1 Introduction

A **DC Machine** is an **electro-mechanical energy conversion device**. There are two types of DC machines; one is the **DC generator**, and another one is known as **DC motor**.

A DC generator converts mechanical power (ωT) into DC electrical power (EI), whereas, a DC motor convert's DC electrical power into mechanical power. The AC motor is invariably applied in the industry for conversion of electrical power into mechanical power, but at the places where the wide range of speeds and good speed regulation is required, like in electric traction system, a DC motor is used. The construction of the DC motor and generator is nearly the same.

The generator is employed in a much-protected way. Hence there is an open construction type. But the motor is used in the location where they are exposed to dust and moisture, and hence it requires enclosures for example dirt proof, fireproof, etc. according to requirement. Although the battery is an important source of DC electric power, it can only supply limited power to any machines. There are some applications where large quantities of DC power are required, such as electroplating, electrolysis, etc. Hence, at such places, DC generators are used to deliver power.

The rotating electrical or DC machine has mainly two parts; one is **Stator**, and another one is **Rotor**. The stator and rotor are separated from each other by an air gap. The stator is the outer frame of the machine and is immovable. The rotor is free to move and is the inner part of the machine. Both the stator and the rotor are made of ferromagnetic materials. Slots are cut on the inner periphery of the stator and the outer periphery of the rotor. Conductors are placed in the slots of the stator or rotor. They are interconnected to form windings. The winding in which voltage is induced is called the **Armature windings.** The winding through which a current is passed to

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produce the main flux is called the **Field windings**. To provide main flux in some of the machine permanent magnets is also used.

2 Right-hand rule

Right-hand rule - a rule which is used for defining direction or "handedness" of magnetic field or magnetic force with relation to the direction of conventional electric current or movement of positive electric charges. For negative charges such as electrons, the direction of the magnetic force is reversed. There are two main versions of the "hand rule": one for **direction of magnetic field**, and another one for **direction of magnetic force**. They are typically represented as two separate rules, but are ultimately resulting from the same underlying principle.

2.1 Magnetic force in motors and generators

It should be noted here that the magnetic force for a positive charge always follows this rule, regardless of any other conditions. Therefore, exactly the same right-hand rule is applicable to both motors and generators.

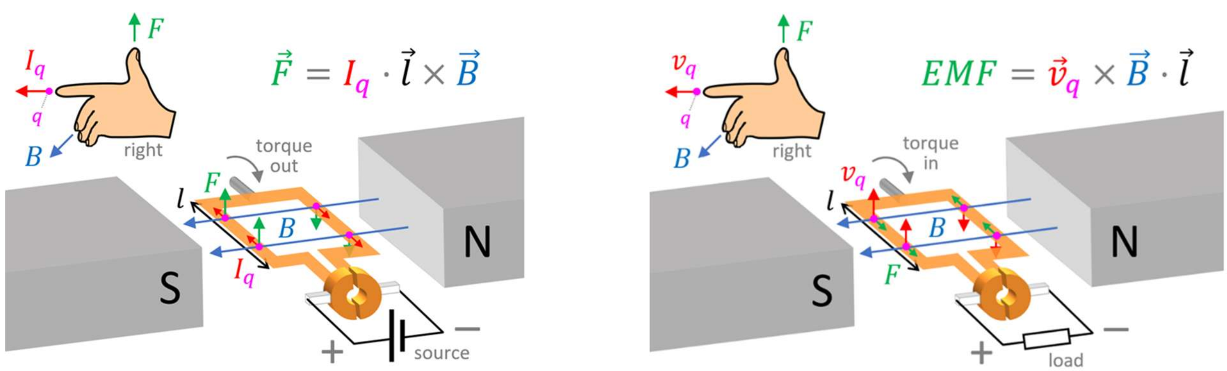

Fig 1 Right hand rule in generator and motor.

In motors, the conventional movement of charges is caused by the conventional current which flows along the conductor in question. The magnetic force will push

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the conductor in the third orthogonal direction, causing physical movement of the conductor and generation of useful output torque.

However, in generators, the charges are originally moved because the wire is pushed by some input torque. The charges move together with the wire, and the magnetic force pushes them along the wire, thus creating an electromotive force (EMF).

