UNIT – II

DC Generators

BEEE- Electrical
Unit -2
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Principle and operation of DC Generator.

Principle:

⇒ An electrical generator is a machine which converts mechanical energy to electrical energy.

⇒ Generator works on the principle of Faraday's law of electromagnetic induction.

⇒ According to faradays law, when ever a conductor cuts a magnetic flux, an Emf induced in it. This Emf cause the current of flow.

Construction:

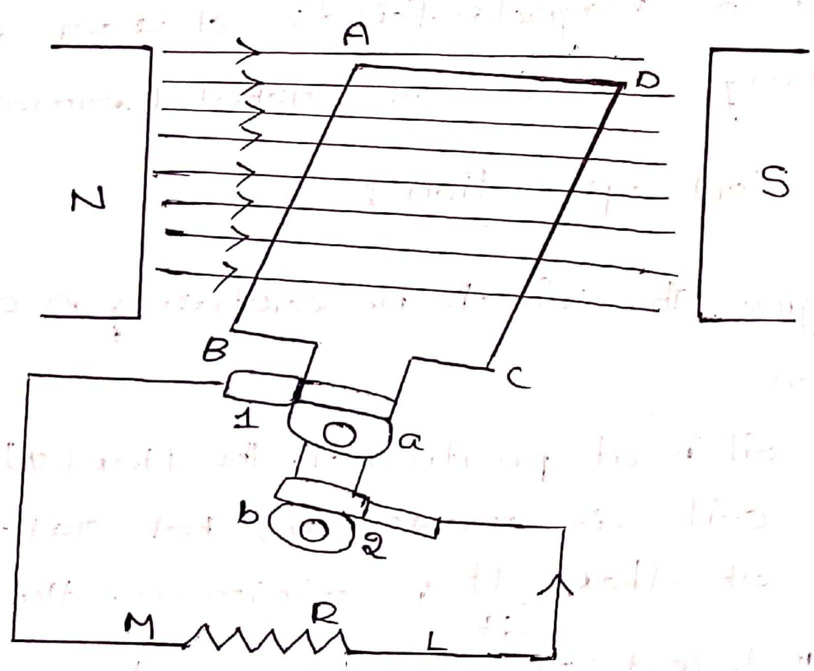


Fig (1).

⟹ Basic components of a generator are:-

1) Magnetic field
2) conductor
3) motion of conductor.

⟹ Fig(1) shows is a single Turn rectangular copper coil ABCD, rotates about it's own axis in a magnetic feild.

⟹ The two Ends of a coil are Joined to two slip rings 'a' anb "b", which are insolated from each other.

⟹ Two brushes, 1 and 2 are placed on sliprings a & b.

⟹ The Function of brushes is to collect current induced in the coil & transfer to External load resistance R.

⟹ Here the Magnetic feilds Stator and rotating coil forms rotor (armature).

<u>Working (or) operation</u>:

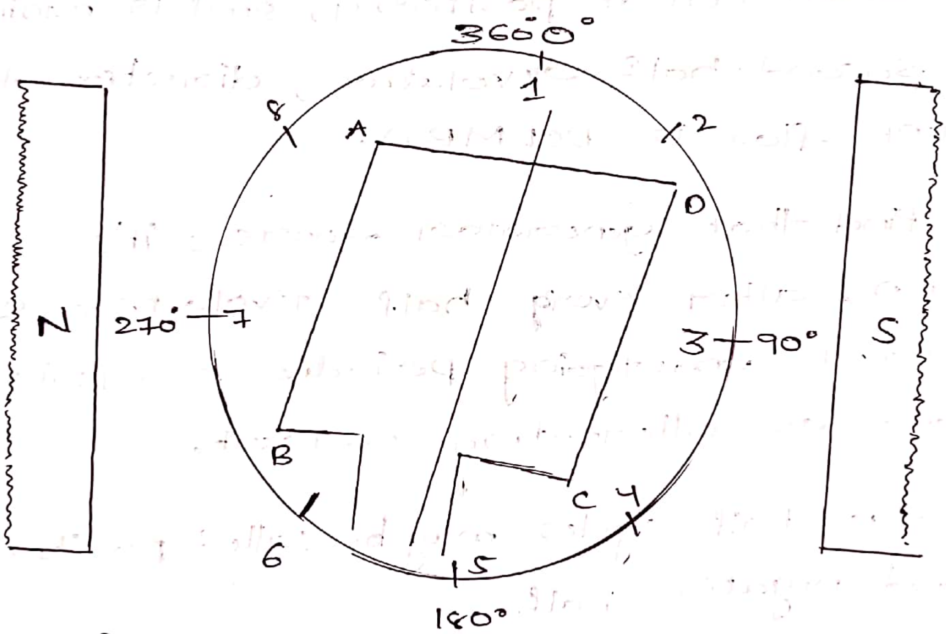
⟹ Imagine the coil to be rotating in clockwise direction

⟹ when coil is at position 1, the Flux (ϕ) linked with coil is maximum, but rate of change of flux $\frac{d\phi}{dt}$ is minimum. Hence the Emf induced (E) is minimum, because ale to Faraday's

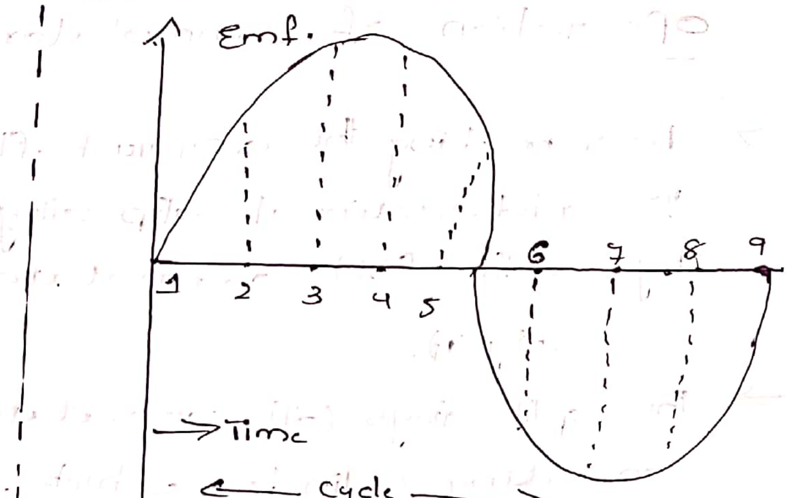
$$E \propto \frac{d\phi}{dt}$$

⇒ When coil is at position 3, the flux ϕ linked with coil is minimum, rate of change of flux $\frac{d\phi}{dt}$ is maximum. Hence Emf is maximum shown in fig (3).

⇒ when coil is at position 5, flux is linked with coil is maximum, rate of change of flux $\frac{d\phi}{dt}$ is minimum. Hence induced Emf is minimum, shown in fig (3).



fig(2)



fig(B)

⟹ The direction of this induced emf is given by Fleming right hand rule, which gives it's direction from A to B & C to D.

⟹ In first half revolution, the direction of current flow is ADMLCD shown in fig (1).

⟹ In next half revolution i.e. from 180° to 360°, the variation in magnitude of emf is similar to first half revolution.

⟹ When coil is at position 7, emf is maximum and when coil at position 9, emf is minimum.

⟹ In second half revolution, direction of current flow is DCLMBA.

⟹ We find that generator reverses it's direction, after every half revolution such a current undergoing periodic reversals is known as alternating current.

⟹ The two half cycles may be called positive and negative half.

Operation of commutator segments:-

⟹ For making the current flow bidirectional to unidirectional slip rings are replaced by split (or) commutator, as shown in fig (4).

⟹ The split rings (or) commutator made up of conducting cylinder which is cut into two halves (or) two segments, insulated from each other by thin sheet of mica.

⟹ It is seen that in first half revolution, current flows along ABMLCD i.e. the brush 1 contact with segments 'a' acts as positive and segment 'b' as negative end of supply.

⟹ In next half revolution, direction of current in the coil is reversed. but at the same time position of segments.

'a' and 'b' have also reversed with the result that brush no 1 comes in touch with segment which is positive i.e. segment 'b' in this case.

⟹ Hence current in the load resistance again flows to M to L. the waveform of current through the external circuit in shown in fig (7).

⟹ The current is unidirectional but not continious like pure dc current.

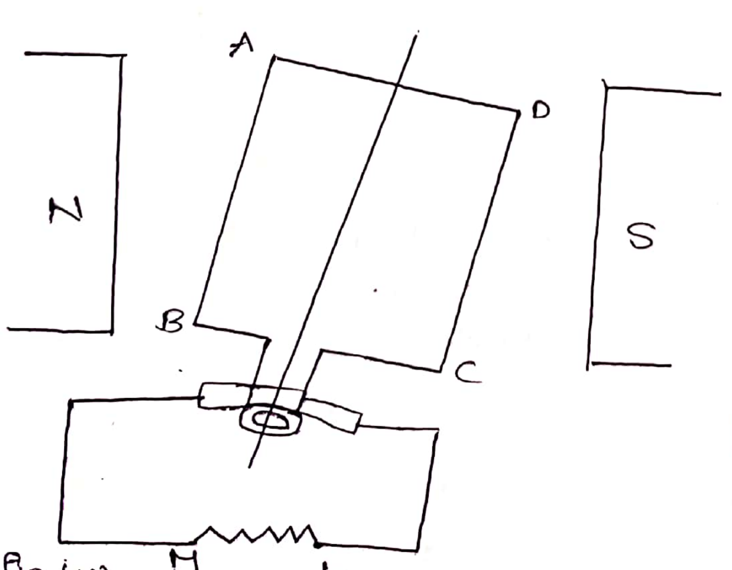


fig (4).

