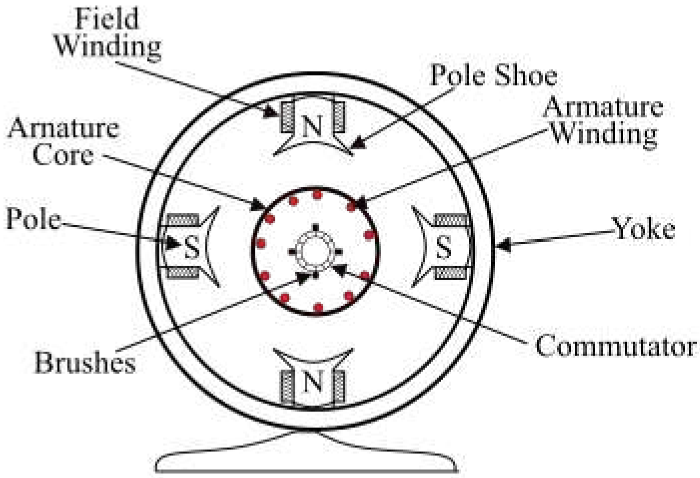
UNIT2

MACHINES AND MEASURING INSTRUMENTS

Construction of a DC Motor

Here is the schematic diagram of a DC Motor



A DC motor consists of six main parts, which are as follows

Yoke

The outer frame of a DC motor is a hollow cylinder made up of cast steel or rolled steel is known as yoke. The yoke serves following two purposes

- It supports the field pole core and acts as a protecting cover to the machine.
- It provides a path for the magnetic flux produced by the field winding.

Magnetic Field System

The magnetic field system of a DC motor is the stationary part of the machine. It produces the main magnetic flux in the motor. It consists of an even number of pole cores bolted to the yoke and field winding wound around the pole core. The field system of DC motor has salient poles i.e. the poles project inwards and each pole core has a pole shoe having a curved surface. The pole shoe serves two purposes

- It provides support to the field coils.
- It reduces the reluctance of magnetic circuit by increasing the cross-sectional area of it.

The pole cores are made of thin laminations of sheet steel which are insulated from each other to reduce the eddy current loss. The field coils are connected in series with one another such that when the current flows through the coils, alternate north and south poles are produced.

Armature Core

The armature core of DC motor is mounted on the shaft and rotates between the field poles. It has slots on its outer surface and the armature conductors are put in these slots. The armature core is a made up of soft steel laminations which are insulated from each other and tightly clamped together. In small machines, the laminations are keyed directly to the shaft, whereas in large machines, they are mounted on a spider. The laminated armature core is used to reduce the eddy current loss.

Armature Winding

The insulated conductors are put into the slots of the armature core. The conductors are suitably connected. This connected arrangement of conductors is known as armature winding. There are two types of armature windings are used – wave winding and lap winding.

Commutator

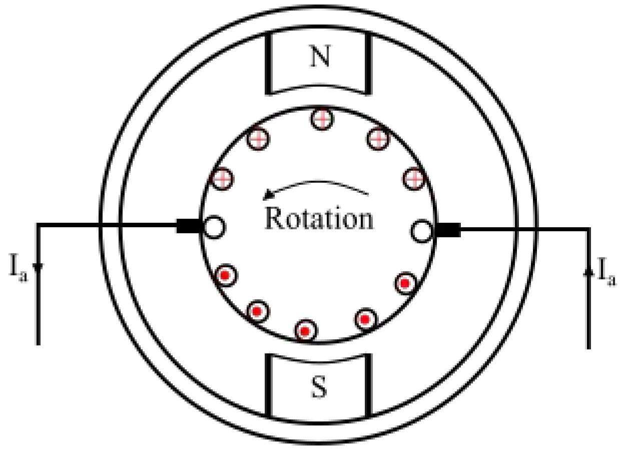
A commutator is a mechanical rectifier which converts the direct current input to the motor from the DC source into alternating current in the armature winding. The commutator is made of wedge-shaped copper segments insulated from each other and from the shaft by mica sheets. Each segment of commutator is connected to the ends of the armature coils.

Brushes

The brushes are mounted on the commutator and are used to inject the current from the DC source into the armature windings. The brushes are made of carbon and is supported by a metal box called brush holder. The pressure exerted by the brushes on the commutator is adjusted and maintained at constant value by means of springs. The current flows from the external DC source to the armature winding through the carbon brushes and commutator.

Working of DC Motor

Consider a two pole DC motor as shown in the figure. When the DC motor is connected to an external source of DC supply, the field coils are excited developing alternate N and S poles and a current flows through the armature windings.

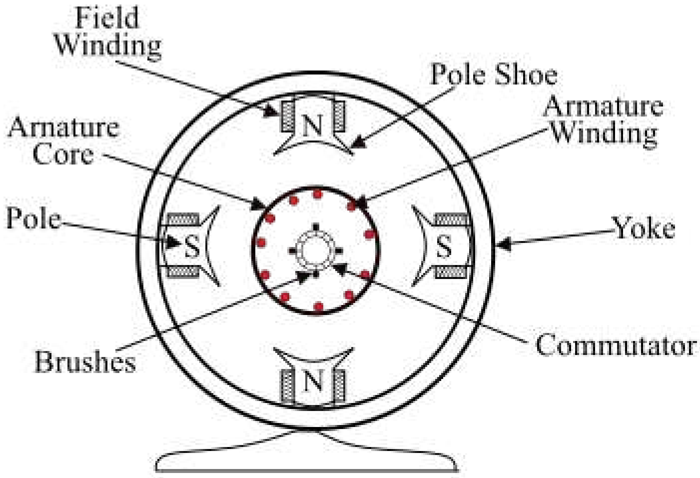


All the armature conductors under N pole carry current in one direction (say into the plane of the paper), whereas all the conductors under S pole carry current in the opposite direction (say out of the plane of the paper). As each conductor carrying a current and is placed in a magnetic field, hence a mechanical force acts on it.

By applying Fleming's left hand rule, it can be seen that the force on each conductor is tending to move the armature in anticlockwise direction. The force on all the conductors add together to exert a torque which make the armature rotating. When the conductor moves from one side of a brush to the other, the current in the conductor is reversed and at the same time it comes under the influence of next pole of opposite polarity. As a result of this, the direction of force on the conductor remains the same. Therefore, the motor being rotating in the same direction.

Construction of a DC Generator

Here is the schematic diagram of a DC Generator



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Armature Core

The armature core of DC generator is mounted on the shaft and rotates between the field poles. It has slots on its outer surface and the armature conductors are put in these slots. The armature core is a made up of soft iron laminations which are insulated from each other and tightly clamped together. In small machines, the laminations are keyed directly to the shaft, whereas in large machines, they are mounted on a spider. The laminated armature core is used to reduce the eddy current loss.

