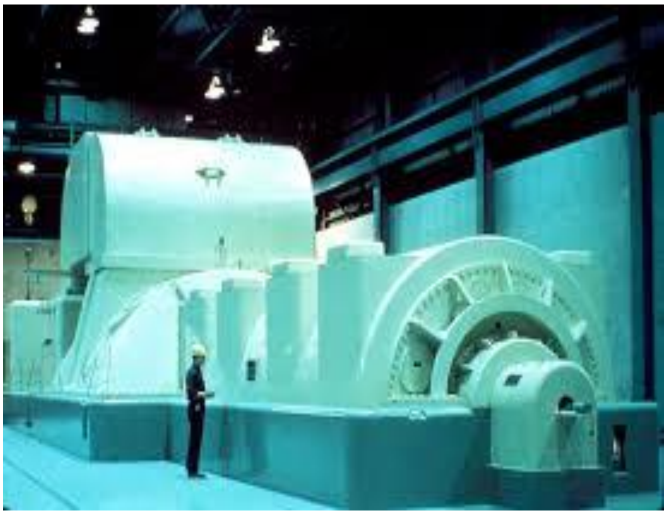
 

19EE2101-ELECTRO MECHANICAL ENERGY CONVERSION-I (EEE)

Course	Professional core	**Credits:**	3
Course	Theory	**Lecture-Tutorial-**	2-1-0
Pre-requisite:	Fundamental concepts of Electrical and Magnetic coupled circuits.	**Sessional Evaluation: External Exam Evaluation:**	40 60

Course Objectives:	Students undergoing this course are expected to learn :
	1. The constructional details, working principles & winding diagrams of DC machines. 2. The types of generators and their applications. 3. The characteristics of DC machines & speed control methods of DC motors. 4.The different performance tests on DC machines. 5. The constructional details, working principle & equivalent circuit of Transformer. 6. The testing of Transformer and Poly phase connections transformer

Course Outcomes:	After completing the course, the student will be able to:	
	CO1	Understand the working principle of Generator and its winding
	CO2	Identify the suitable DC generator for specific applications.
	CO3	Ascertain the suitable DC motor for specific applications.
	CO4	Understand the different tests on the DC machines to determine the performance of machines.
	CO5	Acquire the knowledge of principle, construction, and operation and also analyze the equivalent circuit of Transformer.
	CO6	Conduct different types of tests and identify different connections of a poly-phase transformer.

UNIT-1

DC GENERATORS:

Simple DC Generator working principle – constructional details of DC Machine - operation – Armature windings- types of armature windings and winding drawings – numerical problems – Generated EMF equation- Armature reaction- it's effects and compensating methods- numerical problems.

UNIT – II

TYPES OF DC GENERATORS:

Characteristics of different types of generators – critical field resistance and critical speed – applications – numerical problems - commutation - methods of improving commutation - Compensating windings.

UNIT – III

DC MOTORS:

Working principle – types of DC motors -Torque and Power developed by armature – characteristics of DC motors – Applications & numerical problems - Starting of DC motors - Constructional details of three point and four point starters – numerical problems - Speed control of DC motors – numerical problems.

UNIT – IV

LOSSES AND EFFICIENCY OF DC MACHINE:

Various losses in DC machine and efficiency, condition for maximum efficiency-numerical problems

Testing of DC machines: Brake test - Swinburne's test - Hopkinson's test – Field's test - Retardation test - Separation of iron and friction Losses- numerical problems.

UNIT – V

SINGLE PHASE TRANSFORMERS:

Types of Transformers - Constructional details - Principle of operation – EMF Equation - Phasor diagram - losses and efficiency – regulation - All day efficiency - effect of variations of frequency & supply voltage on iron losses - auto transformers-equivalent circuit - comparison with two winding transformers.

UNIT-VI

TESTING OF TRANSFORMERS AND POLY-PHASE TRANSFORMERS:

OC and SC tests - Sumpner's test - predetermination of efficiency and regulation-separation of losses - parallel operation with equal and unequal voltage ratios - Poly-phase transformers - Poly-phase connections - Y/Y, Y/Δ , Δ /Y, Δ /Δ, Scott Connection and open Δ .

TEXT BOOKS:

1.“Theory and Performance of Electrical machines”, by J.B Gupta - SK Kataria Publishers,2013.

2.“Principles of Electrical Machines”, by VK Mehta, Rohit Mehta - S.Chand, 2006.

ELECTROMECHANICAL ENERGY CONVERSION -I

UNIT-I

INTRODUCTION

- An electrical machine is a device that can convert either mechanical energy to electrical energy or electrical energy to mechanical energy. When such a device is used to convert **mechanical energy to electrical energy, it is called a generator.**
- When it converts **electrical energy to mechanical energy, it is called a motor.** Since any given electrical machine can convert power in either direction, any machine can be used as either a generator or a motor.
- Almost all practical motors and generators convert energy from one form to another through the action of a magnetic field, and only machines using magnetic fields to perform such conversions are considered.
- The **transformer** is an electrical device that is closely related to electrical machines. It **converts ac electrical energy at one voltage level to ac electrical energy at another voltage level. Transformers operate on the same principles as generators and motors.**

- These three types of electric devices are used in modern daily life. Electric motors in the home run **refrigerators, freezers, vacuum cleaners, blenders, air conditioners, fans,** and many similar appliances. In the workplace, motors provide the motive power for almost all tools. Of course, generators are necessary to supply the power used by all these motors.

PRINCIPLE OF ELECTROMECHANICAL ENERGY CONVERSION :

Electromechanical energy conversion is one device which converts energy one form to another form. **Electromechanical device converts electrical energy into mechanical energy and mechanical energy in to electrical energy**. Energy conversation takes place through the medium of **electric field or magnetic field.**

Electromechanical energy conversion devices with **magnetic field** as the coupling medium between electrical and mechanical systems are more common in commercial application.

Electromechanical energy conversion devices may categorized in various parts as under:-

1. The first category of devices, involving **small motion**, processes only low-energy signals from electrical to mechanical or vice versa. These are **microphones, gramophone , loud speakers and low-signal transducers.**
2. The second category consists of **force or torque-producing devices** with limited mechanical motion. These are **electromagnets, relays, moving-iron instruments** etc..
3. The third category includes continuous energy conversion devices like **motors and generators** these are used for bulk energy conversion and utilization.

PRINCIPAL OF ENERGY CONVERSION:-

It's state that the energy cannot be neither created or destroyed. It can only be converted from one form to the another form of energy.
Electric **Generator** converts **mechanical energy into electrical energy.**
Electric **Motor** converts **electrical energy into mechanical energy**.
Electromechanical energy conversion system has basically divided in to three parts,

1.Mechanical system

2.Field coupling system(magnetic field)

3.Electrical system

Principal of energy conversion is based on below equations.