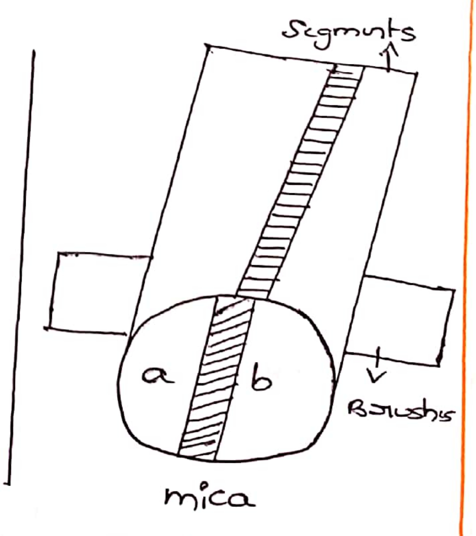


fig (5)

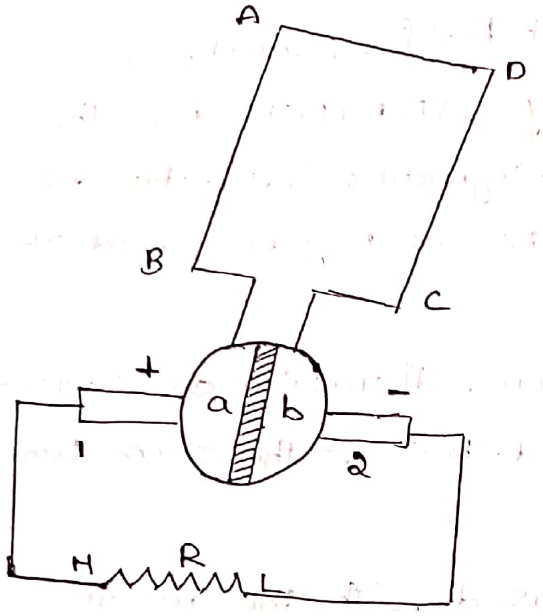


fig 6(a)

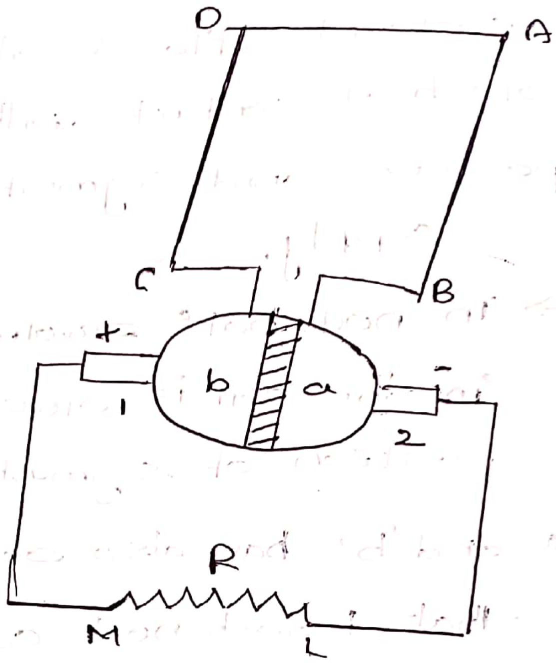


fig 6(b).

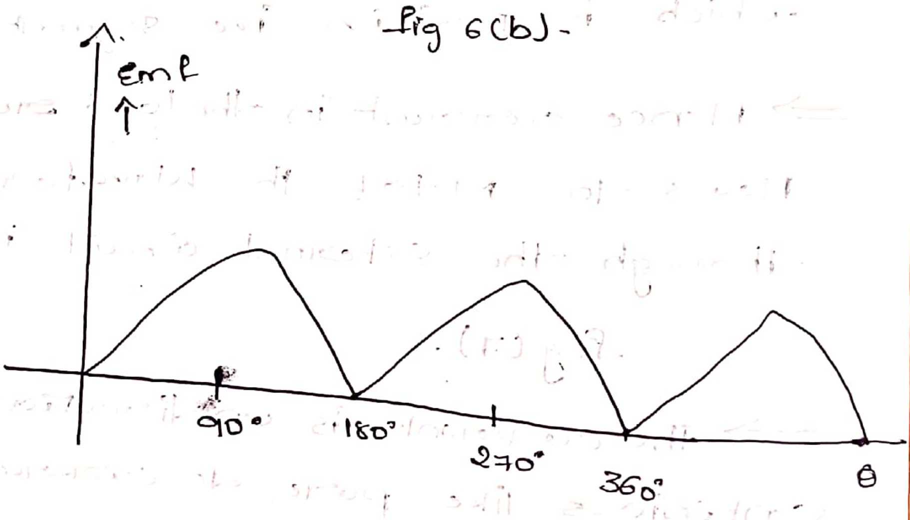
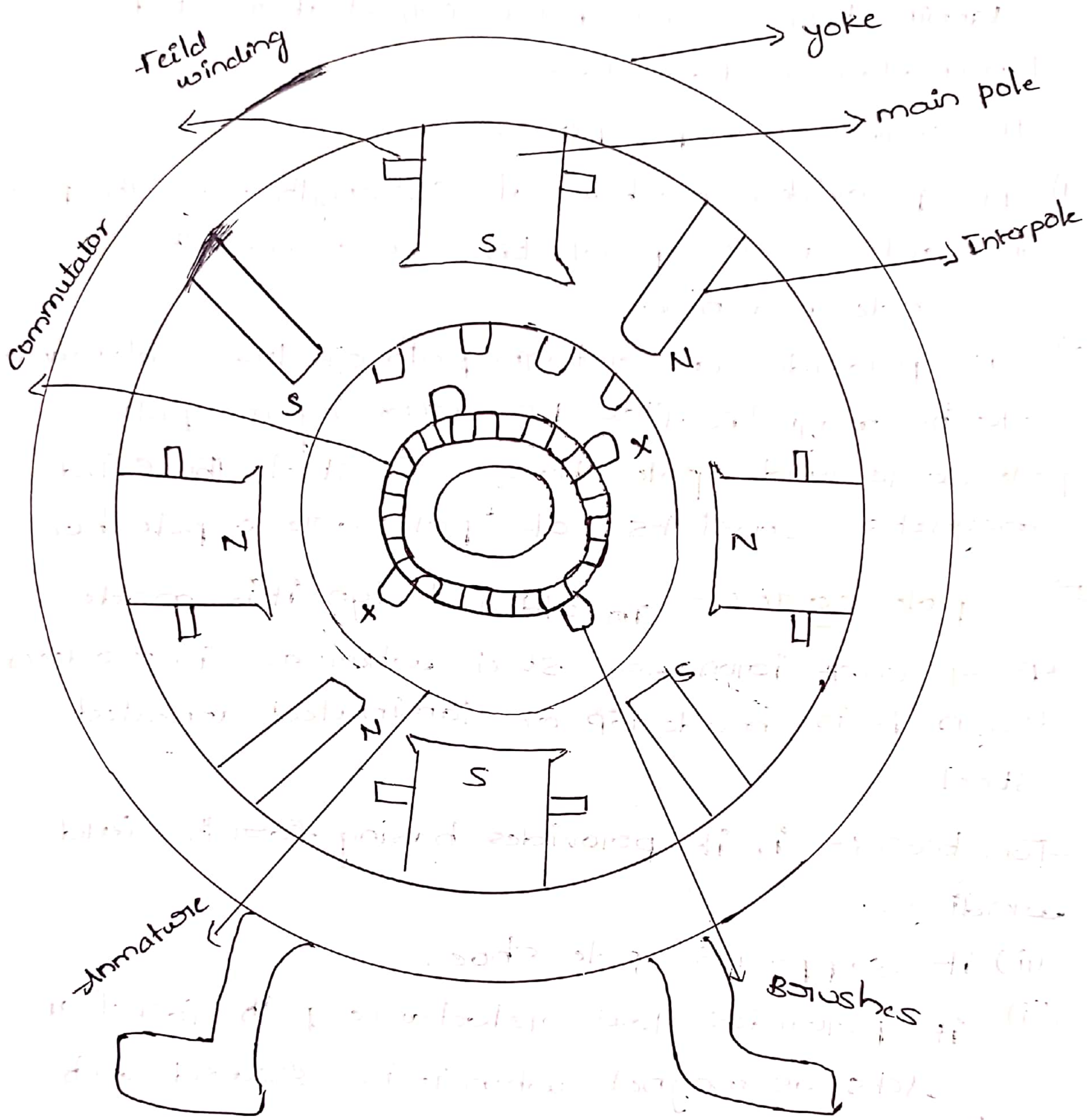


fig (7)

Construction details of a DC machine



- A dc machine either a generator or a motor essentially consists of following main parts.

1) yoke or magnetic frame 2) pole cores and pole shoes
3) Pole coils (or) feild coils. 4) Armature core.
5) Armature winding (or) conductor. 6) commutator.
7) Brushes and Bearings. 8) Interpoles.

yoke :- The outer frame of dc machines is called yoke and is normally made of iron (or) Fabricated steel (or) anneled steel laminations. (or) iron (or) fabricated laminations to reduce.

It serves two purposes.

1) It provides mechanical strength for the poles and acts as a protective cover for the whole machine.

2) It provides a return path of low reluctance to the magnetic flux produced by the poles.

pole core and pole shoes : Si steel the feild magnets consists of pole core & pole shoes.

⇒ pole core :- In older design it is made up of cast iron or steel whereas in modern design it is made up of laminated annealed steel.

Function :- i. it provides hasing for the feild windings.

(ii) it supports pole shoe.

(iii) it provides low reluctance path for flux.

Acts as magnet when it is excited with dc.

⇒ pole shoe :- In older design it is made up of laminated steel or iron where as in modern design it is made up of annealed steel.

Function :- 1) It supports feild windings.

2) It establishes magnetic feild in the airgap by spreading out the flux uniformaly.

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Feild windings:- it is made up of highly conducting materials like copper.

Function:- it carries the current necessary for the establishment of magnetic flux in dc machine.

Commutator:- A commutator is used for collecting current from the Armature conductors. It consists of no. of wedged shaped segments or bars made of copper.

⟹ The commutator along with the brush year helps to convert the AC voltage induced in the Armature conductors into unidirectional voltage across the brushes.

⟹ Interpoles (or) commutating poles:-

The main function of commutating poles is to improve the commutation in dc machine. They are kept in between the main poles and it's winding connected in series with the armature windings.

⟹ The main function of interpoles is to reduce armature reaction there by reducing the sparks at the brush contacts.

Armature: Armature is mounted on shaft and rotates in magnetic feild. It is the major part in dc machine. so it has two parts.

Armature core:- The body of the core is made up of thin sheets or laminations of steels in order to reduce eddy current loss.

Functions:- i) It house armature coils. i.e armature winding or conductors.

Armature windings:- These are made up of very good conducting materials like copper as they carry the entire load current.

Function:- (i) To carry current in case of generator they supply current to the load and for motor takes current from the supply.

ii) The Emf in the generator is induced in these conductors.