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Commutator

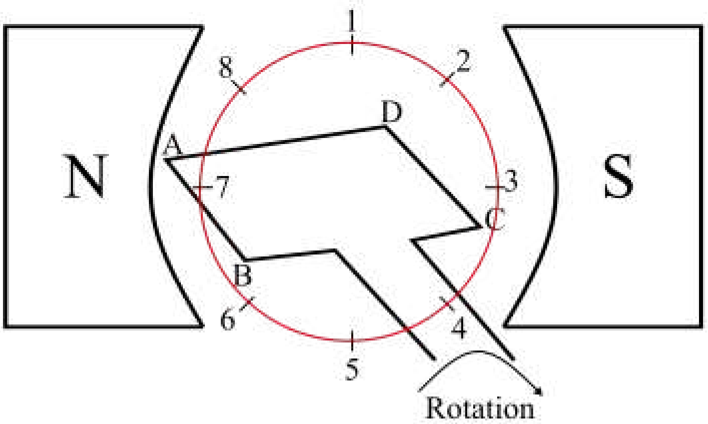
A commutator is a mechanical rectifier which converts the alternating emf generated in the armature winding into the direct voltage across the load terminals. The commutator is made of wedge-shaped copper segments insulated from each other and from the shaft by mica sheets. Each segment of commutator is connected to the ends of the armature coils.

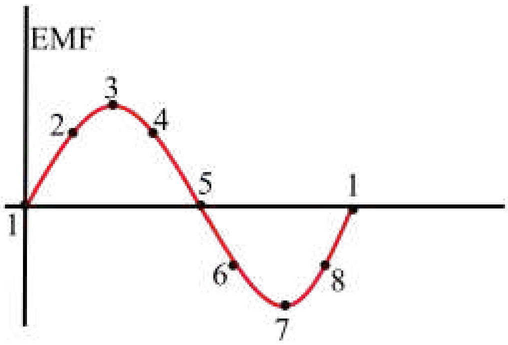
Brushes

The brushes are mounted on the commutator and are used to collect the current from the armature winding. The brushes are made of carbon and is supported by a metal box called brush holder. The pressure exerted by the brushes on the commutator is adjusted and maintained at constant value by means of springs. The current flows from the armature winding to the external circuit through the commutator and carbon brushes.

Working of a DC Generator

Consider a single loop DC generator (as shown in the figure), in this a single turn loop ‘ABCD’ is rotating clockwise in a uniform magnetic field with a constant speed. When the loop rotates, the magnetic flux linking the coil sides ‘AB’ and ‘CD’ changes continuously. This change in flux linkage induces an EMF in coil sides and the induced EMF in one coil side adds the induced EMF in the other.





The EMF induced in a DC generator can be explained as follows

- When the loop is in position-1, the generated EMF is zero because, the movement of coil sides is parallel to the magnetic flux.
- When the loop is in position-2, the coil sides are moving at an angle to the magnetic flux and hence, a small EMF is generated.
- When the loop is in position-3, the coil sides are moving at right angle to the magnetic flux, therefore the generated EMF is maximum.
- When the loop is in position-4, the coil sides are cutting the magnetic flux at an angle, thus a reduced EMF is generated in the coil sides.
- When the loop is in position-5, no flux linkage with the coil side and are moving parallel to the magnetic flux. Therefore, no EMF is generated in the coil.
- At the position-6, the coil sides move under a pole of opposite polarity and hence the polarity of generated EMF is reversed. The maximum EMF will generate in this direction at position-7 and zero when at position-1. This cycle repeats with revolution of the coil.

It is clear that the generated EMF in the loop is alternating one. It is because any coil side (say AB) has EMF in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. Hence, when a load is connected across the terminals of the generator, an alternating current will flow through it. Now, by using a commutator, this alternating emf generated in the loop can be converted into direct voltage. We then have a DC generator.

Construction of Single Phase Transformer

A *single phase transformer* consists of two windings viz. *primary winding* and *secondary winding* put on a magnetic core. The magnetic core is made from thin sheets (called *laminations*) of *high graded silicon steel* and provides a definite path to the magnetic flux. These laminations reduce the *eddy-current losses* while the silicon steel reduces the *hysteresis losses*.

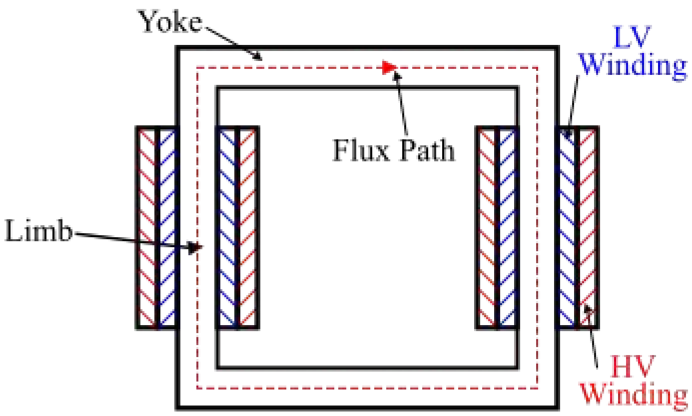
The laminations are insulated from each other by *enamel insulation coating*. The thin laminations are stacked together to form the core of the transformer. The air-gap between the laminations should be minimum so that the excitation current being minimum.

For a single phase transformer, there are two types of transformer constructions viz. the *core type* and the *shell type*.

Core Type Transformer Construction

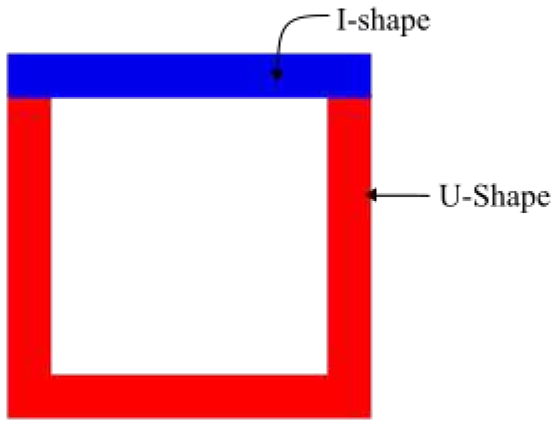
In *core type construction* of the transformer, the magnetic circuit consists of two vertical lags (called *limbs*) and two horizontal sections called *yokes*. To minimise the effect of leakage flux, half of each winding is placed on each limb (see the figure).

The low-voltage winding is placed next to the core while the high-voltage winding over the low-voltage winding to reduce the insulation requirements. Therefore the two windings are arranged as *concentric coils* and known as *cylindrical winding*.



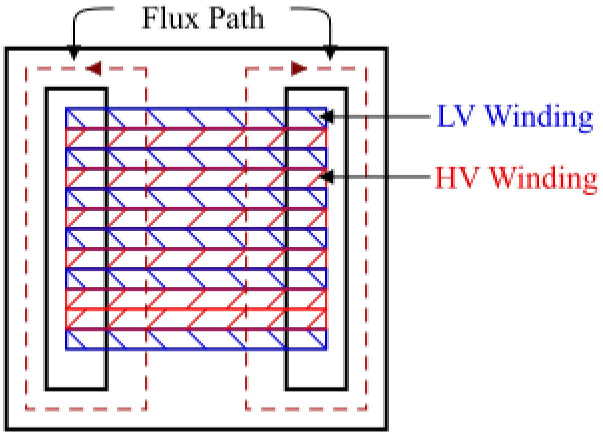
Core Type Construction

The laminations of the core type transformer are of *U-I shape* as shown in the figure.