Energy transfer equation for generator action can be written as, **Mechanical energy input = electrical energy output + losses in field + total energy losses**

Energy transfer equation for motoring action can be written as, **Electrical energy input = mechanical energy output + stored energy by field + total energy losses**

During the energy conversation there are occur some **Losses**, which are following as,

- Core losses or iron losses
- Electrical losses or copper losses
- Mechanicallosses

This all losses are called energy losses,

BASICS OF MAGNETISM:

Magnetism is a property by virtue of which a **piece of solid body attracts iron pieces** and pieces of some other metals.

Such a piece of solid body is called a natural magnet.

The two ends of a magnet are called its poles. When such a magnet is suspended freely by a piece of a silk fiber, it turns and adjusts itself in the direction of North and South of the earth.

The end adjusting itself in the direction of North is called N pole while other is called S pole. When such two magnets are brought near each other, their behaviour is governed by some laws called laws of magnetism.

1. Laws of Magnetism:

Law 1 : It states that **'like' magnetic poles repel and 'unlike' poles attract each other.**

When the two magnets are brought near each other, such that **two like poles** i.e. N and N or S and S are facing each other, then the two magnets experience a **force of repulsion.**

As against this, if **two unlike poles** i.e. N and S or S and N are facing towards each other, then they experience a **force of attraction** and try to attract each other.

Law 2 : This law is experimentally proved by Scientist **Coulomb** and hence also known as coulomb's law.

The force (F) exerted by one pole on the other pole is,

1. Directly proportional to the product of the pole strengths.
2. Inversely proportional to the square of the distance between them and
3. Dependent on the nature of medium surrounding the poles.

Mathematically this law can be expressed as,,

$$F \propto \frac{M_1 M_2}{d^2} \qquad \boxed{F = \frac{K M_1 M_2}{d^2}}$$

Where M_1 and M_2 are the pole strengths of the poles while 'd' is the distance between the two poles.

Where K is constant which depends on the nature of the surrounding.

2. Magnetic Field and Flux

The region around a magnet within which the influence of the magnet can be experienced is called its magnetic field.

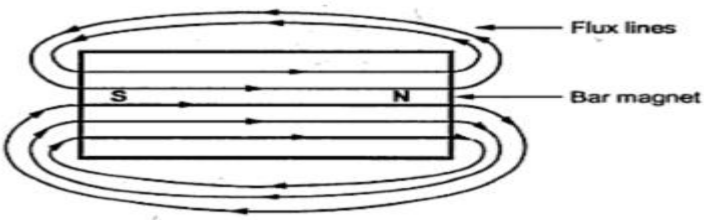
The presence of magnetic field is represented by imaginary lines around a magnet. These are called magnetic lines of force.

The total number of lines force existing in a particular magnetic field is called magnetic flux, denoted by a symbol 'B'. It is measured in a unit weber.

1 weber = 10^8 lines of force

Key point : The lines of force never intersect each other and are like stretched rubber bands and always try to contract in length.

The distribution and direction of such flux lines for a bar magnet is shown in the Fig. 1.



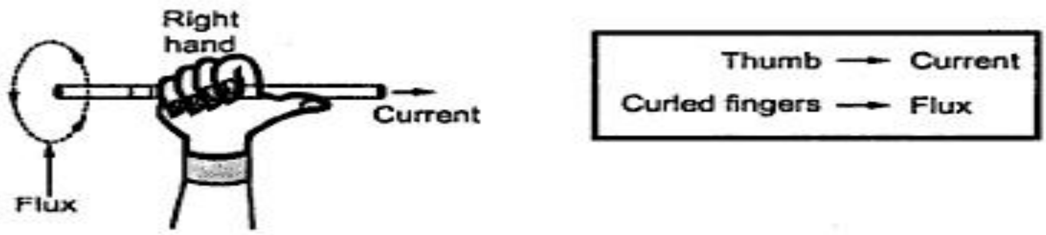
BASICS OF ELECTROMAGNETISM :

When a conductor carries a current, it creates a magnetic field around it. The direction of such magnetic field depends on the direction of the current passing through the conductor.

Let us see in brief, the role to determine the direction of the flux produced by a current carrying conductor.

Right Hand Thumb Rule

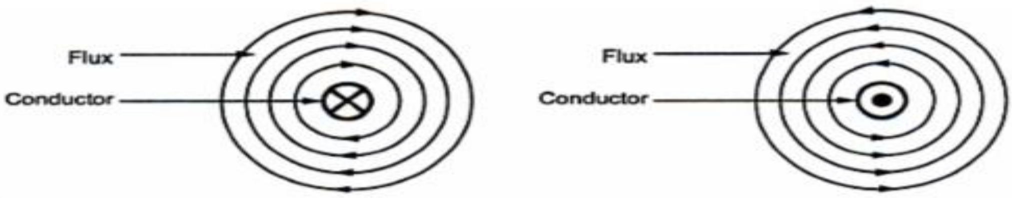
It states that "Hold the current carrying conductor in the right hand such that the thumb is pointing in the direction of current and parallel to the conductor, then curled fingers point in the direction of the magnetic field or flux around it".



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 below Fig a.

While if thumb of right hand is adjusted in the **direction of current shown as 'dot' i.e. coming out of paper,** then curled fingers indicate the **direction of flux as anticlockwise** as shown in the below Fig b.



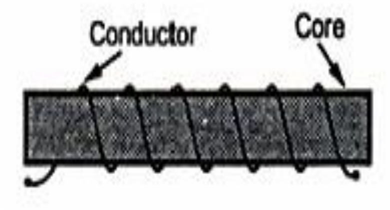
(a) Current moving away from observer (b) Current moving towards observer

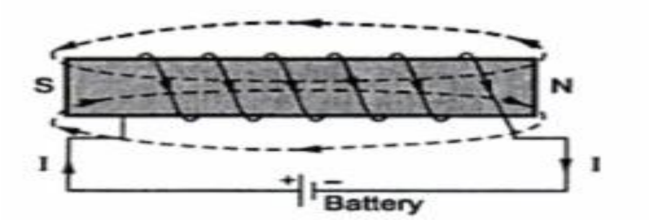
Magnetic Field due to Circular Conductor:

Consider an arrangement in which along conductor is wound with number of turns in a core, close together to form a coil. This is called a solenoid as shown in the below Fig. When such a conductor carries a current, the magnetic field gets produced around the core.

Identifying the direction of flux and hence identifying the two ends of the core as N pole or S pole is important in understanding the principle of d.c. machine. The right hand thumb rule can be modified for such case as stated below,

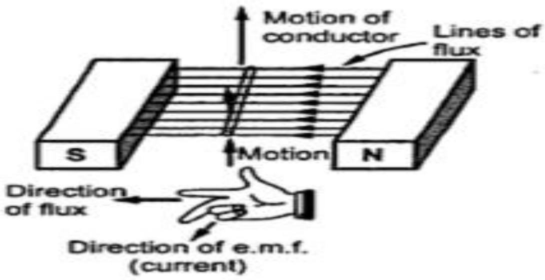
The right hand thumb rule : Hold the solenoid in the right hand such that curled fingers point in the direction of the current through the curled conductor, then the outstretched thumb along the axis of the solenoid points to the North pole of the solenoid or points in the direction of flux lines inside the core.