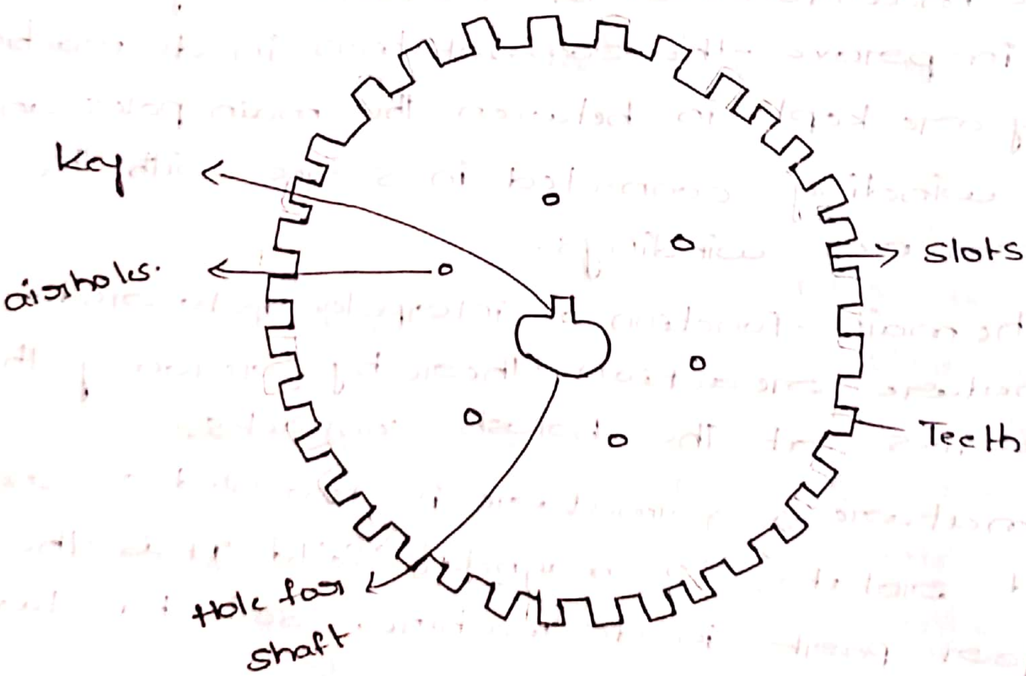


Fig: Armature laminations.

Brushes and Bearings :-

- The brushes whose main function is to collect current from commutator are usually made of carbon or graphite and are in the shape of a rectangular block.
- Bearings give support to rotating shaft with minimum friction.

DC MOTORS

principle and operation of a DC motor :-

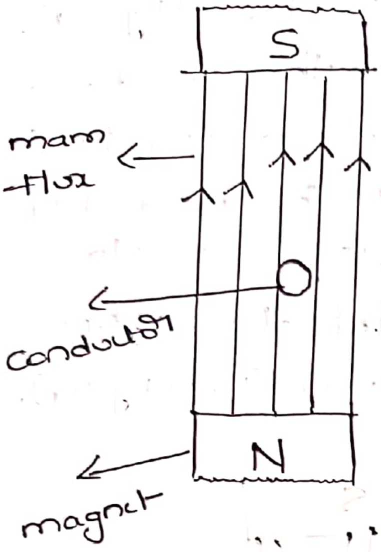
⟹ principle : The principle of operation of a dc motor can be started as

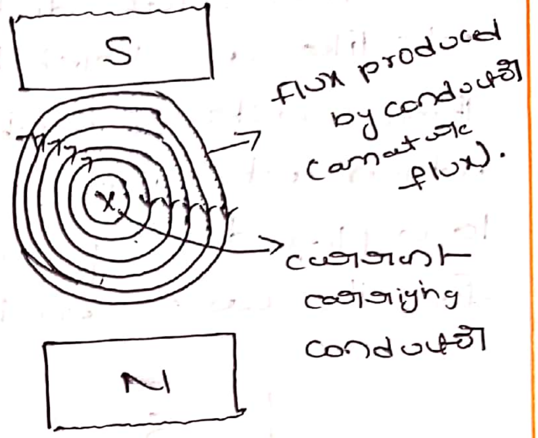
" when a current carrying conductor is placed in a magnetic feild, it experiences a mechanical force".

⟹ operation of dc motors :- consider a single conductor placed in magnetic feild as shown in fig (1). The magnetic feild is produced by a permanent magnet. but in a practical dc motor it is produced by feild winding when it carries a current.

⟹ Now this conductor excited by a separate supply so that it carries a current in a particular direction. consider that caries a current away from an observer as shown in fig (2).

⟹ Any current carrying conductor produces it's own magnetic feild around it hence this conductor also produces it's own flux around. For the direction of current considered, the direction of flux around a conductor is clock wise.





fig(2): flux produced by conductor.

fig(1): main flux produced by magnets.

Now there are two fluxes present,

1) The flux produced by permanent magnet called main flux shown in fig(1).

2) the flux produced by current carrying conductor called armature flux show fig(2).

⇒ These two fluxes are shown in fig(3).

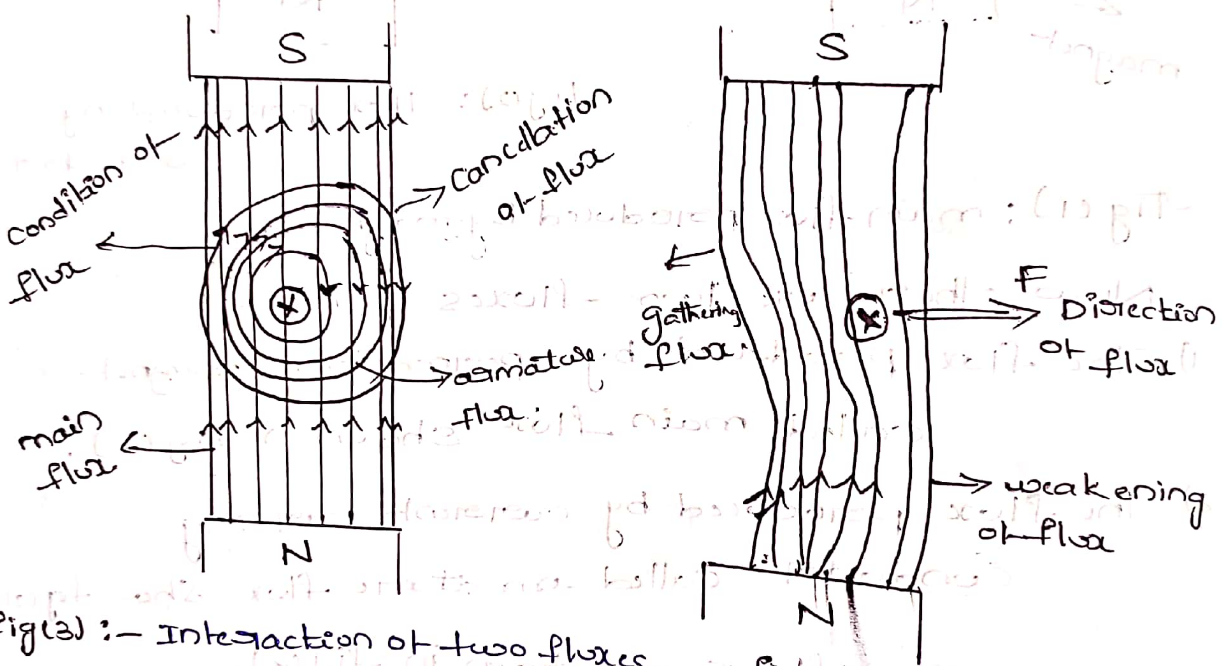
⇒ From this, it is clear on one side of conductor both the fluxes are in the same direction. In this case, on left side of conductor there is gathering of flux lines as two fluxes help (or add) each other.

→ on the right side of conductor. the two fluxes are in oppisite direction and

⇒ Due to this, density of flux lines on right side gets weakend.

⇒ So on the left, there exist high flux density area while on the right of the conductor there exists low flux density area as show fig (4).

⇒ This flux distribution around the conductor acts like a stretched rubber band under tension. there Exists a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e from left to right for the case considered as shown in fig (4).



fig(3) :- Interaction of two fluxes. fig(4) : Force Experienced by conductor.

The magnitude of force experienced by conductor in motor is given by $F = BIl$ newtons.

The direction of force i.e the direction of rotation of motor can be determined by Flemming's Left hand rule.

Principle and operation of Transformer:-

Transformer:-

⟹ Transformer is a device used to transfer the Electrical power from one circuit to another circuit without change in frequency.

⟹ It is used to vary the voltage levels each that to vary the current levels

⟹ It works with the principle of Electromagnetic Induction (or) mutual induction i.e Faradays law of Electromagnetic Induction.

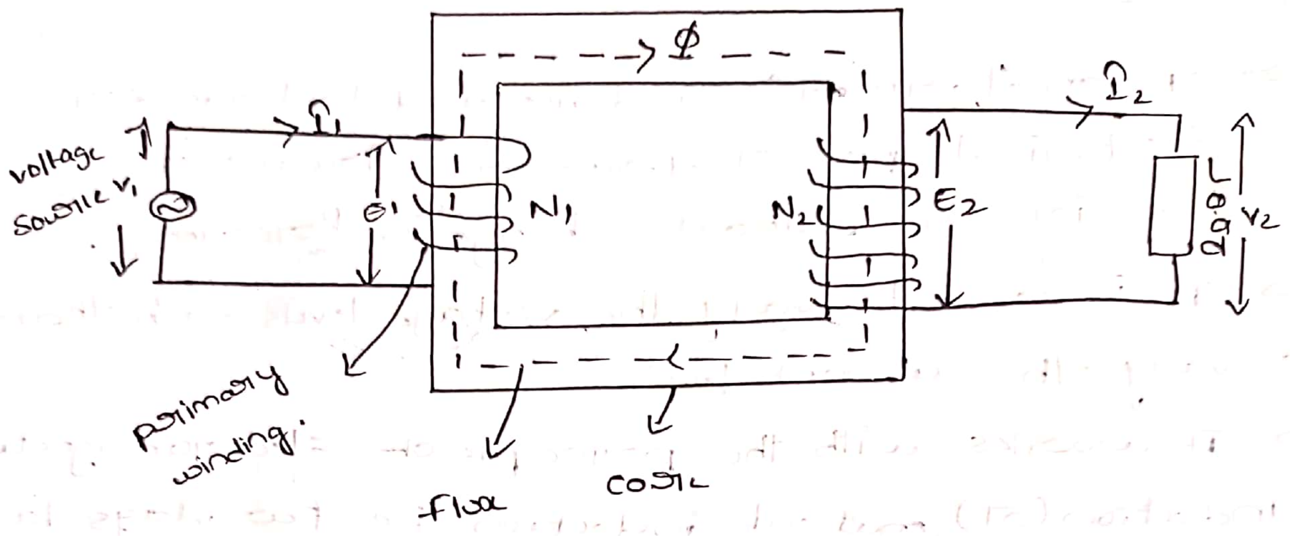
Working principle of Transformer:-

⟹ The working principle of Transformer is based on Mutual Induction between Two coupled coils.