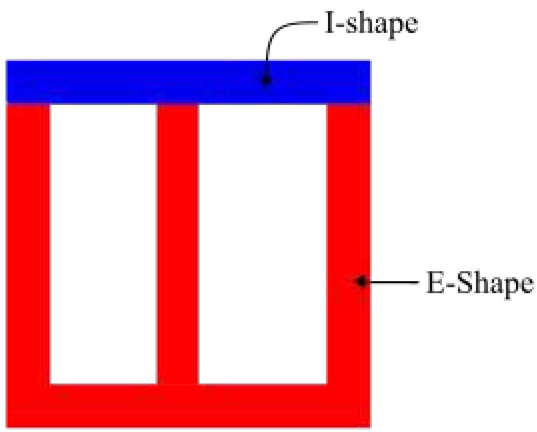
Shell Type Transformer Construction

In the *shell type construction* of transformer, the magnetic circuit consists of three limbs, both the primary and secondary windings are placed on the central limb and the two outer limbs complete the low reluctance flux path. The each winding is sub-divided into sections viz. the low voltage (LV) section and the high-voltage (HV) section, which are alternatively put one over the other in the form of sandwich (see the figure). Therefore, such windings are called *sandwich winding* or *disc winding*.

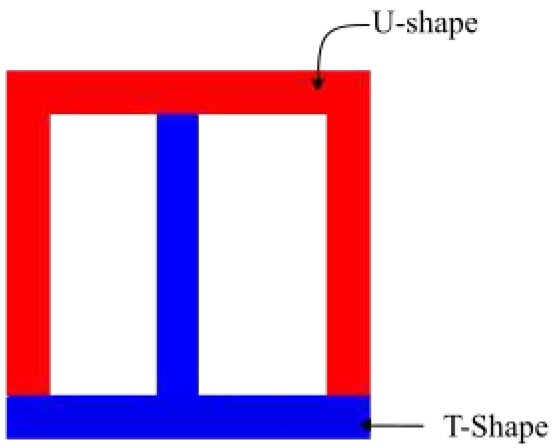


Shell Type Construction

The core of the shell type transformer is made up either *U-T shape* or *E-I shape* (see the figure).



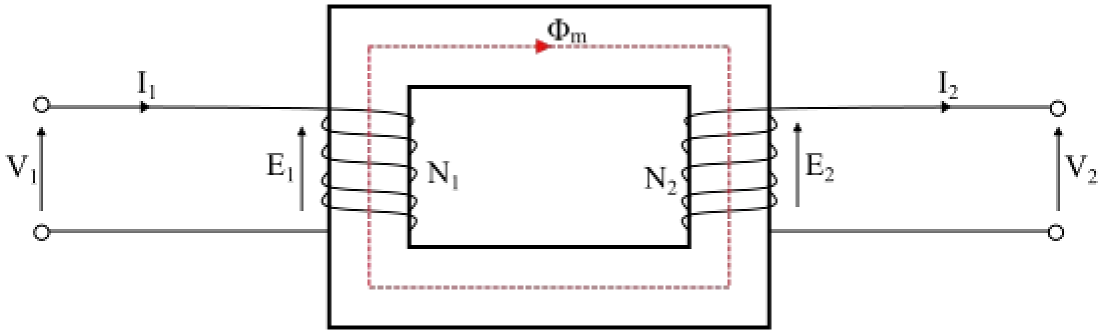
E-I Shape



U-I Shape

Working Principle of Single Phase Transformer

The working of the transformer is based on the *principle of mutual inductance* between two coils wound on the same magnetic core.



When an alternating voltage (V_1) is applied to the primary winding, an alternating magnetic flux (Φ_m) sets up in the core and links with the secondary winding, i.e. the magnetic flux links both the windings of the transformer magnetically. This magnetic flux induces EMF E_1 in the primary winding and E_2 in the secondary winding according to *Faraday's law of electromagnetic induction.*
According to *Lenz' law,*

SecondaryEMF, $E_2 = -N_2 d\phi_m/dt \ldots (2)$

Therefore,

$E_2/E_1 = N_2/N_1 \ldots (3)$

From the above equations, it is clear that the induced EMFs in the primary and secondary windings depends upon the number of turn of the winding.

If $N_1 > N_2$, then $E_1 > E_2$ i.e. the primary EMF is greater than the secondary EMF, the transformer is called as *step-down transformer*.
If $N_2 > N_1$, then $E_2 > E_1$ i.e. the primary EMF is less than the secondary EMF, the transformer is called as *step-up transformer*.
If a load is connected across the terminals of the secondary winding, the secondary EMF causes a current I_2 to flow through the load. In this way, a transformer transfers AC power from one circuit to another circuit with a change in voltage level without any electrical connection between both the circuits i.e. the power from input circuit to output circuit transfers magnetically. During this transfer of electrical power, the frequency does not change.

Construction of 3-Phase Induction Motor

A 3-phase induction motor has two main parts −

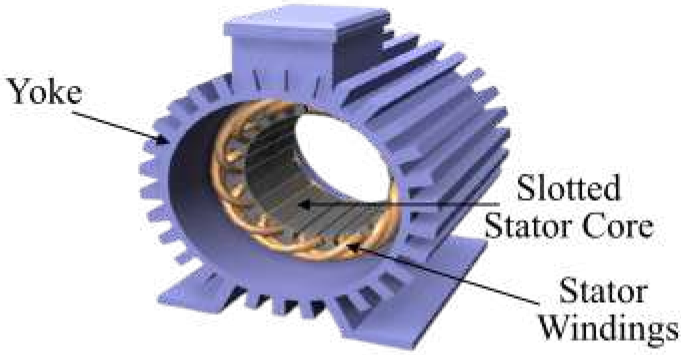
- Stator
- Rotor

The rotor and stator are separated by a small air gap ranges from 0.5 mm to 4 mm depending on the power rating of the motor.

Stator of Three Phase Induction Motor

The stator is the stationary part of the motor. It consists of a steel frame which encloses a hollow cylindrical core. The core of the three phase induction motor is made up of thin laminations of silicon steel to reduce the eddy current and hysteresis losses.

A number of equally spaced slots are provided on the inner periphery of the laminated core as shown in the figure. The insulated conductors are placed in these stator slots and are connected in a suitable manner to form a balanced 3-phase star or delta connected stator winding.



The 3-phase stator windings are wound for a definite number of poles depending upon the requirement of speed, i.e., greater the number of poles, lesser is the speed of the motor and *vice-versa*.

When a balanced 3-phase supply is fed to the stator winding a rotating magnetic field (RMF) of constant magnitude is produced and this RMF induces currents in the rotor circuit by electromagnetic induction.

Rotor of Three Phase Induction Motor

The rotor of an induction motor is a hollow cylindrical laminated core, having slots on its outer periphery. The rotor windings are placed in these rotor slots.

