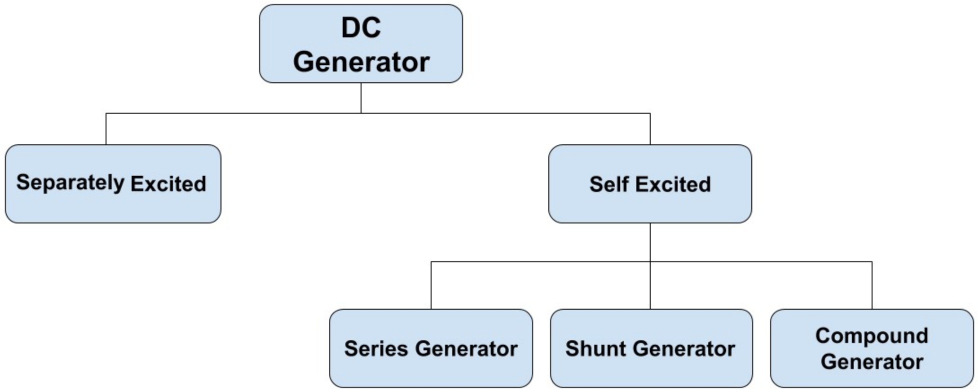
1. The average pitch may be odd or even.
2. The number of coils must be odd.
3. The number of commutator segments must be odd.

vii. For odd numbers of pair of poles :

1. The number of coils may be even or odd.
2. The number of commutator segments may be even or odd.
3. If the number of coils is even, Y_a must be odd and vice-versa.

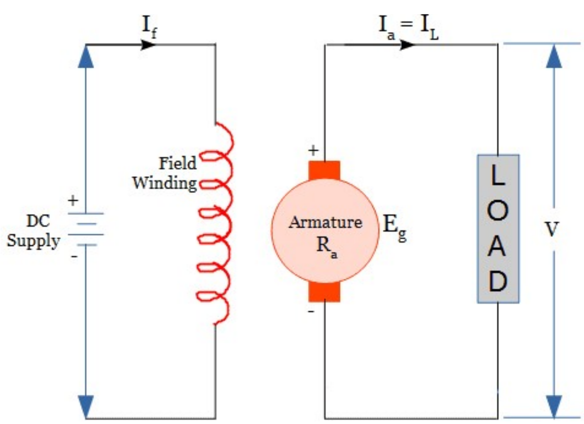
2.2: Types of DC Generator and its equation:

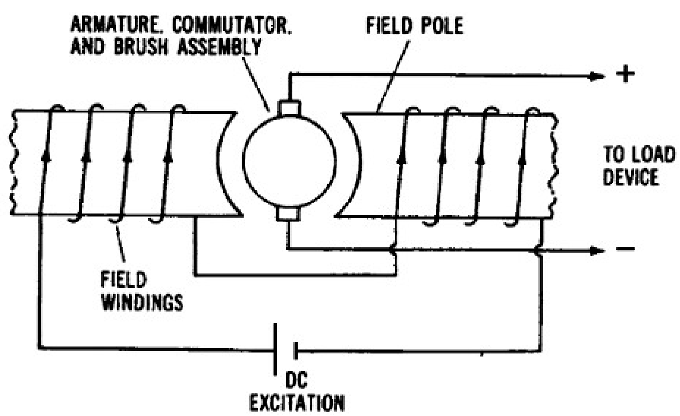
DC generators are classified based on the way in which the field windings are excited. The different types of DC generator are shown below



Separately excited DC Generator:

It is a type of DC generator, in which the field windings are excited from a separate source of supply. The following figure shows the circuit diagram of a separately excite dc generator.





In the above circuit diagram,

I_f – Field current, I_a – Armature current, I_L – Load current,

R_a – Armature winding resistance, V – terminal voltage

Let V_{br} be the voltage drop at the brush contacts.

Armature current is given by, $I_a = I_L$

Applying Kirchoff's Voltage Law to the armature circuit,

$$E_g - I_a R_a - V - V_{br} = 0$$

Thus, the generated Emf equation $E_g = I_a R_a + V + V_{br}$

Power developed in the DC generator = $E_g I_a$

Power delivered to the load = $V I_a$

Self Excited DC Generator:

The self-excited generator produces DC output, whose field windings are excited by the current produced by the generator itself. No separate source is used for filed excitation.