⟹ According to this principle a changing flux creates an induced Emf in each Turn equal to the derivative of flux, so that the total induced Emf across N Turns is

$$E = N \frac{d\phi}{dt}.$$

⟶ This can be seen in Transformer shown in fig (1) as explained be.



Fig(1) General arrangement of a Transformer

⟹ Transformer core is wound with two windings having N_1 and N_2 number of turns.

⟹ The winding with N_1 turns is known as primary winding as it is fed by alternating voltage source.

⟹ This voltage source forms a closed path in the primary so that alternating currents starts flowing through the primary.

⟹ During the path completion of alternating flux through the case, induced Emf are also created in their than the primary windings.

⟹ The winding in which Emfs are induced mutually is known as Secondary winding. This Emf is mutually induced Emf E_2.

Constructional details of a Transformer :-

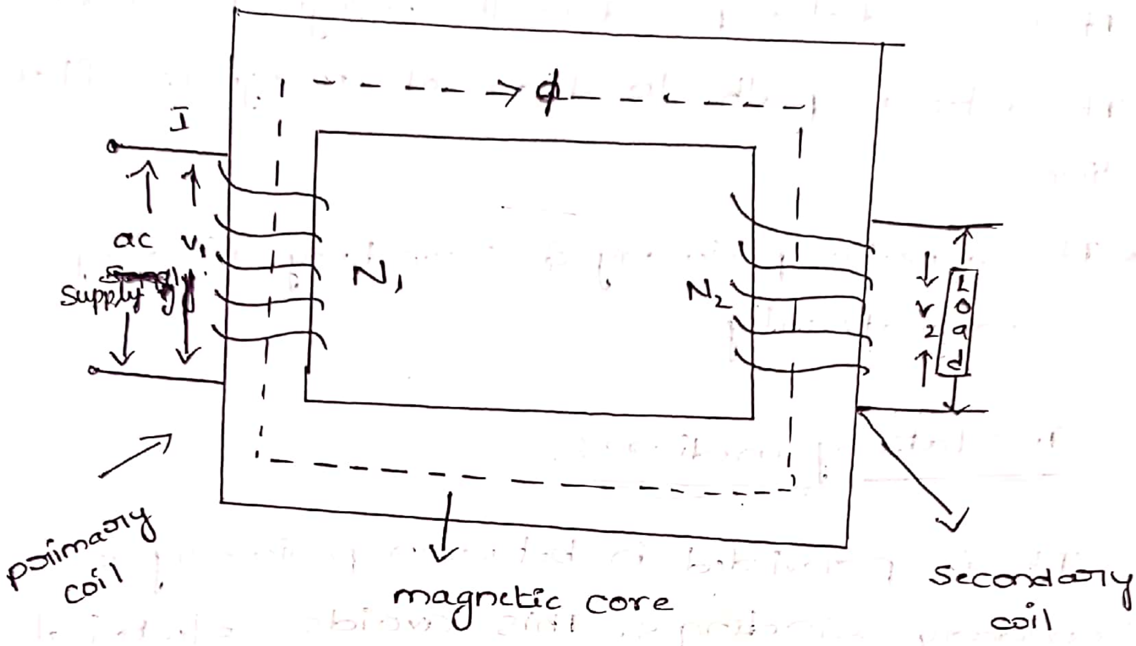


fig (1) General representation of Transformer.

1) Primary winding :- For any Transformer the winding ~~through~~ which the receives the supply from External Source is called primary winding.

2) Secondary winding :-

This winding is the Second winding of the Transformer and through which the Transformer connect to the External load.

3) Magnetic core :-

The magnetic core is the medium through which the Transformer can Transfer the Electrical energy from one circuit to another circuit. The both windings of the Transformer are wound on the same magnetic core.

4) Functions of magnetic core :-

⟹ It is used to produce the magnetic flux.

⟶ It acts as path to flow of magnetic flux lines

⟹ It connects primary & secondary winding magnetically

5) **Insulating medium :-**

⟶ It is provided in between primary & secondary windings. This avoids electrical contacts between primary & secondary windings. Generally oil & air are used as insulating medium.

Types of Transformers

Tc

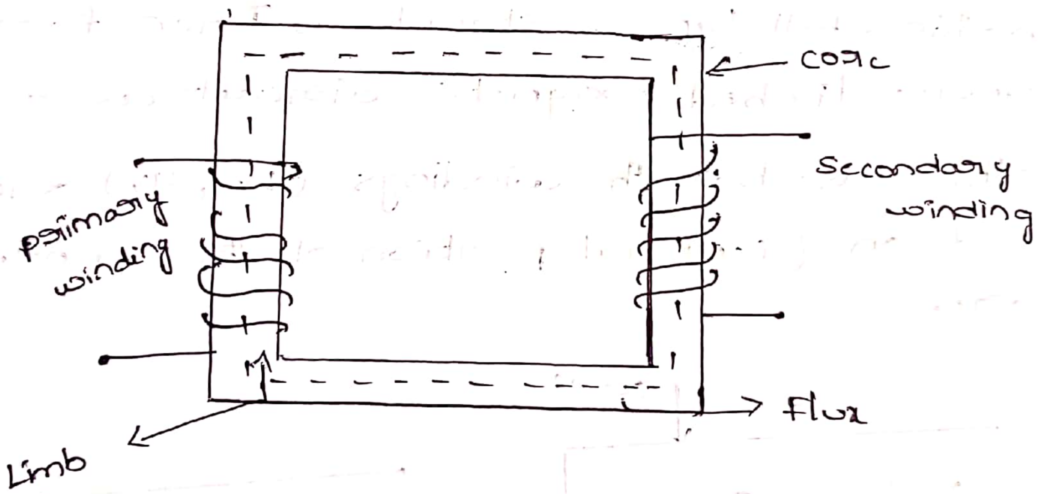
According to the constructions of core, the Transformers can be classified into.

1. core-type 2. shell type 3. Berry Type.

1) core-type :-

⟹ In this type of construction, Transformer has two limbed magnetic circuit as a core and these limbs are surrounded by Transformer windings.

⟹ At first LV winding is placed on the core after that the HV windings as shown fig (2).



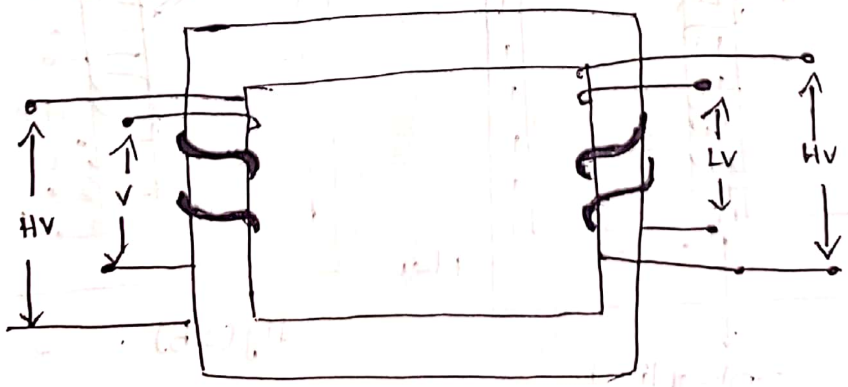


fig (b) construction

Fig (1) core type construction.

Advantages :-

1) core type of Transformers are suitable for Extra high voltage [EHV] and high power levels.

2) It requires less core material compared to shell type construction for a given output and voltage ratings.

Disadvantages :-

1) For a specified Transformers ratings core construction requires more conducting material compared to shell type.

SHELL Type Transformer :-

In this shell type construction, Transformer has three limbed magnetic circuit as a core.

In this case both the windings (LV & HV) are wound on (central portion of the magnetic core.

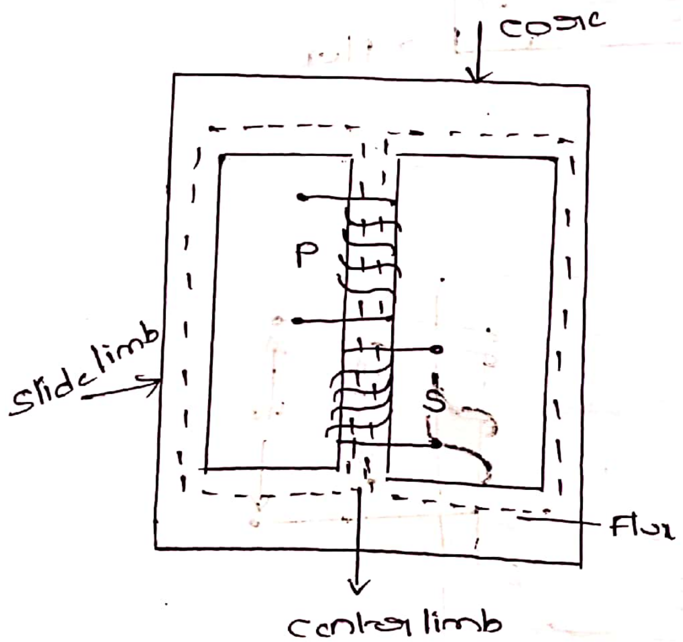


fig (2a) Representation.

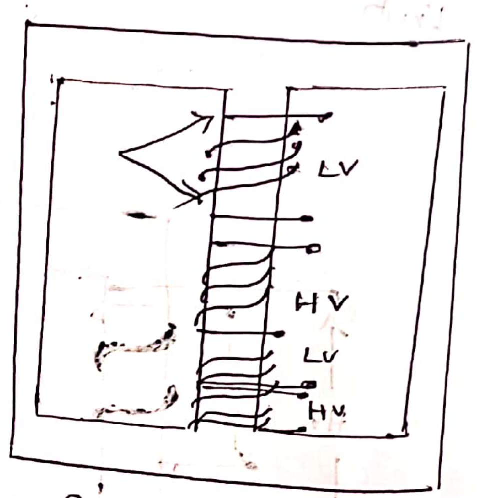


fig (2b) : construction

fig (2) SHell type of construction.

Advantages :-

1. Shell Type Transformers are suitable for Low voltage and low power levels.
2. It requires less conducting materials compared to core type. Construction for a specified output and voltage ratings.

Disadvantages :-

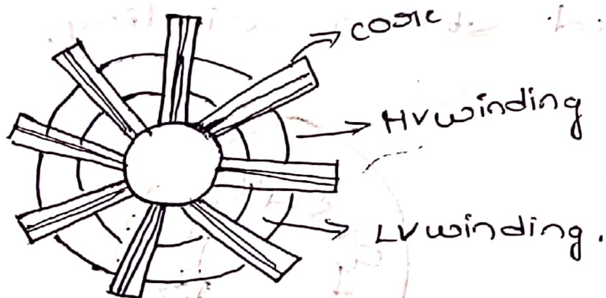
For a given Transformer ratings, shell type constructions requires more core material compared to core type.