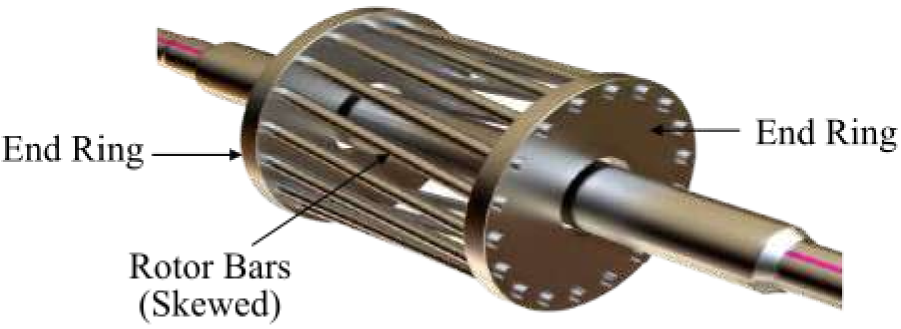
Depending upon the winding arrangement, the rotor of a 3-phase induction motor is of two types −

- Squirrel Cage Type Rotor
- Wound Type or Slip-Ring Type Rotor

Squirrel Cage Type Rotor

The squirrel cage rotor consists of a cylindrical laminated core having slots on its outer periphery which are nearly parallel to the shaft axis or *skewed*. An uninsulated copper or aluminium bar (rotor conductor) is placed in each slot.

At each end of the rotor, the rotor bar conductors are short-circuited by heavy end rings of the same material (see the figure). This forms a permanently short circuited winding which is indestructible. This entire arrangement resembles a cage which was once commonly used for keeping squirrels and hence the name.



This rotor is not connected electrically to the supply but has currents induced in it by the electromagnetic induction from the stator.

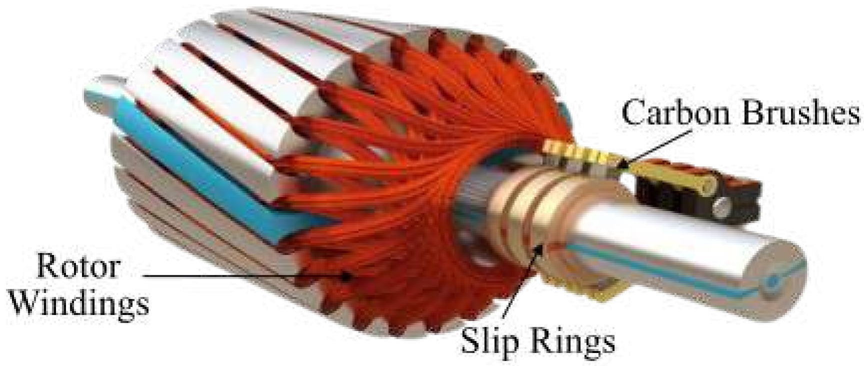
Those 3-phase induction motors which employed squirrel cage rotor are known as *squirrel cage induction motors*. Most of the 3-phase induction motors in the industries use squirrel cage rotor because it has simple and robust construction enabling it to operate in the most adverse environment. Although, it suffers from a disadvantage of low starting torque.

The *skewing* of squirrel cage rotor conductors offers following advantages −

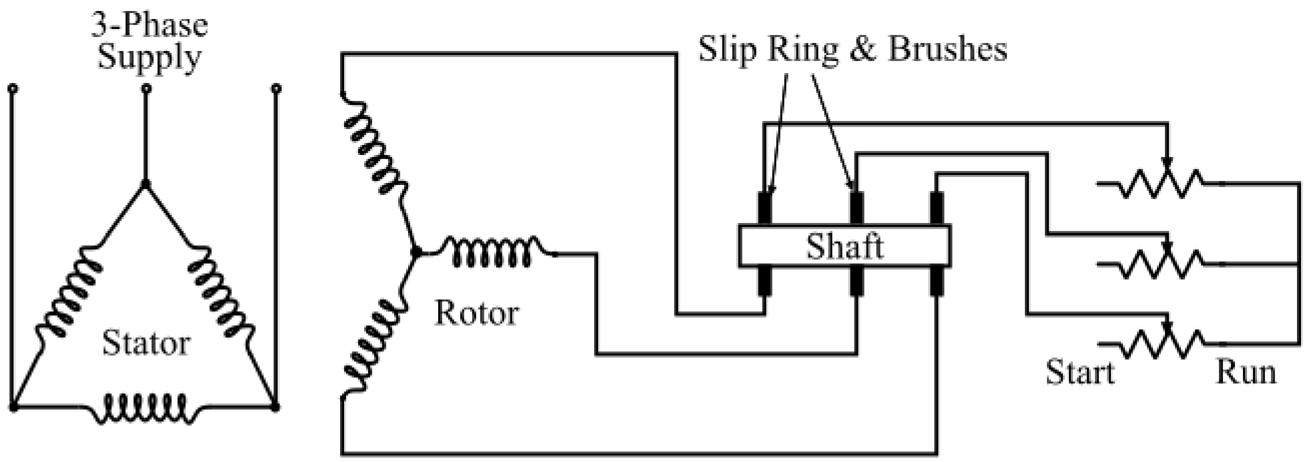
- The noise is reduced during operation.
- More uniform torque is produced.
- The *cogging* or *magnetic* locking tendency of the rotor is reduced. During cogging, the rotor and stator teeth locked with each other due to magnetic action.

Wound Rotor or Slip Ring Rotor

The slip ring rotor consists of a laminated cylindrical armature core. The slots are provided on the outer periphery and insulated conductors are put in the slots. The rotor conductors are connected to form a 3-phase double layer distributed winding similar to the stator winding. The rotor windings are connected in star fashion (see the figure).



The open ends of the star circuit are taken outside the rotor and connected to three insulated slip rings. The slip rings are mounted on the rotor shaft with brushes resting on them. The brushes are connected to three variable resistors which are also connected in star. Here, the slip rings and brushes are used to provide a mean for connecting external resistors in the rotor circuit. The equivalent circuit of the wound rotor is shown in the figure below.

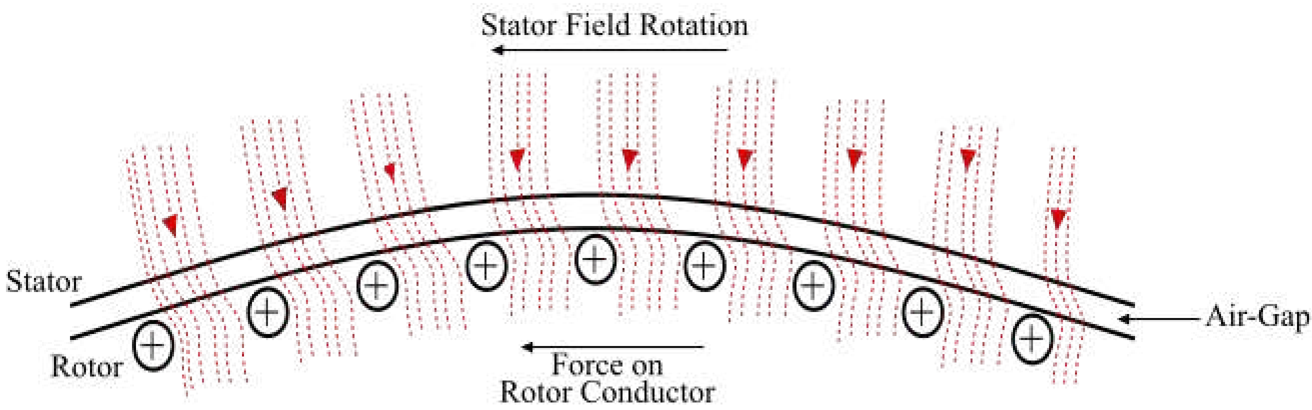


The external resistors enable the variation of each rotor phase resistance to serve following two purposes −

- To increase the starting torque and reduce the starting current from the supply.
- To control the speed of the motor.