In this type of generators, some flux is already present in the poles due to residual magnetism. When the armature is rotated with the residual flux, a small emf and hence some current is induced in the armature conductors. This current will produce more flux, which in turn produces more current to flow through the field winding. It will continue until the field current reaches its rated value.

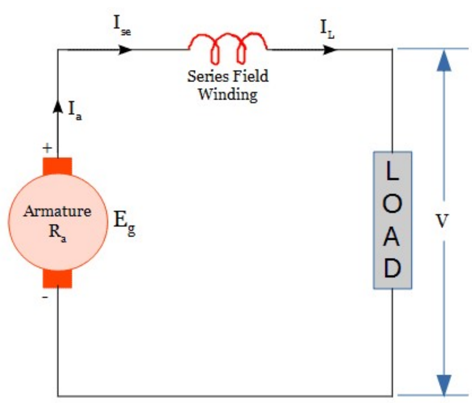
There are three types of self-excited DC generator based on the way, in which the field coils and armature are connected. They are

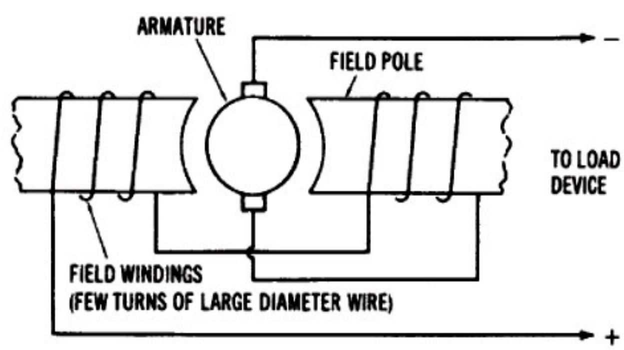
1. Series wound Generator
2. Shunt-wound Generator
3. Compound wound Generator

DC Series Generator:

As the name says, the field winding is connected in series with the armature conductors. Such generators are called a DC series Generator. They have less number of turns with a thick wire having low resistance.

Here, the load is connected in series with the field winding and armature conductors. So all the currents are flows through field winding and load.





In the above circuit diagram,

I_{se} – Shunt field current, I_a – Armature current, I_L – Load current,

R_a – Armature winding resistance, V – terminal voltage, V_{br} – Brush contact drop

Armature current is given by, $I_a = I_{se} = I_L$

Terminal voltage equation is given by, $V = E_g - I_a R_a - I_a R_{se} - V_{br}$

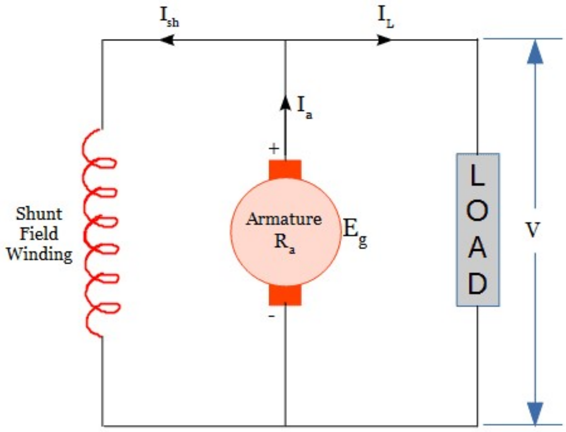
Power developed in the DC generator = $E_g I_a$

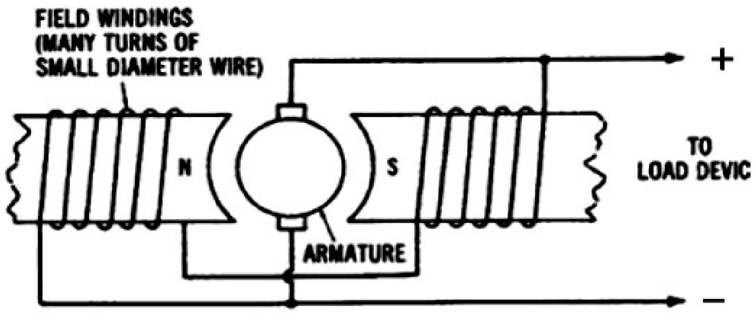
Power delivered to the load = $V I_L$

DC Shunt Generator:

In DC shunt type generator, the field windings are connected across or in parallel with the armature conductors. The field winding has more number of turns and thin wire, having high resistance.