3) Berry Type Transformer :-

This has distributed magnetic circuit. The number of independent magnetic circuits are more than two.

It's core construction is like spokes of a wheel. otherwise it is symmetrical to that of shell type.

diagramatically it can be shown as in fig.



3 - ϕ Induction MOTORS.

Construction Details of 3-ϕ Induction motor:-

Basically, The induction motor consists of two parts, namely.

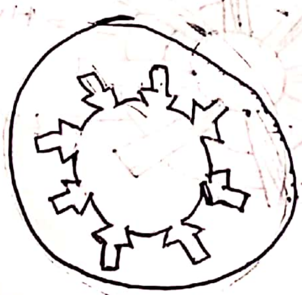
1) Stator: three phase winding which is stationary called stator.

2) Rotor: The part which rotates and is connected to mechanical load through shaft, called rotor.

Stator:-

⟹ The stator has a laminated type of construction made up of stamping which are 0.4 to 0.5mm thick. The stampings are slotted on it's periphery to carry the stator winding. The stampings are insulated from each other. The no. of stampings are stamped together to build stator core. The built up core is then fitted in a cast or fabricated steel frame.

⟹ The slots on the periphery of stator core carries a 3- phase winding connect either in star or delta. This three phase winding is called stator winding.



fig(1): Stator lamination.

ROTOR :- The rotor is placed inside stator. The rotor core is also laminated in construction and uses cast iron. It is cylindrical, with slots on it's periphery. The rotor conductor is placed in the rotor slots.

There are two types of rotor constructions in the induction motor.

They are:

(1) Squirrel cage rotor

(2) Slip ring (or) wound rotor.

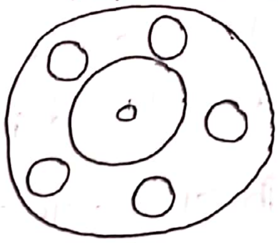
(1) Squirrel cage Rotor :-

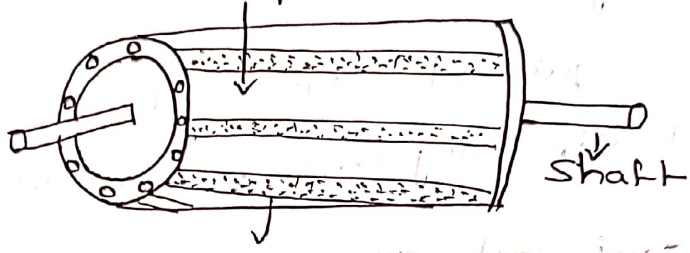
The rotor core is cylindrical and slotted on it's periphery. The rotor consists of uninsulated copper or aluminium bars called rotor conductors. The bars are placed in the slots. These bars are permanently shorted at each end with the help of conducting copper ring called end ring. The entire structure looks like a cage, forming a closed electrical circuit. So the rotor is called squirrel cage rotor.

→ In this type of rotor, the slots are not arranged parallel to the shaft axis but are skewed as shown in fig.

Fig (2a): Squirrel cage rotor.

Fig(2): Symbolic representation.





fig(2c) skewing in rotor construction.

(2) <u>Slip ring rotor (or) wound rotor</u> :-

→ In this type of construction, rotor winding is exactly similar to the stator. The rotor carries a 3-phase star or delta connected, distributed winding.

⇒ The rotor construction is laminated and slotted. The slots contains rotor winding. The three ends of 3-phase winding are permanently connected to slip rings.

→ Slip rings are used to connect external stationary circuit to internal rotating circuit.

→ So in this type of rotor, the external resistances can be added with the help of brushes.

This arrangement is shown in fig.

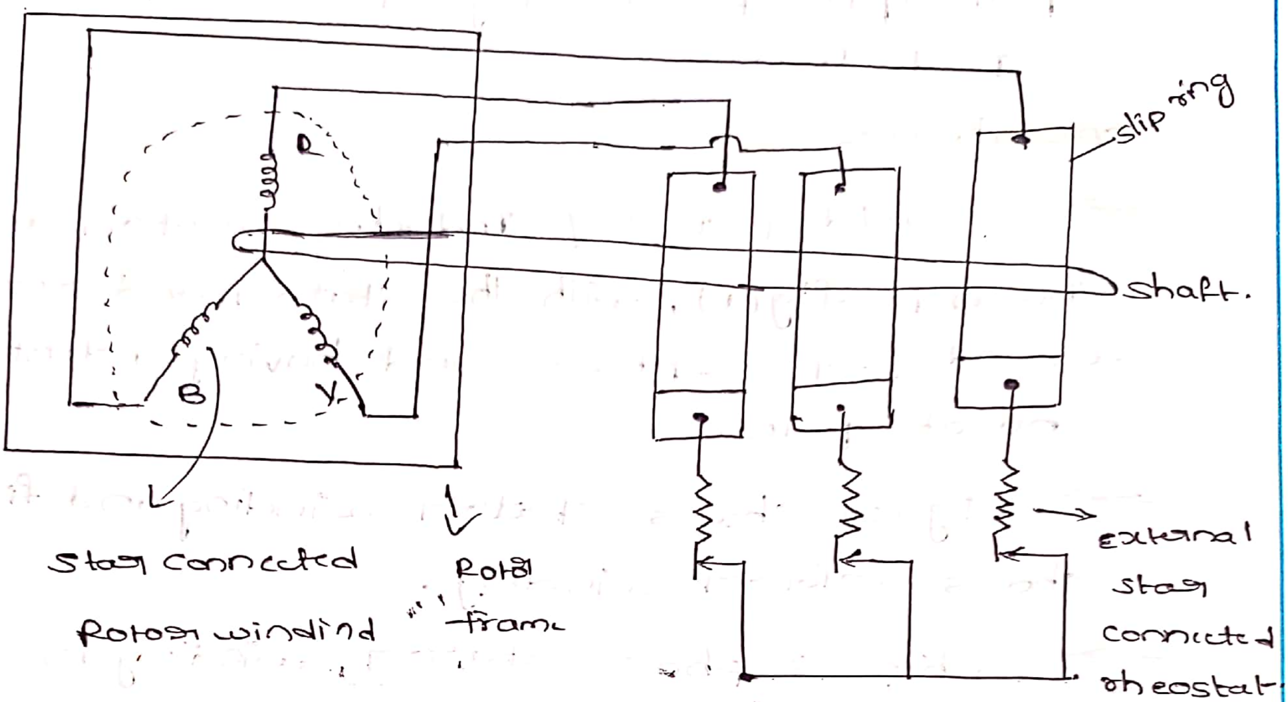


Fig (i) slip ring (or) wound Rotor.

principle and operation of 3-ϕ Induction MOTOR:-

principle: Induction motor works on the principle of Faraday's law of Electromagnetic Induction.

operation:-

→ consider a 3-ϕ Induction motor as shown in fig(1), with the stator and rotor wound for 3-phases and having identical no. of poles.

→ Fig (2) shows stator winding and fig(3) shows rotor winding.

→ when 3-phase stator winding is Energized from 3-phase supply a rotating magnetic feild is setup which rotates at synchronous speed Ns. ($N_s = \frac{120f}{P}$).

→ The rotating magnetic feild passes through airgap and cuts the rotor conductor which are yet stationary.

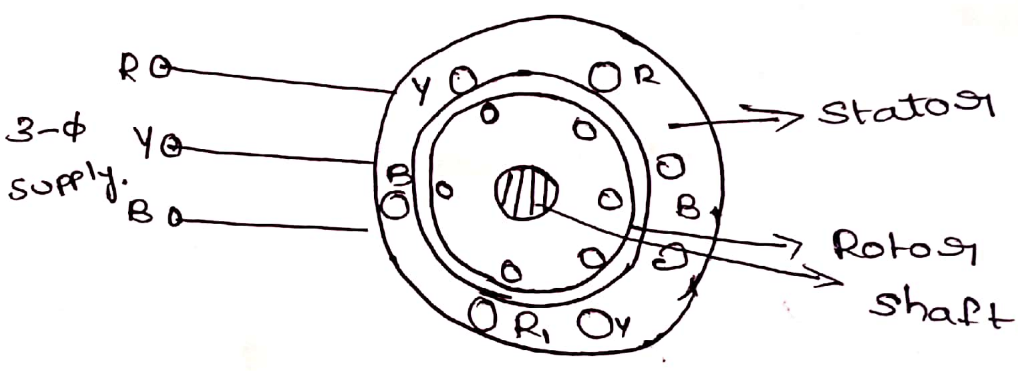
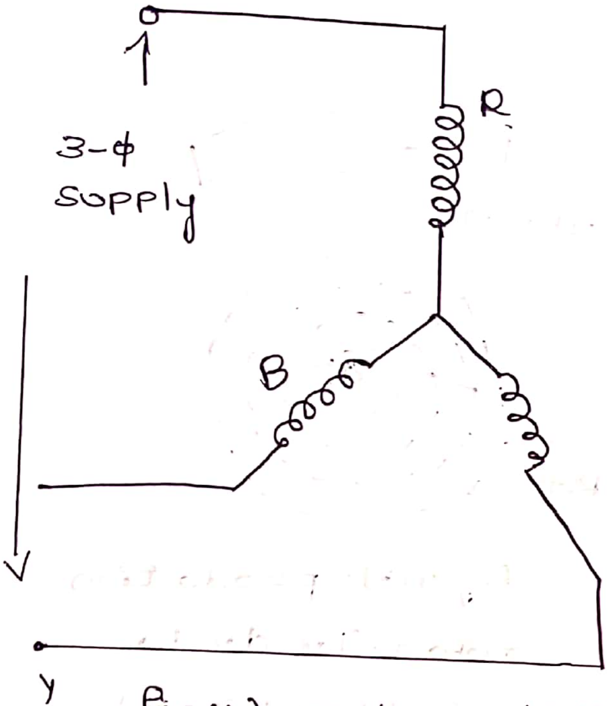
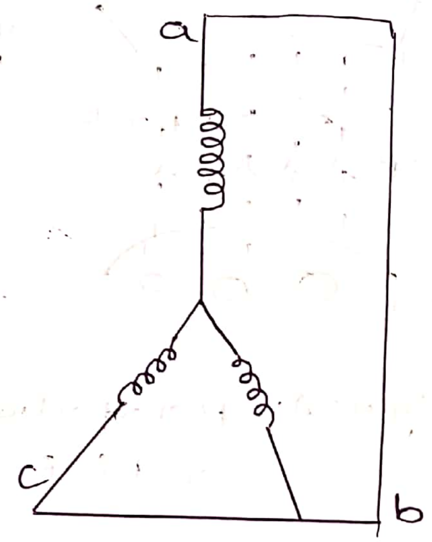


Fig (1) Induction motor.



fig(2) stator winding



fig(3) short circuited rotor winding.