Working Principle of a 3-Phase Induction Motor

The working principle of a 3-phase induction motor can be explained by considering a portion of it as follows−



- When the 3-phase stator winding is fed from a balanced 3-phase supply, a rotating magnetic field (RMF) is produced in the motor. This RMF rotates around the stator at *synchronous speed* which is given by,

SynchronousSpeed,NS=120fPSynchronousSpeed,$N S=120 f P$

- The RMF passes through the air gap and cuts the rotor conductors, which as yet are stationary. Due to the relative motion between the RMF and the stationary rotor conductors, EMFs are induced in the rotor conductors. As the rotor circuit is closed with short-circuit so currents start flowing in the rotor conductors.
- Since the current carrying rotor conductors are placed in the magnetic field produced by the stator winding. As a result, the rotor conductors experience mechanical force. The sum of the mechanical forces on all the rotor conductors produce a torque which moves the rotor in the same direction as the rotating magnetic field. Hence, in such a way the three phase input electric power is converted into output mechanical power in a 3-phase induction motor.
- Also, *according to Lenz's law*, the rotor should move in the direction of the stator field, i.e., the direction of rotor currents would be such that they tend to oppose the cause producing them. Here, the cause producing the rotor currents is the relative speed between the RMF and the rotor conductors. Thus to reduce this relative speed, the rotor starts running in the same direction as that of the RMF.

Advantages of Three Phase Induction Motor

Following are the chief advantages of a 3-phase induction motor −

- It has simple and rugged construction.
- It requires less maintenance.
- It has high efficiency and good power factor.
- It is less expensive.
- It has self-starting torque.

Disadvantages of Three Phase Induction Motor

The disadvantages of a 3-phase induction motor are given as follows −

- The 3-phase induction motors are constant speed motors; hence their speed control is very difficult.
- 3-phase induction motors have poor starting torque and high inrush currents (about 4 to 8 times of the rated current).
- They always operate under lagging power factor and during light loads, they operate at very worst power factor (about 0.3 to 0.5 lagging).

Synchronous Generator – Construction and Working Principle

A *synchronous generator* is a synchronous machine which converts mechanical power into AC electric power through the process of electromagnetic induction.

Synchronous generators are also referred to as **alternators** or **AC generators**. The term "alternator" is used since it produces AC power. It is called synchronous generator because it must be driven at synchronous speed to produce AC power of the desired frequency.

A synchronous generator can be either *single-phase or poly-phase (generally 3phase)*.

Construction of Synchronous Generator or Alternator

As alternator consists of two main parts viz.

- **Stator –** The stator is the stationary part of the alternator. It carries the armature winding in which the voltage is generated. The output of the alternator is taken form the stator.
- **Rotor –** The rotor is the rotating part of the alternator. The rotor produces the main field flux.

Stator Construction of Alternator

The stator of the alternator includes several parts, viz. the frame, stator core, stator or armature windings, and cooling arrangement.

- The stator frame may be made up of cast iron for small-size machines and of welded steel for large-size machines.
- The stator core is assembled with high-grade silicon content steel laminations. These silicon steel laminations reduce the hysteresis and eddy-current losses in the stator core.
- The slots are cut on the inner periphery of the stator core. A 3-phase armature winding is put in these slots.
- The armature winding of the alternator is star connected. The winding of each phase is distributed over several slots. When current flows through the distributed armature winding, it produces an essential sinusoidal space distribution of EMF.

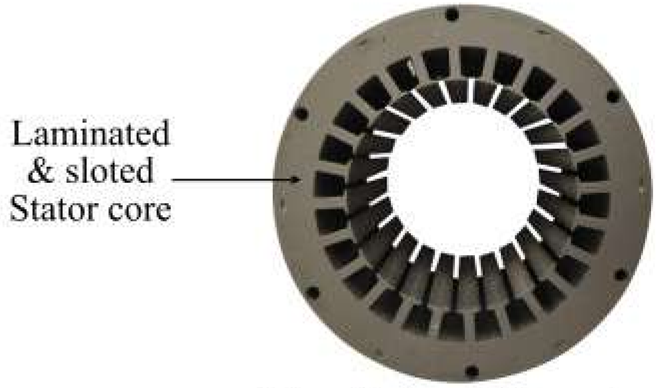


Fig. - Stator of Alternator

Rotor Construction of Alternator

The rotor of the alternator carries the field winding which is supplied with direct current through two slip rings by a separate DC source (also called exciter). The exciter is generally a small DC shunt generator mounted on the shaft of the alternator.

For the alternator, there are two types of rotor constructions are used viz. *the salient-pole type* and *the cylindrical rotor type*.

Salient Pole Rotor

The term *salient means projecting*. Hence, a *salient pole rotor* consists of poles projecting out from the surface of the rotor core. This whole arrangement is fixed to the shaft of the alternator as shown in the figure. The individual field pole windings are connected in series such that when the field winding is energised by the DC exciter, the adjacent poles have opposite polarities.

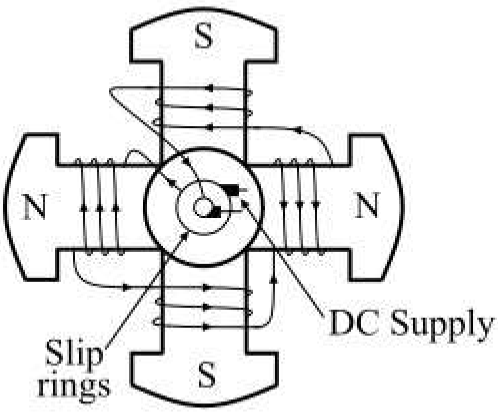


Fig. - Salient Pole Rotor

The salient pole type rotor is used in the low and medium speed (from 120 to 400 RPM) alternators such as those driven by the diesel engines or water turbines because of the following reasons −

- The construction of salient pole type rotor cannot be made strong enough to withstand the mechanical stresses to which they may be subjected at higher speed.
- If the salient field pole type rotor is driven at high speed, then it would cause windage loss and would tend to produce noise.

Low speed rotors of the alternators possess a large diameter to provide the necessary space for the poles. As a result, the salient pole type rotors have large diameter and short axial length.

Cylindrical Rotor

The cylindrical rotors are made from solid forgings of high-grade nickel-chrome-molybdenum steel.