Therefore, the right-hand rule is easy to remember, because the index finger always show the original direction of the charge movement (as if the index finger was pushing the charge), the middle finger always shows the direction of magnetic field, and the thumb always shows the direction of magnetic force. This logic is consistent with the application of the vector cross product, as explained above for the right-handed system of coordinates.

3 Working principle of DC machines

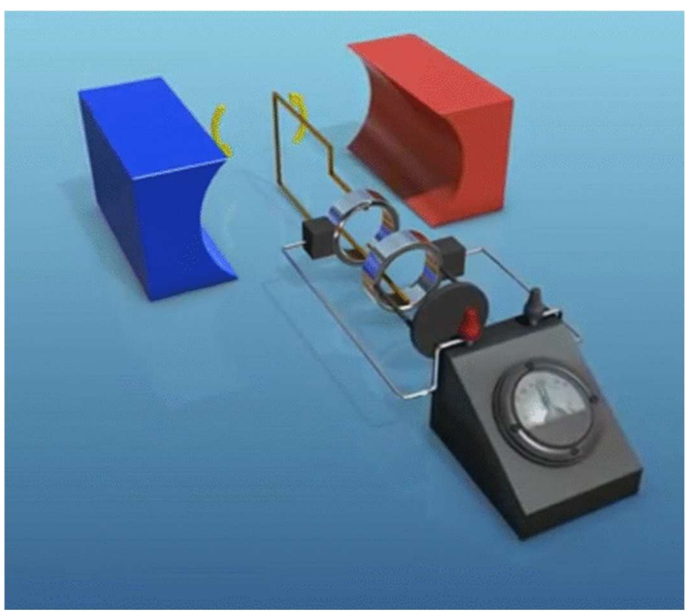

Fig 2 Work principle of DC generator (basic assumption).

Imagine the coil to be rotating in clock-wise direction (shown in Fig.3). As the coil assumes successive positions in the field, the flux linked with it changes. Hence, an e.m.f. is induced in it which is Cut-away view of DC generator proportional to the rate of change of flux linkages ($e = Nd\Phi/dt$). When the plane of the coil is at right angles to lines of flux *i.e.* when it is in position, 1, then flux linked with the coil is maximum but ***rate of change of flux linkages is minimum*.**

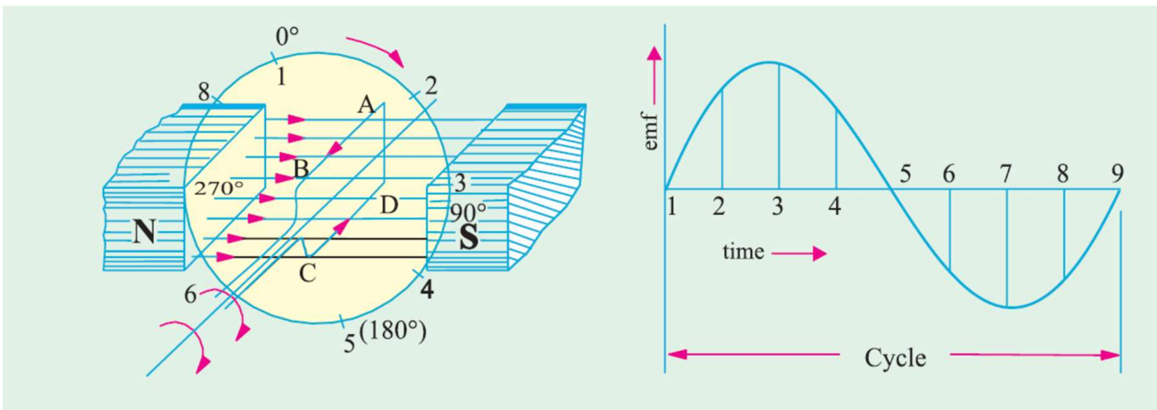

Fig 3 Generated voltage in slip ring generator.

It is so because in this position, the coil sides *AB* and *CD* do not cut or shear the flux; rather they slide along them *i.e.* they move parallel to them. Hence, there is no induced e.m.f. in the coil. Let us take this no-e.m.f. or vertical position of the coil as the starting position. The angle of rotation or time will be measured from this position.

As the coil continues rotating further, the rate of change of flux linkages (and hence induced e.m.f. in it) increases, till position 3 is reached where $\theta = 90^o$. Here, the coil plane is horizontal *i.e.* parallel to the lines of flux. As seen, the flux linked with the coil is minimum but ***rate of change of flux linkages is maximum***. Hence, maximum e.m.f. is induced in the coil when in this position.