⟹ Due to relative speed between the rotating flux and stationary rotor, Emf's are induced in rotor conductors:

⟹ The rotor winding carry the 3-phase currents, if the rotor is short circuited as shown fig (3)

⟹ Now the rotor behaves like a current carrying conductor placed in rotating magnetic field of stator.

⟹ consequently a mechanical force acts on the rotor conductors.

⟹ The sum of mechanical forces on all the rotor conductors produce a torque, which tends to to move the rotor in the same direction as rotating magnetic field.

Fig(4). shows the operation of 3-phase induction motor.

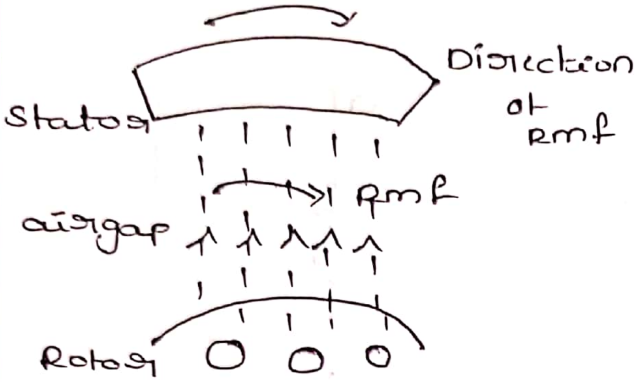


fig 4(a): production of RMF

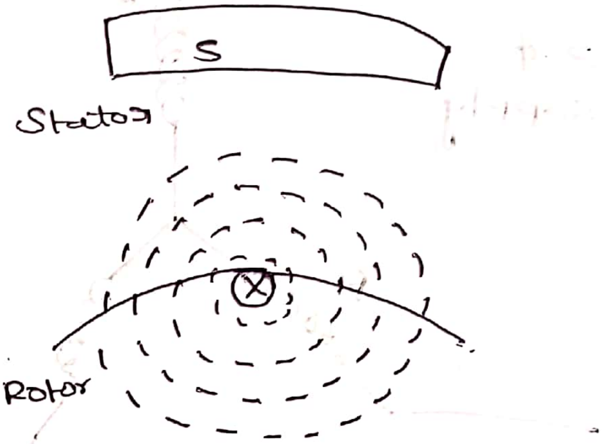


fig 4(b): production rotor flux due to rotor current.

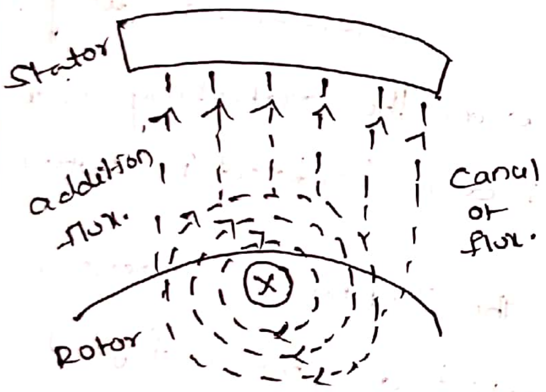
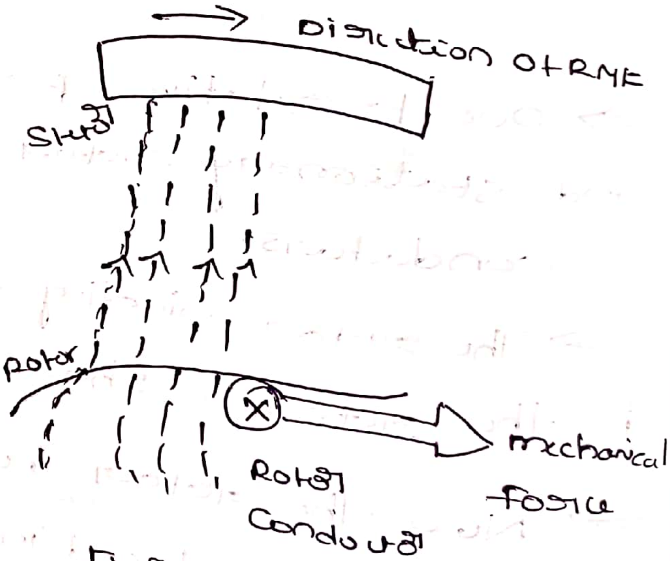


fig (4c): superimposition of two flux.



Fig(4d): direction of force.

Synchronous speed (NS) :-

Definitions :- when 3- phase balanced currents flow through stator winding of 3-phase induction motor, a Rotating magnetic field is produced in the air gap between stator & rotor.

⇒ The speed in which the rotating magnetic feild rotates in space is known as synchronous speed Ns.

$$N_s = \frac{120f}{P}$$

where N_s = synchronous speed.

f = Frequency.

P = No. of poles on stator.

Slip (s):

⟹ The Rotor of an Induction motor runs at speed N, which is always less than Synchronous speed (Ns) of rotating magnetic feild.

⟹ The Relative speed between the rotor & the rotor magnetic feild. is known a "slip" in an induction motor.

⟹ the difference between the synchronous speed N of rotor is called "slip"

$$\text{Slip } s = (N_s - N) \text{ rpm}$$

It is usually expressed as percentage of Synchronous speed.

$$\% \text{ slip, } s = \frac{N_s - N}{N_s} \times 100.$$

Alternators

principle and operation of alternators (or) Synchronous generators.

The working principle of an alternator or AC generator is similar to the basic working.

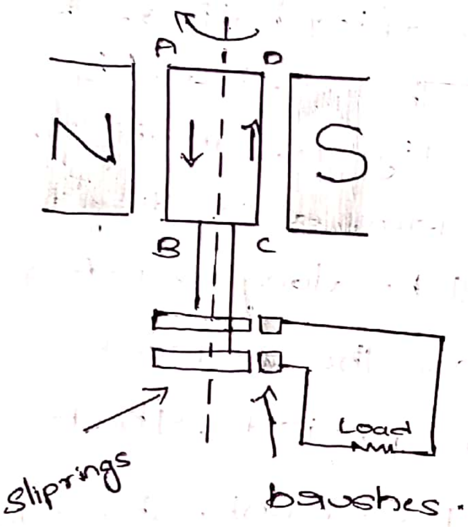


Fig:- case 1

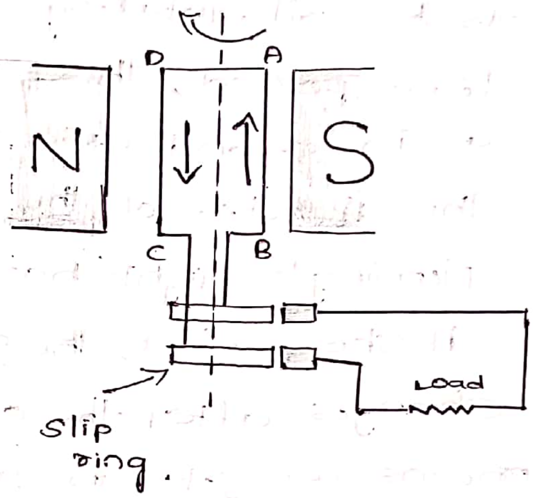


Fig:- Direction of induced current case (2).

Above figure helps you understanding how an alternator or AC generator works. According to the Faraday's law of electromagnetic induction whenever a conductor moves in a magnetic feild EMF gets induced across the conductor. if the close path is provided to the conductor. Induced Emf causes current to flow in the circuit.

Now, see the above figure, Let the coil ABCD is placed in a magnetic feild. The direction of magnetic flux will be from N pole to s pole. The coil is connected to slip rings. and the load is connected through brushes resting on the slip rings.

Now, considered the case 1 from above figure. In this case the the coil is rotating clockwise, direction of induced current can be given by Fleming's right hand rule, and it will be along A-B-C-D.

As the coil rotating clockwise, after half of the time period, the position of the coill will be as in second case of above figure. In this case the direction of the induced current according to Fleming's right hand rule will be along D-C-B-A.

it shows that, the direction of the current changes after the of the time period, that means we get an alternating current. shown in fig (3).

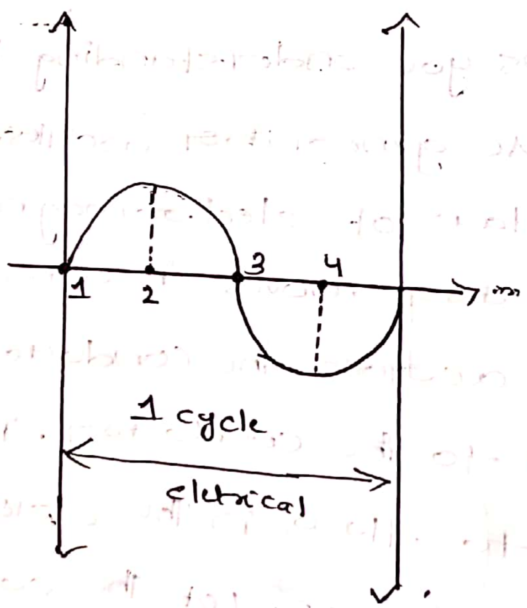


Fig (3)

Construction of alternator (or) Synchronous Generators:-

Alternate consists of two main parts namely Stator and rotor.