Key Point : The direction of flux can be reversed either by changing direction of current through the conductor by reversing the polarities of the supply or by changing the direction of winding of the conductors around the core.

Fleming's Right Hand Rule :

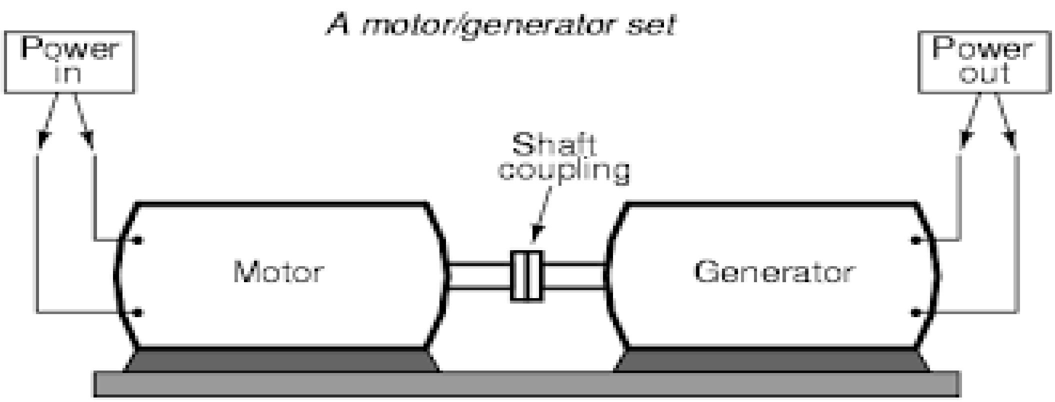


If three fingers of a right hand, namely thumb, index finger and middle finger are outstretched so that every one of them is at right angles with the remaining two, and if this position index finger is made to point in the direction of lines of flux, thumb in the direction of the relative motion of the conductor with respect to flux then the outstretched middle finger gives the direction of the e.m.f. induced in the conductor. Visually the rule can be represented as shown in the below Fig.

D.C.GENERATORS

INTRODUCTION

- The D.C generator converts **Mechanical Energy into Electrical Energy.** The Generator is usually coupled to a **Prime mover.** The prime mover may be a diesel / petrol engine, or a turbine depending upon the rating and application of the Generator.



- The prime mover converts some sort of energy (diesel / petrol / water / steam / gas etc) into Mechanical Energy. This Mechanical Energy is supplied to the Generator (i.e. generator input).
- When the Prime mover (motor) output is given to the Generator, **the Generator Armature starts rotating.** Usually the poles on the yoke are made of Permanent Magnets.
- Therefore, the armature conductors cuts the weak magnetic field established by Permanent Magnets and small **amount of e.m.f is induced** in the armature winding according to Faraday Laws of Electromagnetic induction.
- This induced e.m.f. circulates a small amount of current through the field winding and strengthens the magnetic flux established and hence the induced e.m.f.

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

SIMPLE LOOP GENERATOR

Consider a single turn loop ABCD rotating in a uniform magnetic field with a constant speed as shown in Fig.(1.1). As the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f. induced in these coil sides also changes but **the e.m.f. induced in one coil side adds to that induced in the other.**

(i) When the loop is in position no. 1 [See Fig. 1.1], 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. (1.2).

(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. (1.2).

(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. (1.2).

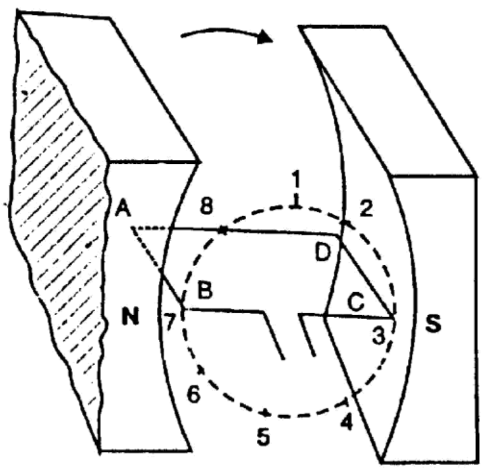


Fig 1.1

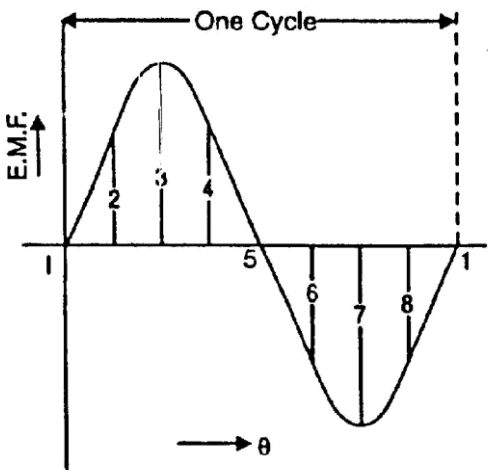
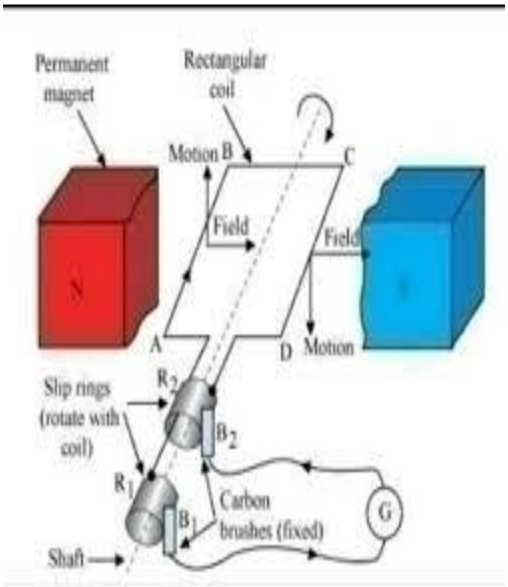


Fig 1.2

(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. 1.2) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.
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.

Let us **connect slip ring** with both ends of the loop. We can connect a load with the loop through the **brushes rest on the slip rings** as shown. In this case, the alternating electricity produced in the loop comes the load. This is an **AC electric generator**.



If a load is connected across the ends of the loop, then alternating current will flow through armature winding, slip rings, brushes to the load.
The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier

ACTION OF COMMUTATOR

- If, somehow, connection of the coil side to the external load is reversed at the same instant the current in the coil side reverses, the current through the load will be direct current. This is what a commutator does.
- Fig. (1.3) shows a commutator having two segments C_1 and C_2. It consists of a **cylindrical metal ring cut into two halves** or segments C_1 and C_2 respectively separated by a thin sheet of mica.
- The commutator is mounted on but insulated from the rotor shaft. The ends of coil sides AB and CD are connected to the segments C_1 and C_2 respectively as shown in Fig. (1.4). Two stationary carbon **brushes rest on the commutator and lead current to the external load.**
- With this arrangement, the commutator at all times connects the coil side **under S-pole to the +ve brush and that under N-pole to the -ve brush.** In Fig. (1.4), the coil sides AB and CD are under N-pole and S-pole respectively.
- Note that segment C_1 connects the coil side **AB to point P** of the load resistance R and the segment C_2 connects the coil side **CD to point Q** of the load. Also note the direction of current through load. It is from **Q to P.**
- After half a revolution of the loop (i.e., 180° rotation), the coil side AB is under S-pole and the coil side CD under N-pole as shown in Fig. (1.5). The currents in the coil sides now flow in the reverse direction but the segments C_1 and C_2 have also moved through 180° i.e., segment **C_1 is now in contact with +ve brush and segment C_2 in contact with -ve brush.**
- Note that **commutator has reversed the coil connections to the load i**.e., coil side AB is now connected to point Q of the load and coil side CD to the point P of the load. Also note the direction of current through the load. It is again from Q to P.