In the next quarter revolution *i.e.* from 90º to 180º, the flux linked with the coil gradually ***increases*** but the rate of change of flux linkages ***decreases*****.** Hence, the induced e.m.f. decreases gradually till in position 5 of the coil, it is reduced to zero value.

So, we find that in the first half revolution of the coil, no (or minimum) e.m.f. is induced in it when in position 1, maximum when in position 3 and no e.m.f. when in position 5. The direction of this induced e.m.f. can be found by applying Fleming's Right-hand rule which gives its direction from *A* to *B* and *C* to *D*. Hence, the direction of current flow is ***ABMLCD***. The current through the load resistance *R* flows from *M* to *L* during the first half revolution of the coil.

In the next half revolution *i.e.* from 180º to 360º, the variations in the magnitude of e.m.f. are similar to those in the first half revolution. Its value is maximum when coil is in position 7 and minimum when in position 1. But it will be found that the direction of the induced current is from *D* to *C* and *B* to *A* as shown in. Hence, the path of current flow is along ***DCLMBA*** which is just the reverse of the previous direction of flow. Therefore, we find that the current which we obtain from such a simple generator reverses its direction after every half revolution. Such a current undergoing periodic reversals is known as alternating current. It is, obviously, different from a direct current which continuously flows in one and the same direction. It should be noted that alternating current not only reverses its direction, it does not even keep its magnitude constant while flowing in any one direction. The two half-cycles may be called positive and negative half-cycles respectively.

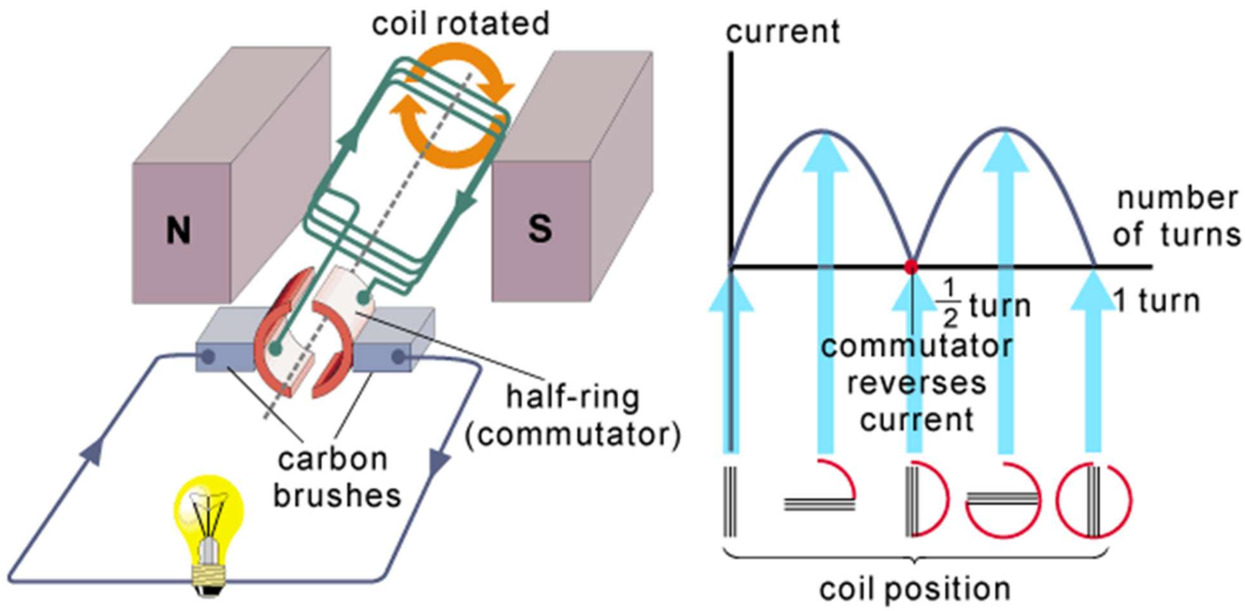

Fig 3. Half ring commutator.

For making the flow of current unidirectional in the ***external*** circuit, the slip-rings are replaced by split-rings. The split-rings are made out of a conducting cylinder which is cut into two halves or segments insulated from each other by a thin sheet of mica or some other insulating material. As before, the coil ends are joined to these segments on which rest the carbon or copper brushes.