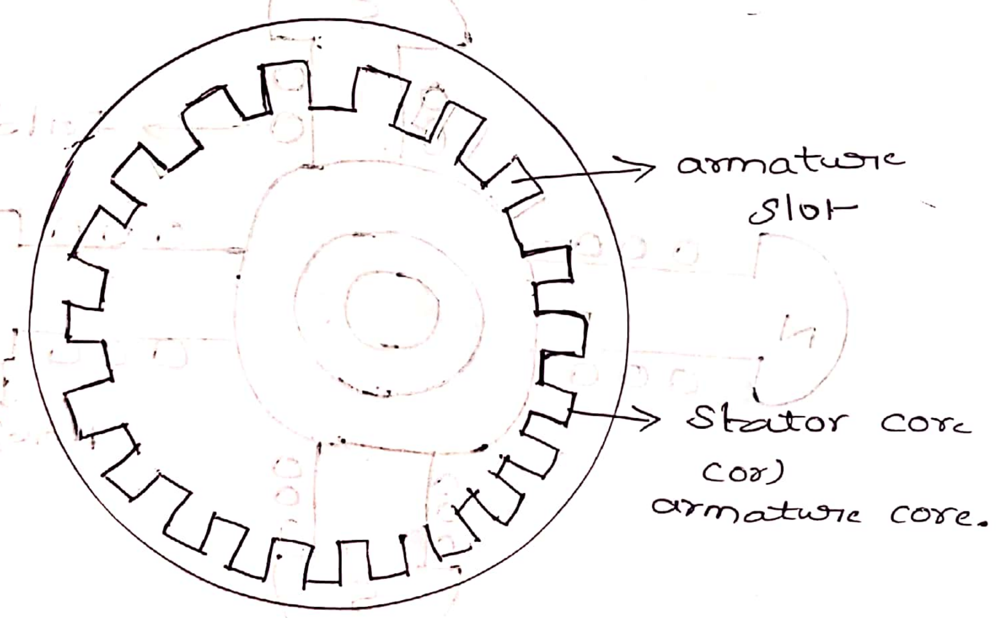
The stator is stationary part of the machine which carries the armature winding.

The rotor is the rotating part of the machine, which produces the main feild flux.

Construction of Alternator.

(1) Stator construction :-

It is the stationary part of the machine and is builtup of sheet steel laminations having slots on it's inner periphery 3-ϕ winding is Placed in these slots and serves as the armature winding of alternator.



(2) **Rotor :-**

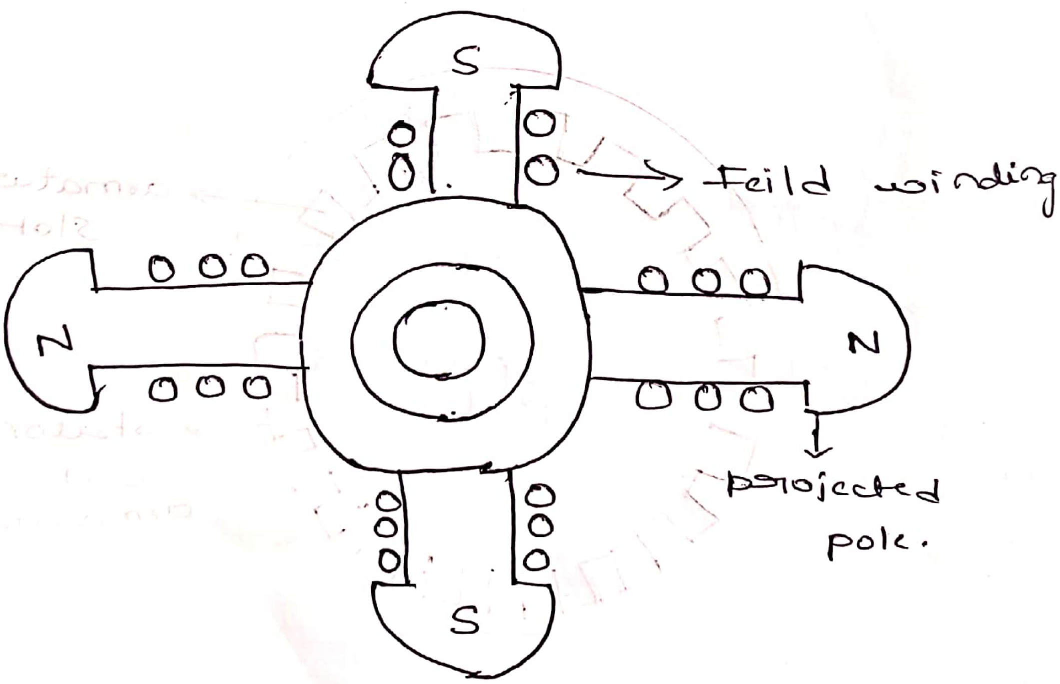
There are two types of rotor construction namely.

1. Salient - pole type.
2. cylindrical rotor (या) Non-salient pole type.

↳ (1) **Salient - pole Rotor** (concentrated):

The term salient means "projecting" Thus, a salient - pole rotor consists of poles projecting out from the surface of the rotor core.

A salient pole synchronous machine has a non-uniform airgap the air gap is minimum under the air gap is minimum under the pole centre and it is maximum in between the poles.



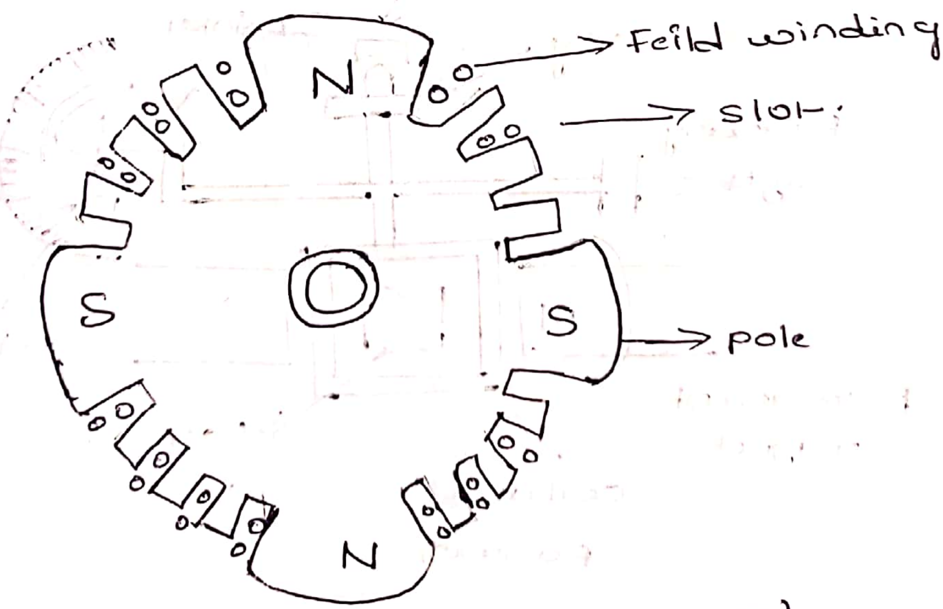
The Field coils are placed on the pole pieces and connected in series. The ends of feild winding are connected to DC supply. through slip rings mounted on shaft of the feild structure.

(2). Non-Salient poles [distributed]:

It has it's rotor constructed that it forms a smooth cylinder. The construction is such that there are no physical poles to be seen as in the salient pole construction.

The rotor of type are used in very high speed alternatives driven by system turbines.

The cylindrical rotor type alternator has two or four poles on the the rotor such a construction provides a greater mechnanical strength. The smooth rotor of the machine makes less winding losses and the operation is less noisy because of uniform air gap.



Fig(1) Non-Salient pole (or)
Smooth cylindrical rotor.

→ ## Permanent Magnet Moving coil instruments (PMMC):-

The permanent magnet moving coil instruments are most accurate type for dc measurements. The action of these instruments is based on the motoring principle. when current carrying the coil is placed in the magnetic feild produced by permanent magnet, the coil Experience a force and moves. As the coil is moving and the magnet is permanent the instrument is called permanent magnet moving coil instrument. This basic princeple is called D'Arsonval principle the amount of force experienced by the coil proportional to the current passing through the coil. the PMMC instrument is show in the below fig.

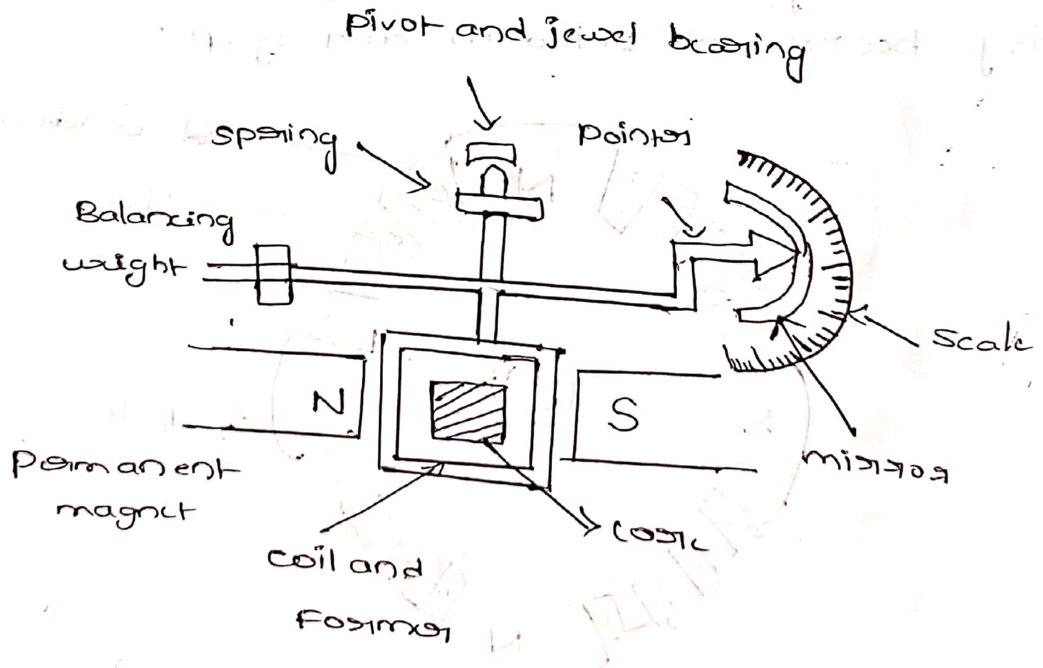


Fig: PMMC

- The moving coil is either rectangular or circular in shape. It has number of turns of fine wire. The coil is suspended so that it is force to turn about it's vertical axis.
- The iron core is spherical if coil is circular and is cylindrical if the coil is rectangular. Due to iron core, the reflecting torque increases increasing the sensitivity of the instrument.
- The controlling Torque is provided by two phosphor bronze hair springs.
- The damping torque is provided by eddy current damping: it is obtained by movement of the aluminimum former, moving in the magnetic feild of the permanent magnet.
- The pointer is carried by the spindle and it moves over a graduated scale. The pointer has light weight so that it can deflect rapidly
- The mirror is placed below the pointer to get the accurate reading by removing the parallax.
- The scale markings of the basic d.c. PMMC instruments are usually linearly spaced as the deflecting torque and hence the pointer deflection are directly propositional to the current passing through the coil.