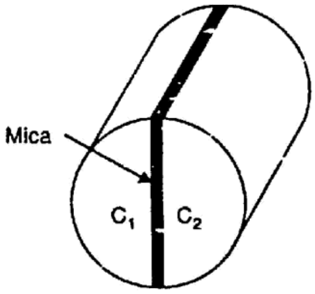


Fig.(1.3)

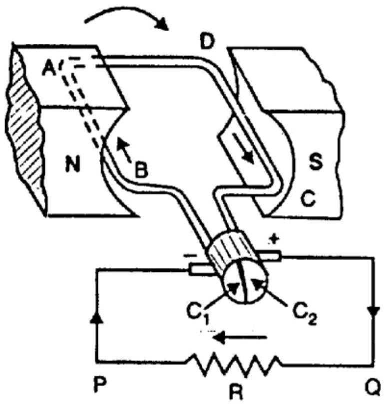


Fig.(1.4)

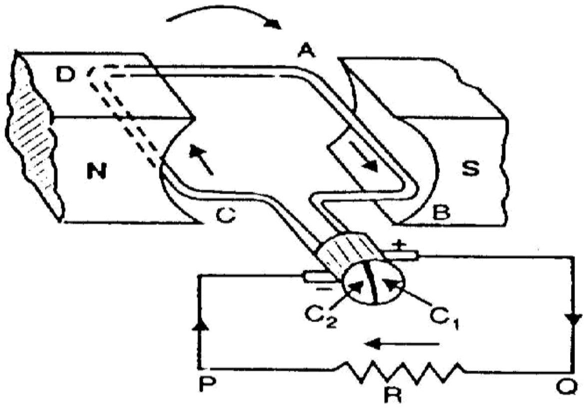


Fig.(1.5)

Thus the alternating voltage generated in the loop will appear as direct voltage across the brushes. It is by the use of commutator that we convert the generated alternating e.m.f. into direct voltage. The purpose of brushes is simply to lead current from the rotating loop or winding to the external stationary load.

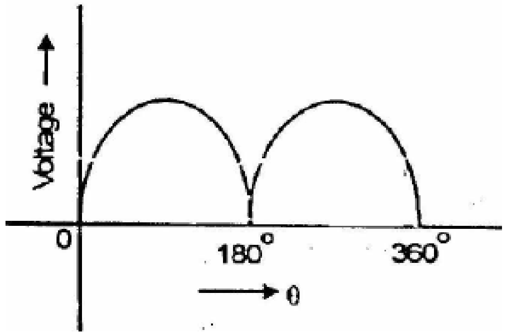
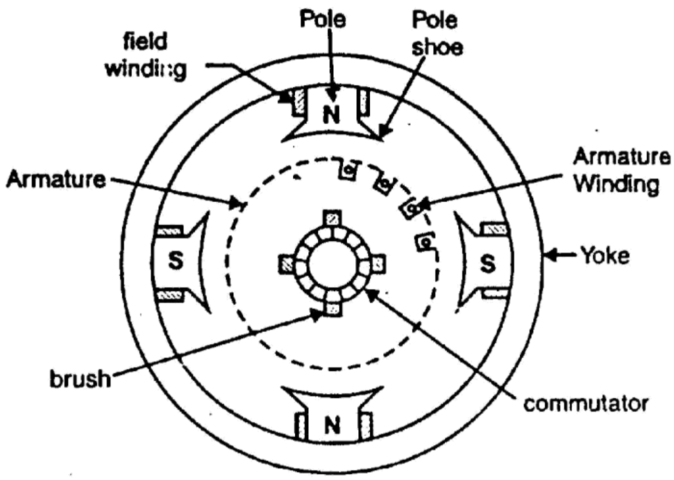


Fig. (1.6)

CONSTRUCTION OF D.C MACHINES



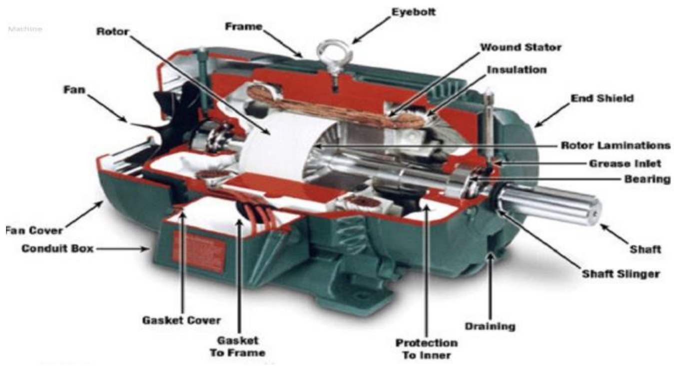


Fig 1.7.

The d.c. generators and d.c. motors have the same general construction. In fact, when the machine is being assembled, the workmen usually do not know whether it is a d.c. generator or motor. Any d.c. machine can be run as a d.c. motor and d.c generator. All d.c. machines have six principal components viz.

(i) Magnetic field system (ii) field winding (iii) armature core (iv) armature winding

(v) commutator (vi) brushes .

1.Magnetic field system (yoke, poles)

The function of the field system is to **produce uniform magnetic field** within which the armature rotates. It consists of a number of salient poles (of course, even number) bolted to the inside of circular frame (generally called yoke).

A) Yoke

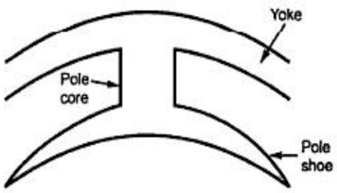
i)Functions :

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 SO2, acidic fumes etc.**

2. It provides **mechanical support to the poles.**

3. It forms a **path 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.

ii) 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.



B. Poles

Each pole is divided into two parts namely,

I) Pole core and II) Pole shoe.

i) 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 and 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.

ii) 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

2. Field Winding :

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

i)Functions :

1.Field coils are mounted on the poles and carry the d.c. exciting current. It produces the magnetic field or flux.The field coils are connected in such a way that adjacent poles have opposite polarity pole. (such that alternate 'N' and 'S' poles are formed.)

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

ii) Choice of material :

It has to carry current hence obviously made up of some conducting material. So aluminium or **copper** is the choice.

3) Armature core :

Armature core is cylindrical in shape mounted on the shaft.