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

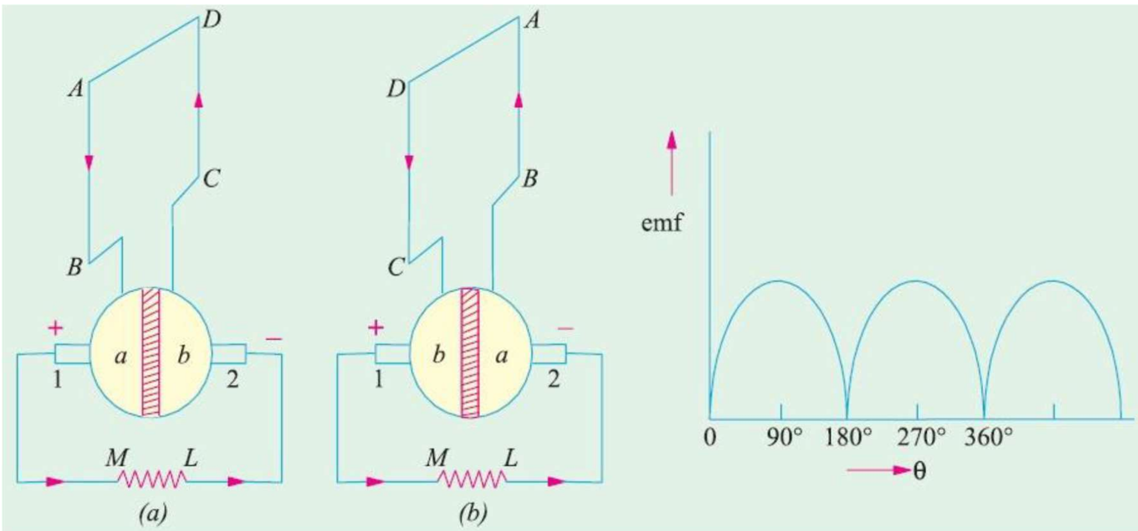

Fig. 4 E.M.F in DC generator with half ring.

It should be noted that the position of brushes is so arranged that the changeover of segments **‘*a*’** and **‘*b*’** from one brush to the other takes place when the plane of the rotating coil is at right angles to the plane of the lines of flux. It is so because in that position, the induced e.m.f. in the coil is zero.

Another important point worth remembering is that even now the current induced in the coil sides is alternating as before. It is only due to the rectifying action of the split-rings (also called commutator) that it becomes unidirectional in the external circuit. Hence, it should be clearly understood that even in the armature of a D.C. generator, the induced voltage is alternating.

Construction of a DC Generator

The simple loop generator has been considered in detail merely to bring out the basic principle underlying construction and working of an actual generator illustrated in Fig. 5 which consists of the following essential parts:

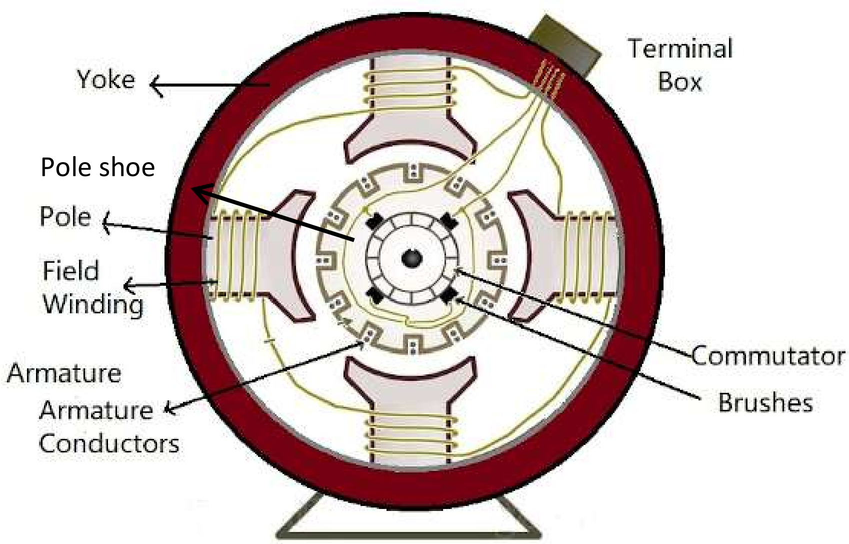

Fig 6. Design of DC machine.