- The construction of the cylindrical rotor is such that there are no-physical poles to be seen as in the salient pole rotor.
- In about two-third of the outer periphery of the cylindrical rotor, slots are cut at regular intervals and parallel to the rotor shaft.
- The field windings are placed in these slots and is excited by DC supply. The field winding is of *distributed type*.
- The unslotted portion of the rotor forms the pole faces.
- It is clear from the figure of the cylindrical rotor that the poles formed are non-salient, i.e., they do not project out from the rotor surface.

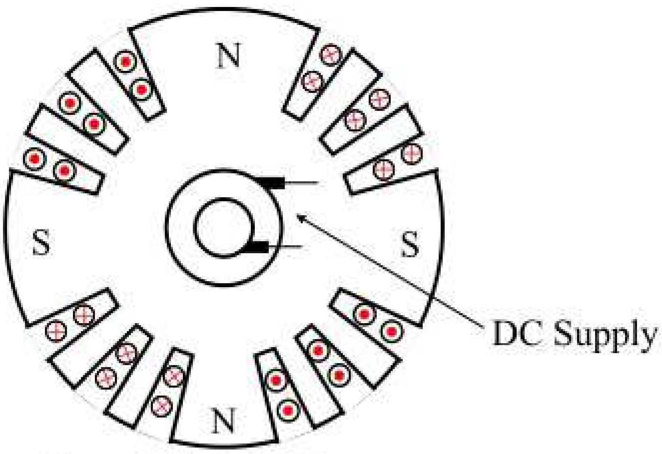


Fig. - Cylindrical Rotor

The cylindrical type rotor construction is used in the high-speed (1500 to 3000 RPM) alternators such as those driven by steam turbines because of the following reasons −

- The cylindrical type rotor construction provides a greater mechanical strength and permits more accurate dynamic balancing.
- It gives noiseless operation at high speeds because of the uniform air gap.
- The flux distribution around the periphery of the rotor is nearly a sine wave and hence a better EMF waveform is obtained.

A cylindrical rotor alternator has a comparatively small diameter and long axial length. The cylindrical rotor alternators are called **turbo-alternators** or **turbo-generators**. The alternator with cylindrical rotor have
always horizontal configuration installation.

Working Principle and Operation of Alternator

An alternator or synchronous generator works on the principle of electromagnetic induction, i.e., when the flux linking a conductor changes, an EMF is induced in the conductor. When the armature winding of alternator subjected to the rotating magnetic field, the voltage will be generated in the armature winding.

When the rotor field winding of the alternator is energised from the DC exciter, the alternate N and S poles are developed on the rotor. When the rotor is rotated in the anticlockwise direction by a prime mover, the armature conductors placed on the stator are cut by the magnetic field of the rotor poles. As a result, the EMF is induced in the armature conductors due to electromagnetic induction. This induced EMF is alternating one because the N and S poles of the rotor pass the armature conductors alternatively.

The direction of the generated EMF can be determined by the Fleming’s right rule and the frequency of it is given by,

$f = N_s P / 120$

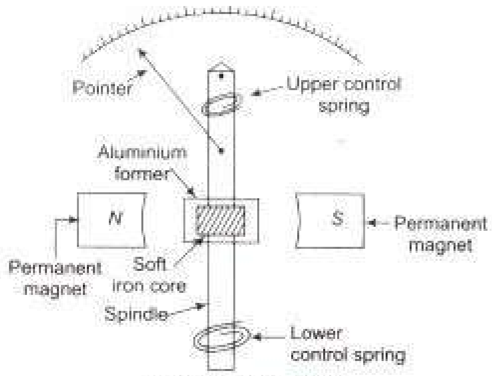
Where,

- N_s is the synchronous speed in RP
- P is the number of rotor poles.

The magnitude of the generated voltage depends upon the speed of rotation of the rotor and the DC field excitation current. For the balanced condition, the generated voltage in each phase of the winding is the same but differ in phase by 120° electrical.

PMMC

A permanent magnet moving coil instrument can measure DC voltage & current. The working principle of these instrument is the same as that of the **D' Arsonval** type of galvanometer, the difference being that a direct reading provided with a pointer & a scale.



Instrument for PMMC

Construction of PMMC Instrument

It has a permanent shoe magnet & a rectangular coil having large number of turns wound on a light aluminium or copper former. A iron core is provided inside the former to provide an easy path for the magnetic lines of force.

The coil is mounted on a spindle. The springs are used to supply current to the moving coil. The pointer is provided on the spindle to indicate the magnitude of quantity being measured

Advantages of PMMC Instrument

- Scale of these instrument is uniform.
- These are accurate & reliable.
- Eddy current damping is quit effective.
- There is no effect of stray magnetic field as it has a strong permanent magnet.
- These instrument require low driving power, hence their power consumption is low.

Disadvantages of PMMC Instrument

- These instrument can operate DC supply only.
- These are costlier than moving iron instrument.

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What is a Moving Iron Instrument?

The instrument which has the moving iron used to measure the current or voltage flow is called the moving iron instrument. The working principle of moving iron instruments mainly depends on the iron movement attracted by the magnetic field to it & repulsion among them. Here, the magnetic field is generated by the current within the coil. The attraction force in this instrument mainly depends on the magnetic field's strength.

The magnetic field is induced by the electromagnet whose magnetic field's strength mainly depends on the magnitude of the current supplies throughout it. The **moving iron instrument diagram** is shown below.

Moving Iron Instrument

This moving iron instrument can be used as a voltmeter or an ammeter. If this **instrument is used as an ammeter** then it has **less number of thick wire turns** and if this **instrument is used as a voltmeter** then it has **more thick wire turns.** So this instrument simply supports both AC & DC.

Construction of Moving Iron Instrument

The moving iron instrument uses a moving element like a plate or soft iron vane. The vane is arranged in such a way that it moves freely within the magnetic field of the inactive coil. This coil is simply excited by the current/voltage whose magnitude is to be measured.

This instrument utilizes an electromagnet like the inactive coil. This electromagnet is not a permanent magnet where the strength of this magnetic field enhances or reduces through the magnitude of the current flow throughout it.

Working of Moving Iron Instrument

The moving iron instrument uses the stationary coil of aluminum/copper wire which functions like an electromagnet once current flows throughout it. The magnetic field strength induces through the electromagnet is directly proportional to the current flowing throughout it.

The vane of the iron/plates supply throughout the coil increases the stationary coil's inductance. Here inductance is the conductor's property which enhances their electromotive force once the unstable current supplies through it.