The armature core is keyed to the machine shaft and rotates between the field poles. It consists of slotted **soft-iron laminations** (about 0.4 to 0.6 mm thick) that are stacked to form a cylindrical core.

i) Functions :

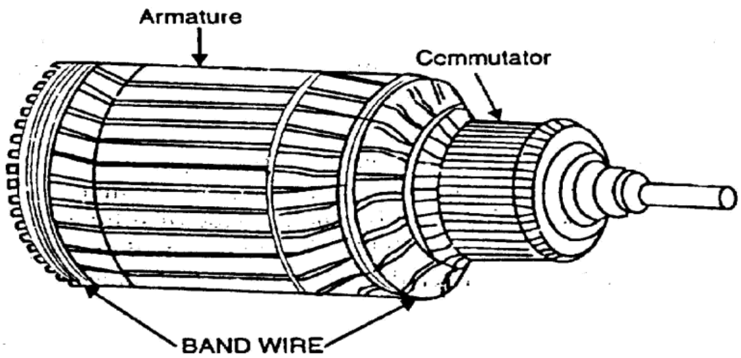
1.Armature core provides **house for armature winding** i.e. armature conductors.

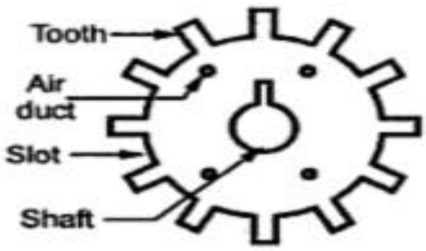
2.To provide a **path of low reluctance to the magnetic flux** produced by the field winding.

ii) 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.





4) 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.

i) 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.

ii) 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.**

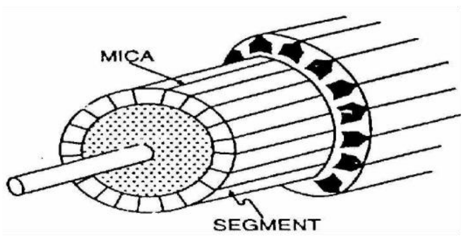
5.Commutator

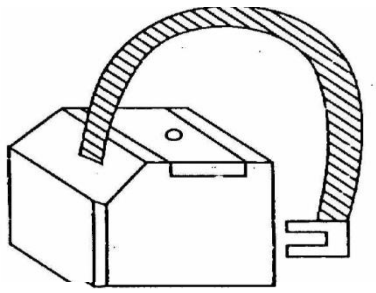
The basic nature of e.m.f. induced in the armature conductors is alternating. This needs **rectification** in case of d.c. generator, which is possible by a device called commutator.

i) Functions :

1. To collect the 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.

ii) 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 the 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.

6. Brushes

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

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

ii) 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.

ARMATURE WINDINGS:

The armature winding is the main current-carrying winding in which the electromotive force or counter-emf is induced. The current in the armature winding is known as the armature current.

The location of the winding depends upon the type of machine. A d.c. machine (generator or motor) generally employs windings distributed in slots over the circumference of the armature core.

Each conductor lies at right angles to the magnetic flux and to the direction of its Movement. Therefore, the induced e.m.f. in the conductor is given by;

e = B l v volts

where B = magnetic flux density in Wb/m2

l = length of the conductor in metres

v = velocity (in m/s) of the conductor

TYPES OF ARMATURE WINDING:

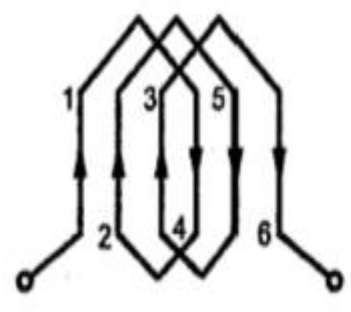
We have seen that there are number of **armature conductors, which are connected in specific manner as per the requirements, w**hich is called armature winding.

The different armature coils in a d.c. armature Winding must be connected in series with each other by means of end connections (back connection and front connection) in a manner so that the **generated voltages of the respective coils will aid each other** in the production of the terminal e.m.f. of the winding.

According to the way of connecting the conductors, armature winding has basically two types namely,

a) Lap winding **b) Wave winding**

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 shown in the Fig. 1.



As seen from the Fig. 1, there is overlapping of coils while proceeding.

Note : Due to such connection, the **total number of conductors get divided into 'P' number of parallel paths,** where P = number of poles in the machine.

Large number of parallel paths indicate high current capacity machine hence **lap winding is preferred for high current rating generators.**

2. Wave Winding

In this type of connection, winding always travels ahead **avoiding overlapping.** It travel 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 the Fig. 2.

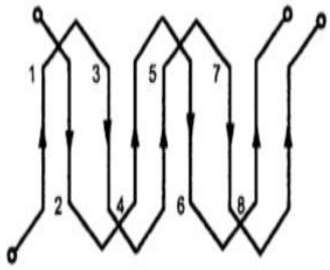


Fig. 2 Wave winding

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

Note : Due to this type of connection, the total number of conductors get divided into **two number of parallel paths** always, irrespective of number of poles of the machine. As number of parallel paths are less, it is **preferrable 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.**

3. Comparison of Lap and Wave Type Winding:

	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 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 500 A.

WINDING TERMINOLOGIES:

a) Conductor : (z)

Each individual length of wire lying within the magnetic field, **placed in the armature slot is called the conductor.**

b) Turn :

The two conductors placed in different slots when connected together, forms a turn.

When the two conductors lying in a magnetic field are connected in series, so that induced emf becomes double.

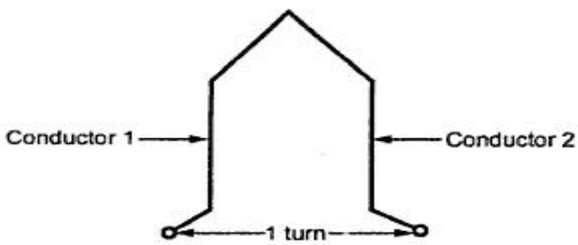


Fig. 1 Single Turn

Z = 2 x Number of turns.

c) **Coil :**

When one or more turns are connected in series and the two ends of it are connected to adjacent commutator segments(in lap winding) it is termed as a coil.

For simplicity of connections, the **turns are grouped together to form a coil**. If coil contains only one one turn it is called single turn coil while coil more than one turn is called **multiturn coil.**

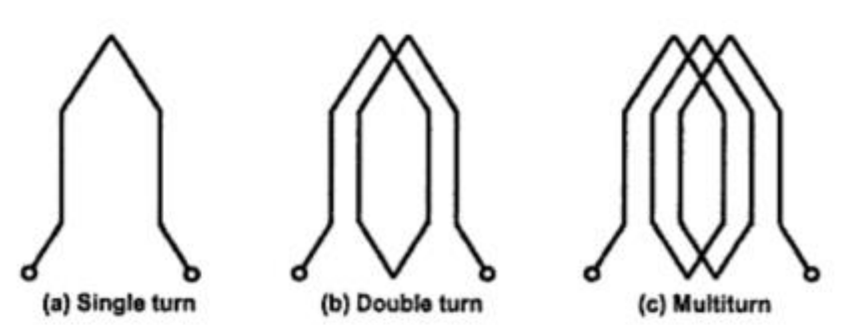


Fig. 2 Armature coils

POLE-PITCH

It is the distance measured in terms of **number of armature slots or armature conductors per pole.** Thus if a 4-pole generator has 16 coils, then number of slots = 16.