1. Magnetic Frame or Yoke
2. Pole-Cores and Pole-Shoes
3. Pole Coils or Field Coils
4. Armature Core
5. Armature Windings or Conductors
6. Commutator
7. Brushes and Bearings

Of these, the yoke, the pole cores, the armature core and air gaps between the poles and the armature core or the magnetic circuit whereas the rest form the electrical circuit.

3.1 Yoke

The outer frame or yoke serves double purpose:

(*i*) It provides mechanical support for the poles and acts as a protecting cover for the whole machine.

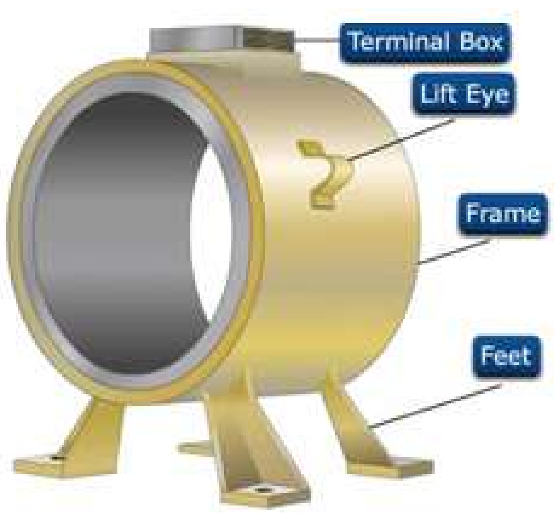

Fig 6. Yoke.

(*ii*) It carries the magnetic flux produced by the poles.

In small generators where cheapness rather than weight is the main consideration, yokes are made of cast iron. But for large machines usually cast steel or rolled steel is employed. The modern process of forming the yoke consists of rolling a steel slab round a cylindrical mandrel and then welding it at the bottom. The feet and the terminal box etc. are welded to the frame afterwards. Such yokes possess sufficient mechanical strength and have high permeability.

3.2 Pole Cores and Pole Shoes

The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes

(*i*) They spread out the flux in the air gap and also, being of larger cross-section, reduce the reluctance of the magnetic path

(*ii*) They support the exciting coils (or field coils).

There are two main types of pole construction: -

(*a*) The pole core itself may be a solid piece made out of either cast iron or cast steel but the pole shoe is laminated and is fastened to the pole face by means of counter sunk screws.

(*b*) In modern design, the complete pole cores and pole shoes are built of thin laminations of annealed steel which are riveted together under hydraulic pressure. The thickness of laminations varies from 1 mm to 0.25 mm. The laminated poles may be secured to the yoke in any of the following two ways:

- Either the pole is secured to the yoke by means of screws bolted through the yoke and into the pole body.
- The holding screws are bolted into a steel bar which passes through the pole across the plane of laminations.

3.3 Pole Coils

The field coils or pole coils, which consist of copper wire or strip, are former wound for the correct dimension. Then, the former is removed and wound coil is put into place over the core.

When current is passed through these coils, they electromagnetic the poles which produce the necessary flux that is cut by revolving armature conductors.

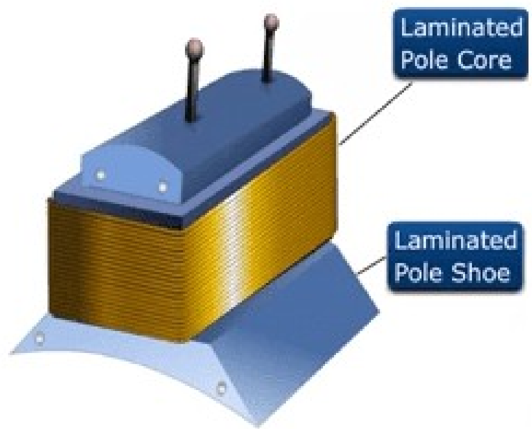

Fig 7. Pole Coil.

3.4 Armature Core

It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. In addition to this, its most important function is to provide a path of very low reluctance to the flux through the armature from a *N*-pole to a *S*-pole.

It is cylindrical or drum-shaped and is built up of usually circular sheet steel discs or laminations approximately 0.5 mm thick. It is keyed to the shaft.