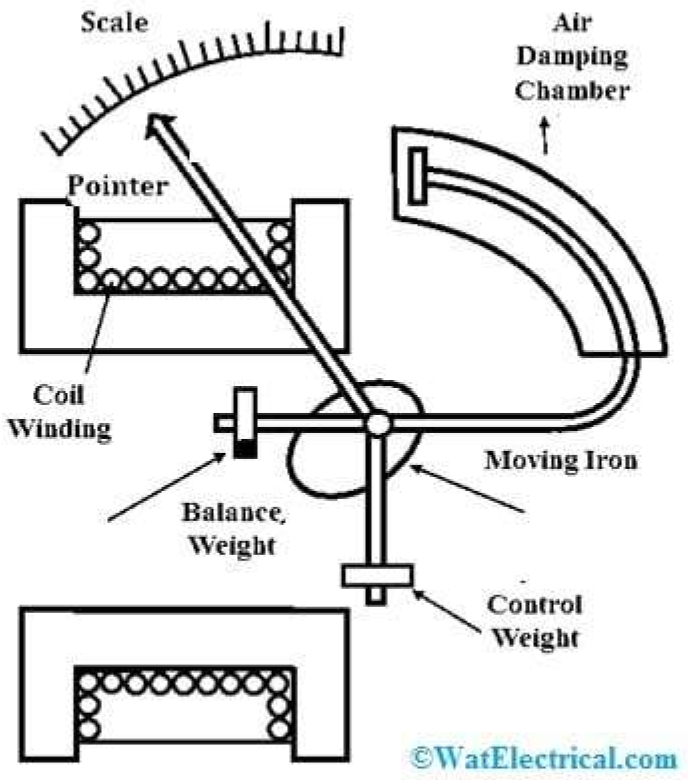
The electromagnet will attract the iron vane which passes throughout the coil and looks to reside in the minimum reluctance lane. The vane passes throughout the coil and will experience a repulsion force that is caused by the electromagnet. This force increases the coil inductance's strength and this occurs due to the reluctance & inductances being inversely proportional to each other.

Types of the Moving Iron Instruments

These instruments are classified into two types attraction type and repulsion type which are discussed below.

Attraction Type Moving Iron Instrument

The attraction type moving iron instrument working principle mainly depends on magnetic attraction, because it attracts an iron piece once arranged close to a magnetic field. Here, this magnetic field is generated through an electromagnet.



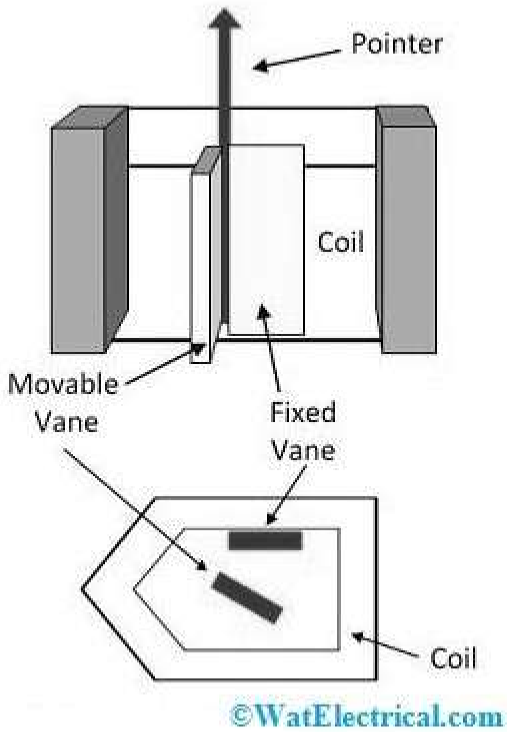
Attraction Type Moving Iron Instrument

This type of moving iron instrument includes a flat fixed coil with a slight opening. A moving iron in this instrument is designed with soft iron that is mounted on a spindle. Here, the coils are wounded with a no. of turns which depends on the instrument range. The pointer in this instrument is mounted on a spindle that includes a graduated scale used to show the deflection.

Once coil winding is coupled across the supply to be measured, then a magnetic field will be set up. So, the magnetic field's intensity is higher within the coil as compared to the outside intensity thus low reluctance will exist within the coil. When the moving iron attempts to occupy the low reluctance position, then it is moved & attracted to the fixed coil. Once the iron piece gets moved, then the pointer in the instrument also moves to illustrate the deflection. So, this instrument achieves the equilibrium position once the deflecting torque is balanced by the controlling torque.

Repulsion Type Moving Iron Instrument

The repulsion type instrument includes two vanes otherwise iron plate where one vane is permanent & another vane is movable. In this type of instrument, the fixed vane is connected to the coil and the movable vane is placed on the spindle. So this spindle simply carries the pointer to move on a scale.



Repulsion Type

At first, the current does not flow throughout the coil so, the two vanes within the instrument will get touched each other & the pointer will be at zero position. Once current is supplied throughout the coil, then the magnetic field will be set up & two vanes get magnetized by similar polarities. At one end, north poles are generated in both the vanes, and at the other end, south poles are generated. Because of this, a repulsive force exists in between two vanes & the movable vane attempts to move away from the fixed vane.

Thus, the movable vane moves because of the repulsive force & the pointer on a spindle will show deflection. Once the controlling torque is equivalent to the deflecting torque then the pointer will stop deflecting. As a result, the total repulsion force mainly depends on the strength of the magnetization field produced by the coil. This magnetic field mainly depends on the supplied current. In this type of moving the iron instrument, torque control is provided through the damping torque as well as spiral springs which are provided through air friction.

The **disadvantages of moving iron instruments** include the following.

- The scale is not uniform.
- The power utilization is high for a low range of voltage.
- The errors in this instrument can be caused because of the hysteresis within the iron & stray magnetic field.
- Change within frequency can cause very serious errors in AC measurements.
- The spring stiffness will decrease when the temperature increases.
- This instrument is nondirectional, so its accuracy is low.
- Power consumption is high.

Applications

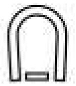
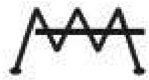
The applications of moving iron instruments include the following.

- These instruments are mainly used as an ammeter, voltmeter & wattmeter which can work on both AC & DC.
- These are used for measuring alternating currents & voltages.
- These types of Instruments are used at power frequencies within laboratories.
- These MI instruments are extensively used in switchboards & labs.\

Difference between Moving Coil Instrument and Moving Iron Instrument

Both moving coil and moving iron instruments are widely used in electrical and electronics measurements. The following table compares and contrasts the various features of these two instruments −

Basis of Difference	Moving Coil Instrument	Moving Iron Instrument
Definition	A measuring instrument which involves the movement of a coil in a magnetic field of a permanent magnet to measure the electric current or voltage is called moving coil instrument or M. C. instrument or PMMC instrument.	The measuring instrument in which a core of soft iron moves in a magnetic field of an electromagnet to measure the electrical current or voltage is called moving iron instrument or M. I. instrument.
Operating principle	The operation of the moving coil instrument is based on the fact that a current carrying coil experiences a force that tends to move it when placed in a magnetic field of a permanent magnet.	The operation of a moving iron instrument is based on the magnetism, i.e. magnetic field attracts a magnetic material such as iron, etc.