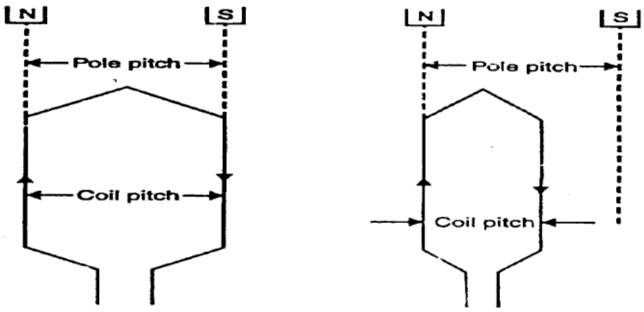
$$\boldsymbol{Pole\ pitch = \frac{16}{4} = 4\ slots}$$

$$Pole\ pitch = \frac{No. of\ conductors}{No. of\ poles} = \frac{16\ X\ 2}{4} = 8\ conductors$$

For example if there are 64 conductors and 8 poles then pole pitch is 64/8 = 8.

$$Pole\ pitch = \frac{No. of\, armature\ slots}{No. of\ poles}$$

COIL SPAN OR COIL PITCH (Y_S)

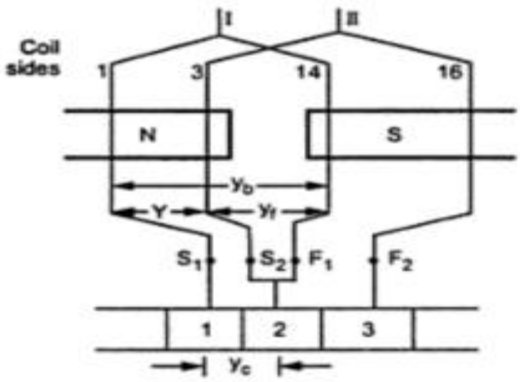


It is the distance measured in terms of the **number of armature slots (or armature conductors) between two sides of a coil.** Thus if the coil span is 9 slots, it means one side of the coil is in slot 1 and the other side in slot 10.

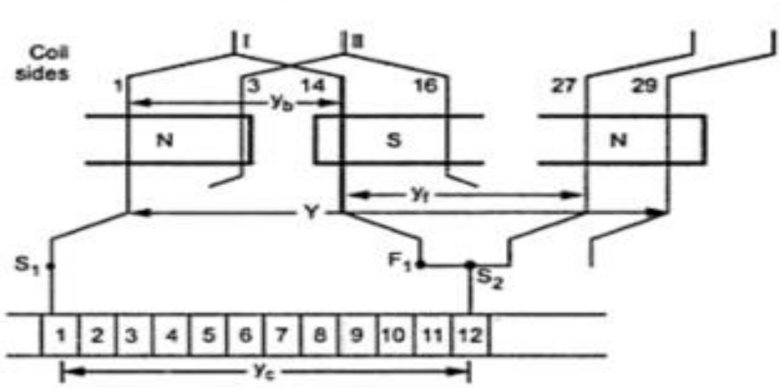
The two coil sides of a coil are embraced by number of teeth which is known as coil span. The coil span is normally equal to pole pitch, while in few cases it is not possible to have the coil span exactly equal to pole pitch. This situation comes when the number of slots are not divisible by number of poles.

BACK PITCH (Y_b.)

It is defined as the distance in terms of number of armature conductors between the last and the first conductors of the coil.It is shown for lap and wave type of winding in the Fig. 1.



(a) Lap type



(b) Wave type

The back pitch for the winding shown in the Fig. 1 is Yb = 14 - 1 = 13 as coil sides 1and 14 are of coil number 1.

FRONT PITCH (Y_F)

The number of armature conductors or elements spanned by a coil on the front is called the front pitch and is denoted by Y_f.

The front pitch may be defined as the distance in terms of armature conductors **between the second conductor of one coil and the first conductor of the next coil** which are connected to the same commutator segment at the front i.e. commutator end of the armature.

RESULTANT PITCH (Y_R)

It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected. It is denoted by Y_R.

COMMUTATOR PITCH (Y_C)

It is defined as the distance measured in terms of commutator segments between the segments to which the two ends of the coil are connected. It is denoted by Y_C.

WINDING PITCH

It is defined as the distance between the **starts of two consecutive coils** measured in terms of coil sides. It is denoted by Y.

For lap winding, Y = yb - yf

For Wave winding, Y = yb + yf

For the lap winding shown in the Fig. 1 the winding pitch is Y = 13 - 11 = 2 while for wave winding Y = 13 + 13 = 26

GENERAL RULES FOR D.C. ARMATURE WINDINGS :

In the design of d.c. armature winding (lap or wave), the following rules may be followed:

(i) The back pitch (Y_B) as well as front pitch (Y_F) should be nearly equal to pole pitch. This will result in increased e.m.f. in the coils.

(ii) Both pitches (Y_B and Y_F) should be odd. This will permit all end connections (back as well as front connection) between a conductor at the top of a slot and one at the bottom of a slot.

(iii) The number of commutator segments is equal to the number of slots or coils (or half the number of conductors).

No. of commutator segments = No. of slots = No. of coils

It is because each coil has two ends and two coil connections are joined at each commutator segment

(iv) The winding must close upon itself i.e. it should be a closed circuit winding.

Relations between Pitches for Simplex Lap Winding

In a simplex lap winding, the various pitches should have the following relation:

(i) The back and front pitches are odd and are of opposite signs. They differ numerically by 2,

$\therefore \quad Y_B = Y_B = Y_F \pm 2$

$Y_B = Y_F + 2$ for progressive winding

$Y_B = Y_F - 2$ for retrogressive winding

(ii) Both Y_B and Y_F should be nearly equal to pole pitch.

(iii) Average pitch $=(Y_B + Y_F)/2$. It equals pole pitch (= Z/P).

(iv) Commutator pitch, $Y_C = \pm 1$

$Y_C = +1$ for progressive winding

$Y_C = -1$ for retrogressive winding

(v) The resultant pitch (Y_B) is even, being the arithmetical difference of two odd numbers viz., Y_B and Y_F.

(vi) If Z = number of armature conductors and P = number of poles, then,

$$\text{Polr - pitch} = \frac{Z}{P}$$

IMPORTANT POINTS REGARDING WAVE WINDING

In a simplex wave winding Both the pitches, back pitch and front pitch must be odd numbers.

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

Commutator pitch, Yc=Average pitch, Yav

The average pitch Yav is given by

$Yav=(Yb+Yf)/2 =(Z\pm2)/P$

where Z is the number of conductors or coil sides and P is the number of poles. In order that the wave winding may close itself, the average pitch Yav must be a whole number and agree to the above formulae.

E.M.F. EQUATION OF A D.C. GENERATOR

We shall now derive an expression for the e.m.f. generated in a d.c. generator.