The load is connected across the armature as shown in the diagram below. A small amount of current will flow through the field winding and more current flows through the armature.





In the above circuit diagram,

I_{sh} – Shunt field current, I_a – Armature current, I_L – Load current,

R_a – Armature winding resistance, V – terminal voltage, V_{br} – Brush contact drop

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

Shunt field current: $I_{sh} = V/R_{sh}$, Where R_{sh} – shunt field resistance

Terminal voltage equation is given by, $V = E_g - I_a R_a - V_{br}$

Power developed in the DC generator = $E_g I_a$

Power delivered to the load = $V I_L$

DC Compound Generator:

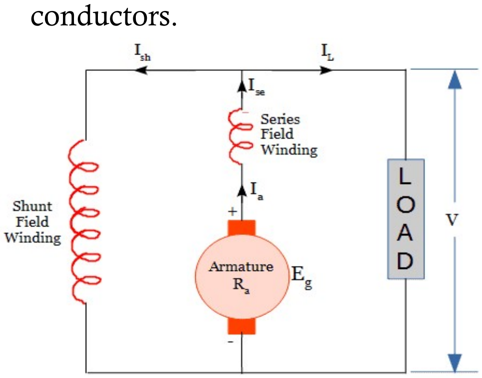
DC compound generator has both shunt field winding and series field winding. One field winding is connected in series with the armature and another field winding is connected in parallel with the armature.

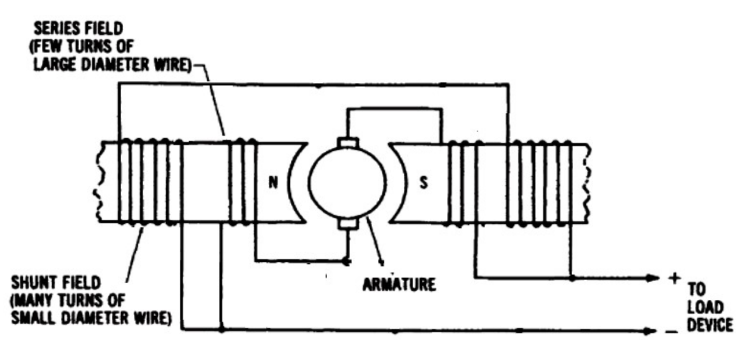
DC Compound generator can be classified into two different types based on the way of connection

1. Long shunt DC Compound generator
2. Short shunt DC Compound generator

Long shunt DC Compound generator:

The below figure shows the circuit diagram of long shunt DC compound generator. In this shunt field winding is connected in parallel with a combination of series field winding and armature conductors.





In the above circuit diagram,

I_{sh} – Shunt field current, I_{se} – Shunt field current, I_a – Armature current, I_L – Load current,

R_a – Armature winding resistance, V – terminal voltage, V_{br} – Brush contact drop

Armature current is given by, $I_a = I_{se} = I_L + I_{sh}$

Shunt field current: $I_{sh} = V/R_{sh}$, Where R_{sh} – shunt field resistance

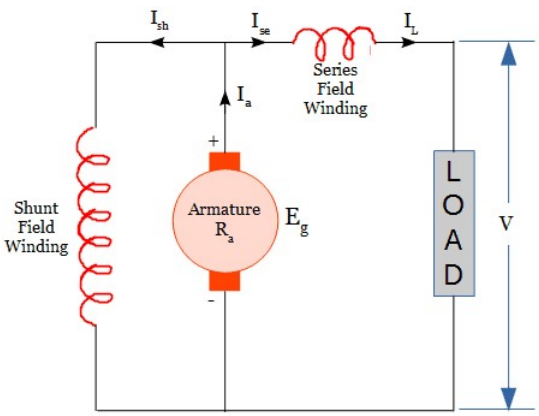
Terminal voltage equation is given by, $V = E_g - I_a R_a - I_a R_{se} - V_{br}$

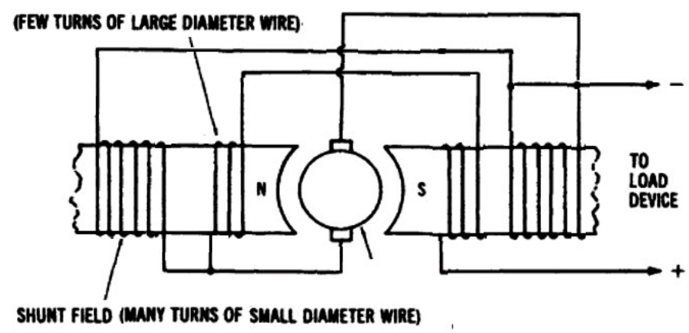
Power developed in the DC generator = $E_g I_a$

Power delivered to the load = $V I_L$

Short shunt DC Compound generator:

In short shunt DC compound generator, the shunt field winding is connected across the armature conductors and this combination is connected in series with a series field winding. The following figure shows the circuit diagram of short shunt DC compound generator.