Circuit Symbol		
Reading scale	The moving coil instrument has a uniform reading scale.	The moving coil instrument has a non-uniform scale, which is cramped at starting end.
Measurement	Moving coil instruments can measure direct current (DC) only.	Moving iron instruments can measure direct current (DC) as well as alternating current (AC).
Deflection of pointer	In the moving coil instruments, the deflection of pointer is directly proportional to the current in the coil, i.e. $\theta \propto I$.	In the moving iron instruments, the deflection of the pointer is directly proportional to square of current, i.e. $\theta \propto I^2$.
Accuracy	Moving coil instruments are comparatively more accurate.	Moving iron instruments are less accurate than M. C. instruments.
Construction	The construction of a moving coil instrument is relatively complex because it uses a moving coil and stationary magnetic field.	The moving iron instrument has simple construction because it uses a stationary coil.
Robustness	Moving coil instruments are very sensitive in construction, i.e. these are less robust.	Moving iron instruments are robust in construction.
Damping	Eddy current damping is provided in moving coil instruments.	Air friction damping is provided in moving iron instruments.
Controlling torque	Moving coil instruments use a control spring to provide the controlling torque.	In moving iron instruments, the controlling torque is provided by either gravity control or spring control.
Magnet	Moving coil instrument uses permanent magnet.	Moving iron instrument uses electromagnet.

Sensitivity	Moving coil instruments are more sensitive.	The sensitivity of moving iron instrument is less.
Coil construction	The coil of a moving coil instrument is always made of thin wire with less number of turns.	The construction of coil for a moving iron instrument depends on the magnitude of current or voltage measured.
Rotating element	In a moving coil instrument, the rotating element is a coil of fine wire.	Moving iron instrument has a core of soft iron as a rotating element.
Basic range of current	The basic current range for a moving coil instrument is 10 μA to 100 mA.	The basic range of current for a moving iron instrument is relatively high, from 10 mA to 100 A.
Power consumption	Moving coil instruments consumes less power.	Moving iron instruments consumes high power.
Used as	Moving coil instruments are mainly used as a measuring instrument for DC.	Moving iron instruments are mainly used as an indicating instrument.
Hysteresis loss	The hysteresis loss does not occur in a moving coil instrument.	The hysteresis loss takes place in a moving iron instrument.
Cost	Moving coil instruments are expensive.	Moving iron instruments are relatively less expensive.

Conclusion

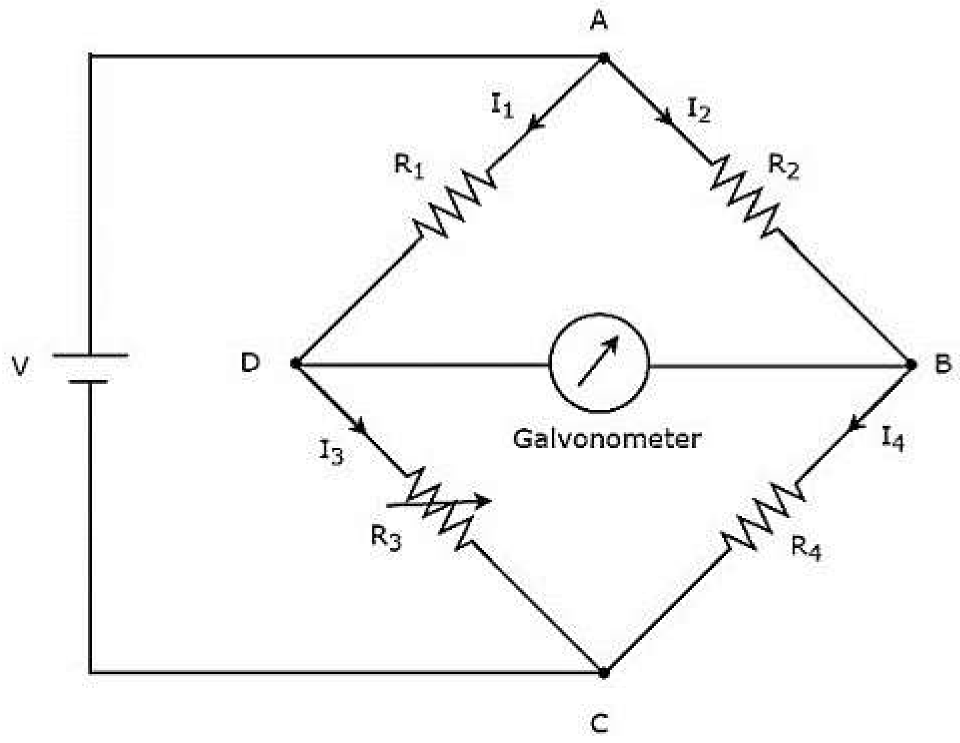
The most significant difference between moving iron and moving coil instruments is that a moving iron instrument can measure both AC and DC, whereas a moving coil instrument can measure DC only.

Wheatstone's Bridge

Wheatstone's bridge is a simple DC bridge, which is mainly having four arms. These four arms form a rhombus or square shape and each arm consists of one resistor.

To find the value of unknown resistance, we need the galvanometer and DC voltage source. Hence, one of these two are placed in one diagonal of Wheatstone’s bridge and the other one is placed in another diagonal of Wheatstone’s bridge.

Wheatstone’s bridge is used to measure the value of medium resistance. The **circuit diagram** of Wheatstone’s bridge is shown in below figure.



In above circuit, the arms AB, BC, CD and DA together form a **rhombus** or square shape. They consist of resistors R2�2, R4�4, R3�3 and R1�1 respectively. Let the current flowing through these resistor arms is I2�2, I4�4, I3�3 and I1�1 respectively and the directions of these currents are shown in the figure.

The diagonal arms DB and AC consists of galvanometer and DC voltage source of V volts respectively. Here, the resistor, R3�3 is a standard variable resistor and the resistor, R4�4 is an unknown resistor. We can **balance the bridge**, by varying the resistance value of resistor, R3�3.

The above bridge circuit is balanced when no current flows through the diagonal arm, DB. That means, there is **no deflection** in the galvanometer, when the bridge is balanced.

The bridge will be balanced, when the following **two conditions** are satisfied.

- The voltage across arm AD is equal to the voltage across arm AB. i.e.,

$$V_{AD} = V_{AB}$$

$$\Rightarrow I_1 R_1 = I_2 R_2 \qquad \text{Equation 1}$$

- The voltage across arm DC is equal to the voltage across arm BC. i.e.,
  $V_{DC}=V_{BC}$

  $\Rightarrow I_3R_3=I_4R_4 \Rightarrow$ Equation 2

From above two balancing conditions, we will get the following **two conclusions.**

- The current flowing through the arm AD will be equal to that of arm DC. i.e.,
  $I_1=I_3$

- The current flowing through the arm AB will be equal to that of arm BC. i.e.,
  $I_2=I_4$

Take the ratio of Equation 1 and Equation 2.

$$\frac{I_1R_1}{I_3R_3}=\frac{I_2R_2}{I_4R_4} \qquad \text{Equation 3}$$

Substitute, $I_1=I_3$ and $I_2=I_4$ in Equation 3.

$$\frac{I_3R_1}{I_3R_3}=\frac{I_4R_2}{I_4R_4}$$

$$\Rightarrow \frac{R_1}{R_3}=\frac{R_2}{R_4}$$

$$\Rightarrow R_4=\frac{R_2R_3}{R_1}$$

By substituting the known values of resistors R_1, R_2 and R_3 in above equation, we will get the **value of resistor,** R_4.