The slots are either die-cut or punched on the outer periphery of the disc and the keyway is located on the inner diameter as shown. In small machines, the armature stampings are keyed directly to the shaft. Usually, these laminations are perforated for air ducts which permit axial flow of air through the armature for cooling purposes. Such ventilating channels are clearly visible in the laminations.

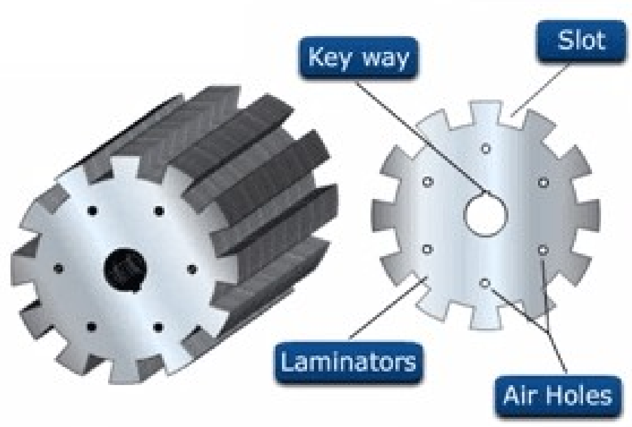

Fig 8. Armature core.

Up to armature diameters of about one meter, the circular stampings are cut out in one piece as shown in Fig above. But above this size, these circles, especially of such thin sections, are difficult to handle because they tend to distort and become wavy when assembled together. Hence, the circular laminations, instead of being cut out in one piece, are cut in a number of suitable sections or segments which form part of a complete ring.

A complete circular lamination is made up of four or six or even eight segmental laminations. Usually, two keyways are notched in each segment and are dovetailed or wedge-shaped to make the laminations self-locking in position.

The purpose of using laminations is to reduce the loss due to eddy currents. Thinner the laminations, greater is the resistance offered to the induced e.m.f., smaller the current and hence lesser the I_2 R loss in the core.

3.5 Armature Windings

The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape in a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots which are lined with tough insulating material. This slot insulation is folded over above the armature conductors placed in the slot and is secured in place by special hard wooden or fiber wedges.

The winding of the machine is classified into two types. They are closed type winding and Open type winding. The classification of winding is shown in the figure below.

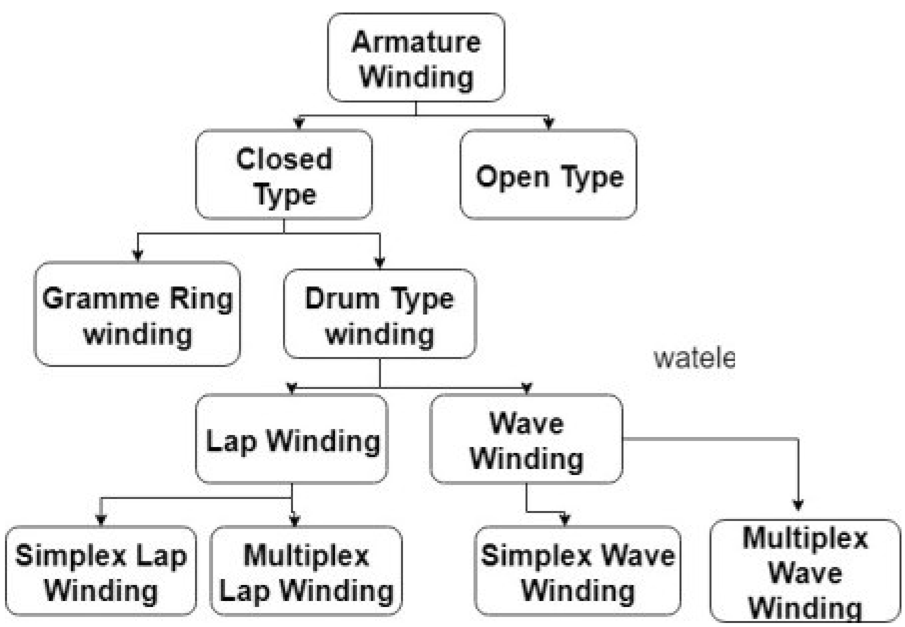

Fig 9. Classification of armature windings.