→ Moving Iron Instruments:

I) The moving iron instruments are classified as;

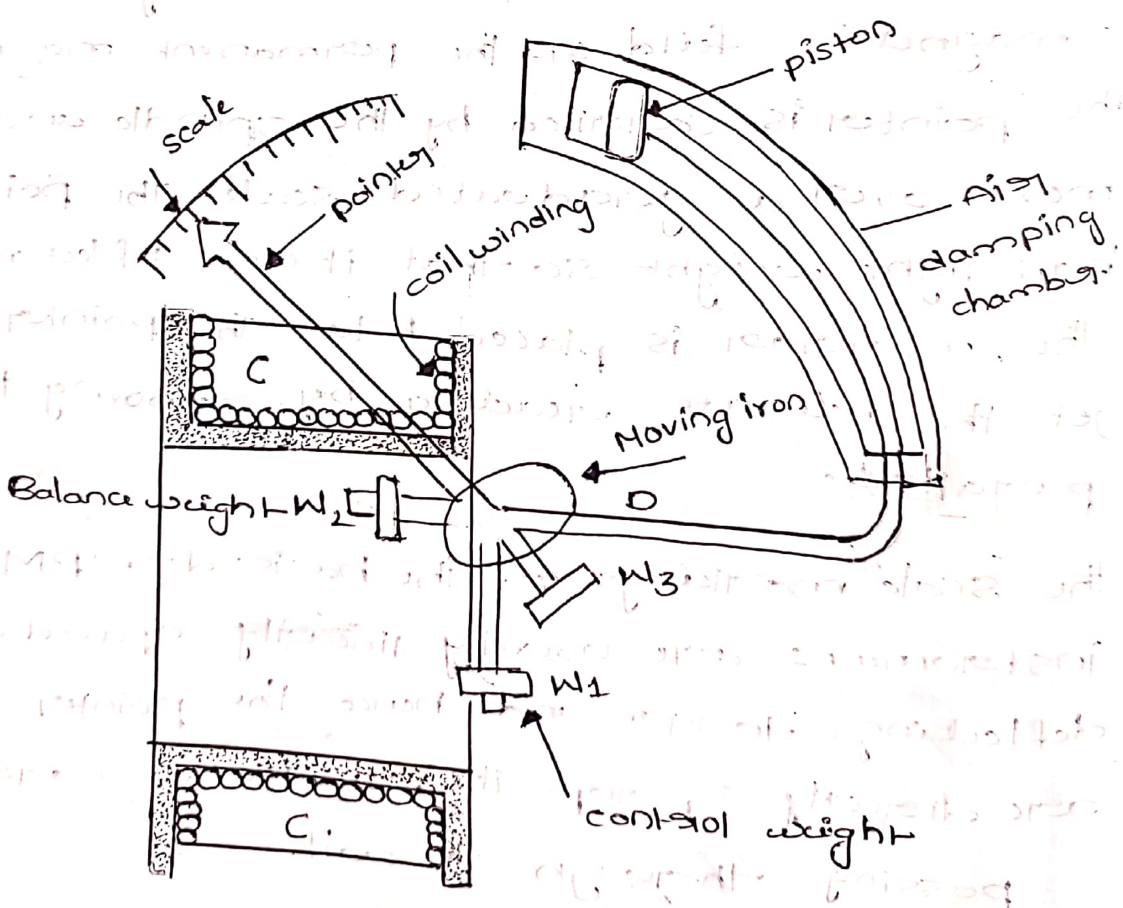
i) Moving iron attraction type instruments and

ii) Moving iron repulsion type instruments,

i) Moving Iron Attraction Type Instruments.

The basic working principle of these instrument is very simple that a soft iron pieces. brought near the magnets gets attracted by the magnet.

The construction of the attraction type instrument is shown in fig:



Moving iron attraction type instrument.

- It consists of a fixed coil C and moving iron piece 'D'.
- The coil is flat and has a narrow slot like opening. The moving iron is a flat disc which is eccentrically mounted on the spindle.
- The spindle is supported between the jewel bearings. The spindle carries a pointer which moves over a graduated scale.
- The controlling torque is provided by the springs.
- The damping torque is provided by the air friction. A light Aluminimum piston is attached to the moving system. It moves in a fixed chamber. The chamber is closed at one end. It can also be provided with the help of vane attached to the moving system.

II) <u>Moving Iron Repulsion Type Instrument:-</u>

These instruments have two vanes inside the coil, the one is fixed and other is movable. When the current flows in the coil, both the vanes are magnetised with like polarities induced on the same side. Hence due to the repulsion of like polarities, there is a force of repulsion between the two vanes causing the movement of the moving vane. The repulsion type instruments are the most commonly used instruments.

The two different designs of repulsion type instruments are.

(i) Radial vane type and (ii) co-axial vane type.

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(i) Radial vane Repulsion Type Instrument:

- The shows the radial vane repulsion type instruments.
- The two vanes are radial strips of iron. the fixed true vaned is attached to the coil. The movable vane is attached to the spindle and suspended in the introduction feild of the coil. The needle of the instrument is attached to this vane.
- Eventhough the current through coil is alternating, there is always repulsion between the like poles of the fixed and the movable vane. Hence the deflection of the pointer is always in the same direction. The deflection is effictively proportional to the actual current and hence the scale is calibrated directly to read amperes or volts.

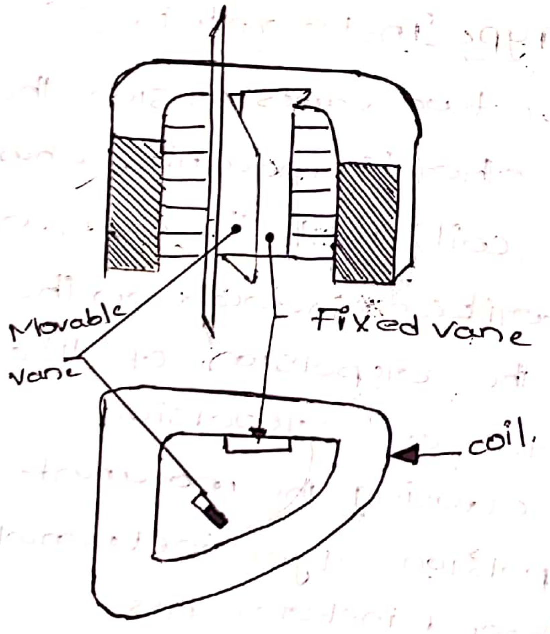

fig (a) Radial vane type

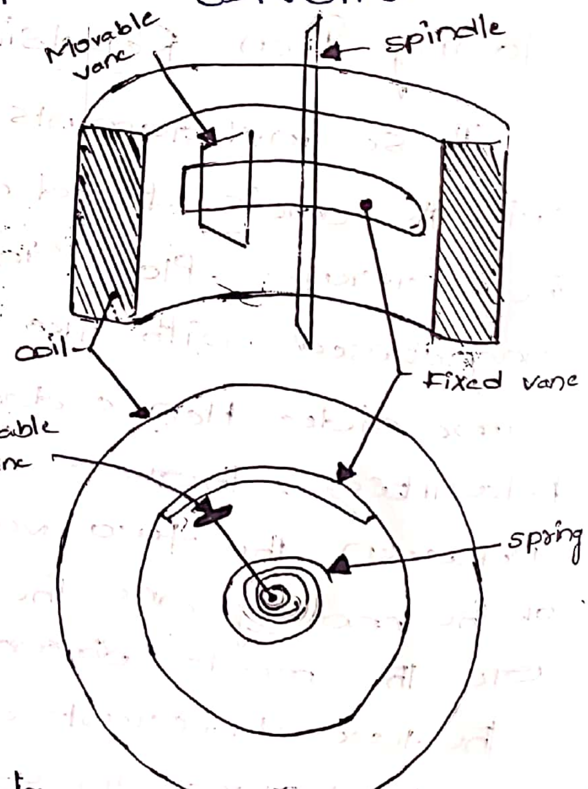

fig (b). co-axial vane type

(ii) <u>co-axial vane type</u>. In this type of Instruments. the fixed and moving vanes are sections of co-cylinders as shown in fig (b).

- The controlling torque is provided by springs.
- The damping torque is produced by air friction as in attraction type instruments.
- The moving iron instruments are unpolarised instruments. i.e they are independent the direction in which the current passes.

∴ These instruments can be used on both a.c and d.c.

Wheatstone Bridge.

* **Wheatstone Bridge :-** A very important device used in the measurement of medium resistances is the wheatstone Bridge.

* It is an accurate and reliable instrument and is extensively used in industry.

* The wheatstone bridge is an instrument for making comparison measurement and operates upon in as instruments in null indication principle.

* The basic circuit of a wheatstone bridge. it has four resistive arms, consisting of resistances P, Q, R and S together with a source of emf (a battery) and a null detector usually galvanometer or other sensitive current meter.

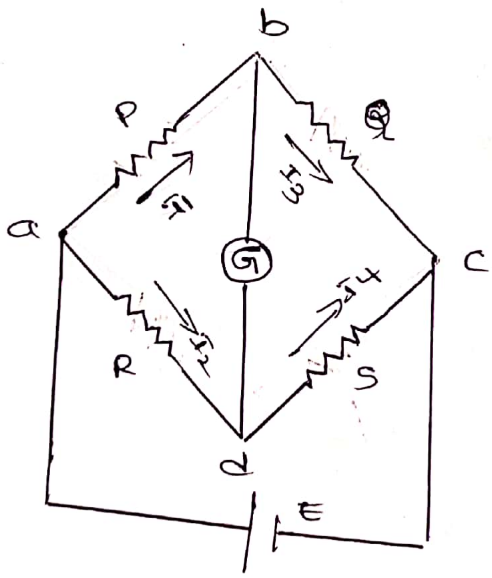

Fig: wheatstone bridge

The current through the galvanometer depends on the potential difference between point c and d.

The bridge is said to be balanced when there is no current through the galvanometer or when the potential difference across the galvanometer is zero.

This occurs when the voltage from point 'b' to point 'a' equals the voltage from point 'd' to point 'b'; or by referring to the other battery terminal, when the voltage from point 'd' to point 'c' equals the voltage from point 'b' to point 'c'.

For bridge balance, we can write:

$$I_1 P = I_2 R$$

For the galvanometer current be zero, the following condition also exist:

$$I_1 = I_3 = \frac{E}{P+Q}$$

$$I_2 = I_4 = \frac{E}{R+S}$$

Combing eq 14.11, 14.12 and 14.13 and we obtain

$$\frac{\cancel{E}}{P+Q} P = \left(\frac{\cancel{E}}{R+S}\right) R$$

$$\frac{P}{P+Q} = \frac{R}{R+S}$$

$$QR = PS.$$

The well known expression for the balance of wheatstone bridge if three of the resistance and know the fourth may be determined from eqn: $\boxed{R = S\frac{P}{Q}}$