In the above circuit diagram,

I_{sh} – Shunt field current, I_{se} – Shunt field current, I_a – Armature current, I_L – Load current,

R_a – Armature winding resistance, V – terminal voltage, V_{br} – Brush contact drop

Armature current is given by, $I_a = I_L + I_{sh}$ where $I_L = I_{se}$

Terminal voltage equation is given by, $V = E_g - I_a R_a - I_{se} R_{se} - V_{br}$

Generated Emf equation, $E_g = V + I_a R_a + I_{se} R_{se} + V_{br}$

Voltage drop across shunt field winding = $I_{sh} R_{sh}$

Shunt field current: $I_{sh} = (E_g - I_a R_a - V_{br})/R_{sh}$, Where R_{sh} – shunt field resistance

By substituting the value of E_g in the above equation, we get shunt field current

$$I_{sh} = (V + I_{se} R_{se})/R_{sh}$$

Power developed in the DC generator = $E_g I_a$ Power delivered to the load = $V I_L$

2.3: Derivation of EMF Equation of a DC Machine – Generator and Motor:

Let,

- **P** – number of poles of the machine
- **ϕ** – Flux per pole in Weber.
- **Z** – Total number of armature conductors.
- **N** – Speed of armature in revolution per minute (r.p.m).
- **A** – Number of parallel paths in the armature winding.

In one revolution of the armature, the flux cut by one conductor is given as:

$$\text{Flux cut by one conductor} = P\varphi \quad \text{wb} \dots \dots (1)$$

Time taken to complete one revolution is given as:

$$t = \frac{60}{N} \quad \text{seconds} \quad \dots \dots (2)$$

Therefore, the average induced e.m.f in one conductor will be:

$$e = \frac{P\varphi}{t} \quad \dots \dots (3)$$

Putting the value of (t) from Equation (2) in the equation (3) we will get

$$e = \frac{P\varphi}{60/N} = \frac{P\varphi N}{60} \quad \text{volts} \quad \dots \dots (4)$$

The number of conductors connected in series in each parallel path = Z/A.

Therefore, the average induced e.m.f across each parallel path or the armature terminals is given by the equation shown below:

$$E = \frac{P\varphi N}{60} \times \frac{Z}{A} = \frac{PZ\varphi N}{60\ A} \quad \text{volts}$$

If the DC Machine is working as a Generator, the induced emf is given by the equation shown below:

$$E_g = \frac{PZ\ \varphi\ N}{60\ A} \quad \text{volts}$$

Where $\mathbf{E_g}$ is the **Generated Emf**

If the DC Machine is working as a Motor, the induced emf is given by the equation shown below:

$$E_b = \frac{PZ\varphi N}{60\ A} \quad \text{volts}$$

In a motor, the induced emf is called **Back Emf (E_b)** because it acts opposite to the supply voltage.

For simplex wave-wound generator Number of parallel paths **A=2**

For simplex lap-wound generator Number of parallel paths **A=P**

Example:

A four pole generator, having wave wound armature winding has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7mWb?

Example:

An 8 pole Dc generator has 500 armature conductors, and a useful flux of 0.05Wb per pole. What will be the emf generated if it is lap-connected and runs at 1200 rpm? What must be the speed at which it is to be driven produce the same emf if it is wave-wound?

Example:

A 4 pole generator with wave wound armature has 51 slots each having 24 conductors. The flux per pole is 10 mWb. At what speed must the armature rotate to give an induced emf of 0.24 kV. What will be the voltage developed, if the winding is lap connected and the armature rotates at the same speed?

Example:

A 4 pole, lap wound, d.c. generator has a useful flux of 0.07 Wb per pole. Calculate the generated e.m.f. when it is rotated at a speed of 900 r.p.m. with the help of prime mover. Armature consists of 440 numbers of conductors. Also calculate the generated e.m.f. if lap wound armature is replaced by wave wound armature.

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