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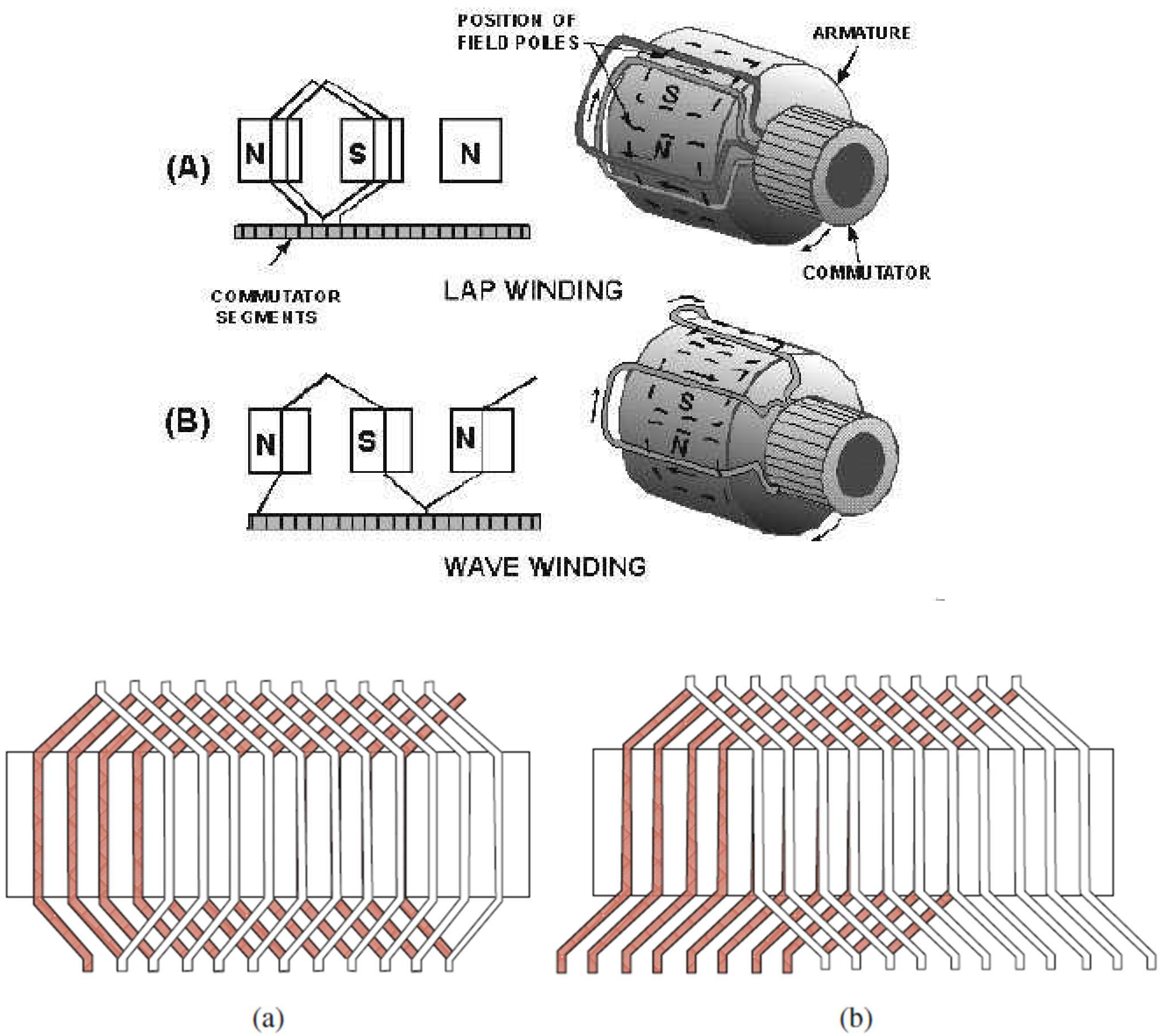

Fig 10. Lap vs Wave type.

3.6 Commutator

The function of the commutator is to facilitate collection of current from the armature conductors. As shown in fig 10, it rectified *i.e.* converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high-conductivity hard-drawn or drop forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils. Each commutator segment is connected to the armature conductor by means of a copper lug or strip (or riser). To prevent them from flying out under the action of centrifugal forces, the segments have *V*-grooves, these grooves being insulated by conical mica rings.

3.7 Carbon Brushes

These brushes are connected with the commutators and get current from the commutator and provides to the load. These are constructed with the carbon and their main function is to reduce the sparking at load and machine connection points.

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