Let, φ = flux/pole in Wb

Z = total number of armature conductors

P = number of poles

A = number of parallel paths

A= 2 ... for wave winding

A= P ... for lap winding

N = speed of armature in r.p.m.

E_g = e.m.f. of the generator = e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature,

d φ = P φ webers

Time taken to complete one revolution, dt = 60/N second

$$\text{e.m.f generated/conductor} = \frac{d\phi}{dt} = \frac{p\phi}{60/N} = \frac{p\phi N}{60}$$

e.m.f. of generator, Eg = e.m.f. per parallel path

= (e.m.f/conductor) x No. of conductors in series per parallel path

$$= \frac{p\phi N}{60} \times \frac{Z}{A}$$

$$\therefore E_g = \frac{p\phi ZN}{60A}$$

For lap winding type A= P

$$\therefore E_g = \frac{\phi ZN}{60}$$

For wave winding type A =2.

$$\therefore E_g = \frac{p\phi ZN}{120}$$

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 e.m.f. in the armature 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.**

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

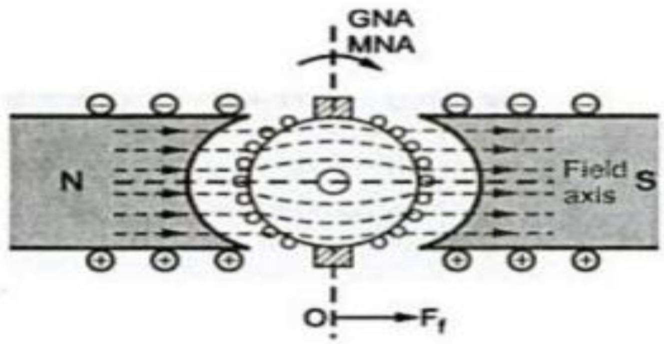
The armature reaction will try to make the main field flux to be weakened. Also it will distort the main flux. These two effects of armature reaction will **reduce the generated voltage and may cause sparking at the brushes.**

Concept of Armature Reaction

To understand the concept of armature reaction, consider a two pole d.c.generator. For simplicity we will assume that the brushes are touching the armature conductors directly, although, they 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. 1. **The flux is distributed 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 left 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. 1 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.



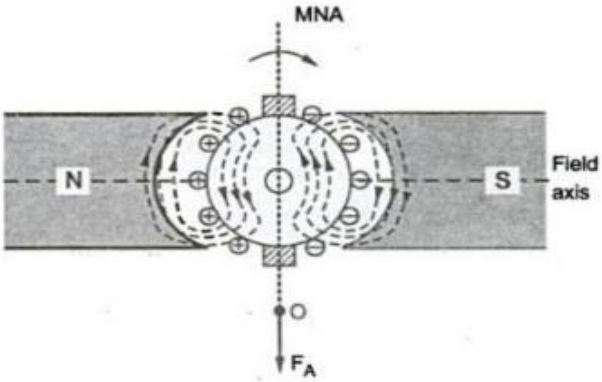


Fig. 1 **Fig. 2**

The brushes are always kept along MNA.
Thus MNA can also be called '**axis of commutation**' since reversal current takes place along this axis.

As shown in the Fig. 1, vector OF_f represents **the m.m.f. producing the mainfield flux** both in magnitudes as well as in the direction. MNA is perpendicular to vector OF_f.

Now we will consider that the **field coils are unexcited whereas the armature conductors are carrying current.** Under this case the field setup by the armature conductors is as shown in the Fig. 2.

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 brush axis. In other words current carrying armature conductors try to magnetize the armature core along the brush axis.

The vector OF_A shown in the Fig. 2. represents the armature m.m.f. both in magnitude and direction. This m.m.f. depends on the magnitude of the armature current.

we have considered the main m.m.f. and armature m.m.f. separately as if they are existing independently.

In practice the two m.m.f.s exist simultaneously in the generator under load conditions.

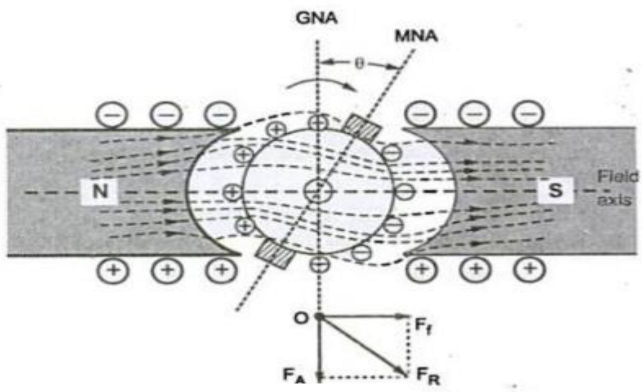


Fig 3

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. 3. The flux is crowded or concentrated at the trialing pole tips but weakened out at the leading pole tips.

Note: The pole tip which is met first during rotation by armature conductor is known as leading pole tip and other is known as trialing pole tip.

The resultant m.m.f. OF_R 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 OF_R. The MNA gets shifted through an angle θ so that brushes are also shifted and are along 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. 4. It can also be seen that the brush shifts in the same direction as that of direction of rotation of armature.

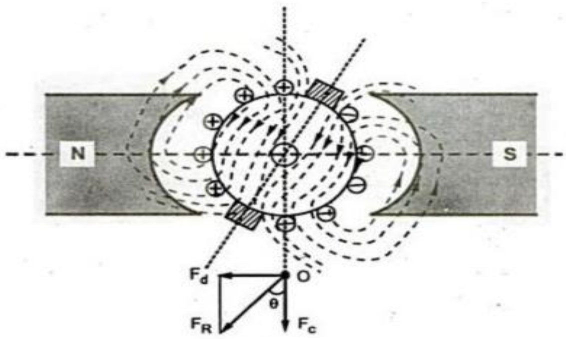


Fig 4

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 OF_R in the Fig. 4. It is inclined at an angle θ to the left instead of being vertical.

The armature m.m.f. represented by vector OF_R can be resolved into two components, OF_d parallel to the polar axis and OF_c perpendicular to the axis. The component OF_R is in direct opposition with field m.m.f. vector OF_f. This will tend to reduce the total flux. Hence this component is called demagnetizing component of the armature reaction whereas the other component OF_c is at right angles to vector OF_f. This will produce distortion in the main field. Hence this component is called cross magnetizing component of the armature reaction.

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

Demagnetising and Cross Magnetizing Conductors

The conductors which are responsible for producing demagnetizing and distortion effects are shown in the Fig.5.

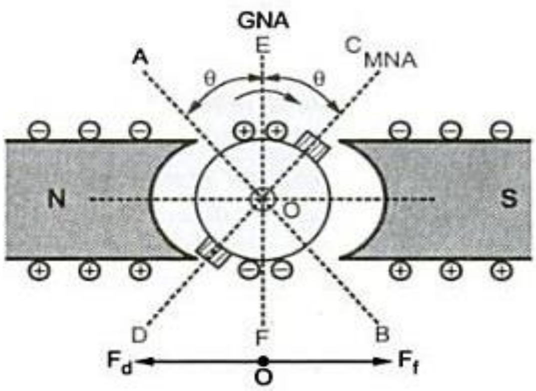


Fig 5

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 demagnetizing armature conductors.**

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 magnetizing armature conductors which will cause distortion in main field flux.**

These conductors are shown in the Fig. 6

Calculation of Demagnetizing and Cross Magnetizing Amp-Turns

Let us find out the number of demagnetizing and cross magnetizing amp-turns.

Let Z = Total number of armature conductors.

P = Number of poles.

I=Ic=Current in a conductor (Parallel Path)

Ia = Armature conductor current (Amperes).

= Ia/2 for simplex wave winding

= Ia/P for simplex lap winding

θ_m = Forward lead of brush (mechanical degrees).

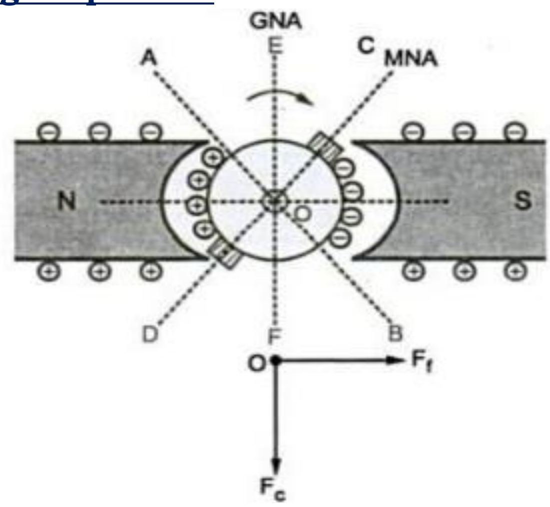


Fig 6

The conductors which are responsible for **demagnetizing ampere-turns** are lying in the region spanning **4 θm degrees**. The region is between angles **AOC and BOD**, as shown in the fig6.

∴ Total number of armature conductors lying in angles AOC and BOD.

$$= \frac{4\theta_m}{360} \times Z$$

Since two conductors form one turn,

$$\text{Total number of turns in these angles} = \frac{1}{2} \cdot \frac{4\theta_m}{360} \times Z$$

$$= \frac{2\theta_m}{360} \times Z$$

$$\therefore \text{ Demagnetising amp-turns} = \frac{2\theta_m}{360} \times IZ$$

$$\therefore \text{ Demagnetising amp-turns / pole} = \frac{\theta_m}{360} \times IZ$$

$$\therefore \quad \boxed{AT_d \text{ per pole} = ZI \times \frac{\theta_m}{360}}$$

The conductor which are responsible for cross magnetizing ampere turns are lying between the angles AOD and BOC, as shown in the Fig.5.

Total armature-conductors / pole = Z/P

From above we have found an expression for demagnetizing conductors per pole.

$$\text{Demagnetising conductors / pole} = Z = \frac{2\theta_m}{360}$$

$$\therefore \text{ Cross magnetising conductors/pole} = \frac{Z}{P} - Z\frac{2\theta_m}{360}$$

$$= Z\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$$

$$\therefore \text{ Cross magnetising amp-conductors / pole} = ZI\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$$

Since two conductors from one turn,

$$\text{Cross magnetising amp-turns / pole} = \frac{1}{2} \cdot ZI\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$$

$$= ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$$

$$\therefore \quad \boxed{AT_c \text{ per pole} = ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right]}$$

If the brush shift angle is given in electrical degrees then it should be converted into mechanical degrees by using the relation,

$$\boxed{\theta_{mechanical} = \frac{\theta_{electrical}}{\text{Pair of poles}} = \frac{\theta_{electrical}}{P/2} = \frac{2\theta_{electrical}}{P}}$$

Example :

A wave wound 4 pole d.c. generator with 480 armature conductors supplies a current of 144 A. The brushes are given an actual lead of 10^{o}. Calculate the demagnetizing and cross magnetizing amp turns per pole.

Solution :

P = 4, Z = 480, I_a = 144 A

For wave wound,

$I_c = I = I_a/2$
$= 144/2 = 72$ A
$\theta_m = 10^o$

$$AT_d/\text{pole} = ZI\frac{\theta_m}{360}$$

$$= \frac{480 \times 72 \times 10}{360}$$

$$= 960$$

$$AT_c/\text{pole} = ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right] = 480 \times 72\left[\frac{1}{2 \times 4} - \frac{10}{360}\right]$$

$$= 3360$$

EFFECTS OF ARMATURE REACTION

The various effects 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 than no load**. Thus **iron losses are observed to be more on load than on no load.**

3) Due to the 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.**

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-magnetizing 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 trialing 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 neutralized. 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.

Use of compensating Winding :

The compensating windings are basically used to **neutralize 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 sown in the Fig. 1.**

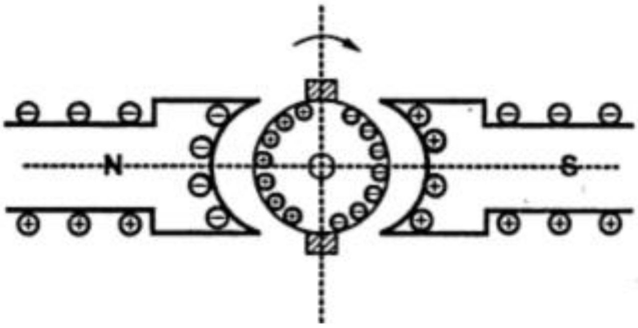


Fig 1

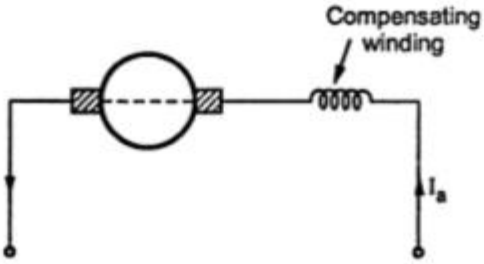


Fig 2

The symbolic representation of compensating winding is shown in the Fig. 2.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 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 this windings flow in opposite direction to that in armature conductors below the pole shoes. This will counterbalance the cross magnetizing effect of armature reaction which may cause flashover between the segments**.

Note : 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

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

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

Since two conductors form one turn.

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

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

Interpoles

Since the distortion 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.

Example

Calculate the number of conductors on each pole piece in a compensating winding for a 10 pole d.c. generator which has lap wound armature containing 800 conductors. Assume ratio of pole arc to pole pitch to be 0.7.

Solution : P = 10 , Z = 800

$$\frac{\text{Pole arc}}{\text{Pole pitch}} = 0.7$$

Ampere turns per pole for compensating winding

$$= \frac{I_a Z}{2AP} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

Number of turns per pole for compensating winding

$$= \frac{Z}{2AP} \times \frac{\text{Pole arc}}{\text{Pole pitch}} = \frac{800}{2 \times 10 \times 10} \times 0.7 = 2.8$$

Since 2 conductors form one turn.

Compensating conductors / pole = 2 x 2.8 = 5.6 = 6