It is seen that in the first half of the revolution current flows always along ABLMCD i.e. brush no 1 in contact with segment a. In the next half revolution, in the figure the direction of the induced current in the coil is reversed. But at the same time the position of the segments a and b are also reversed which results that brush no 1 comes in touch with the segment b. Hence, the current in the load resistance again flows from L to M. The wave from of the current through the load circuit is as shown in the figure. This current is unidirectional.

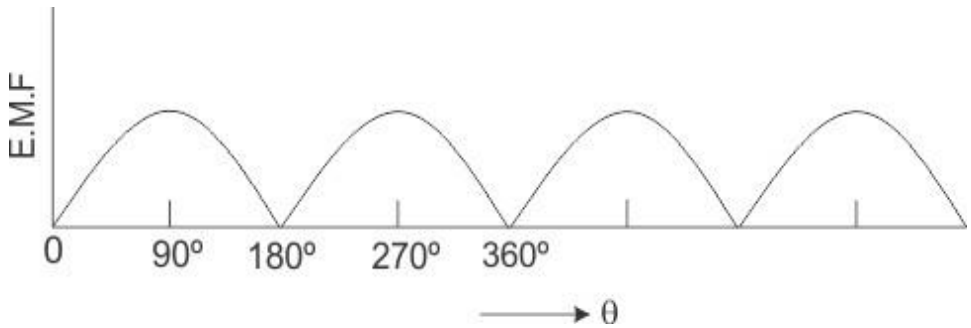


Fig: Output waveform of generator

This is basic working principle of DC generator, explained by single loop generator model. The position of the brushes of DC generator is so arranged that the change over of the segments a and b from one brush to other takes place when the plane of rotating coil is at right angle to the plane of the lines of force. It is so become in that position, the induced emf in the coil is zero.

Construction of a DC Machine:

A DC generator can be used as a DC motor without any constructional changes and vice versa is also possible. Thus, a DC generator or a DC motor can be broadly termed as a DC machine. These basic constructional details are also valid for the construction of a DC motor. Hence, let's call this point as construction of a DC machine instead of just 'construction of a DC generator.

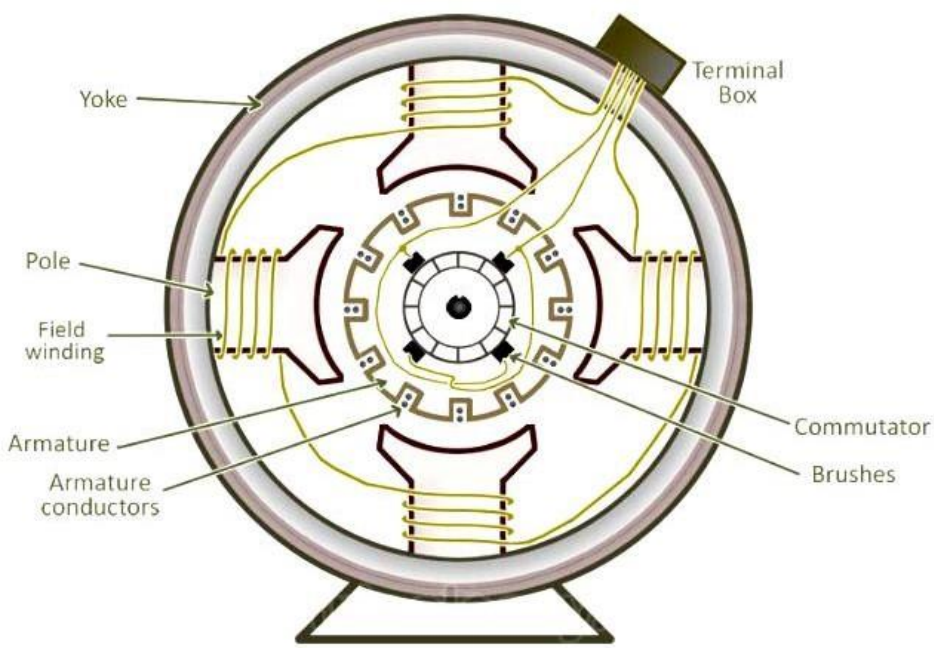


Figure 1: constructional details of a simple 4-pole DC machine

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

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

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

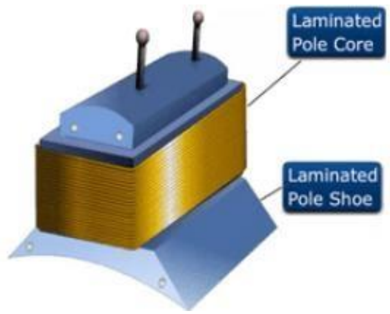


Figure 2: Pole Core and Poles Shoes representation

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

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

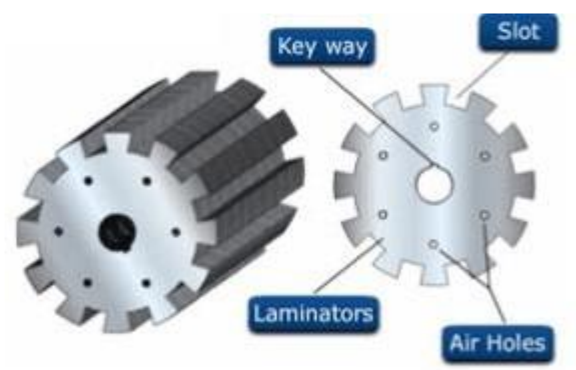


Figure 3: Armature of DC machine

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

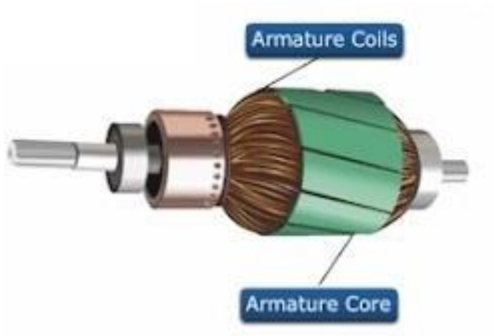


Figure 4: Armature Winding/coil of DC machine

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

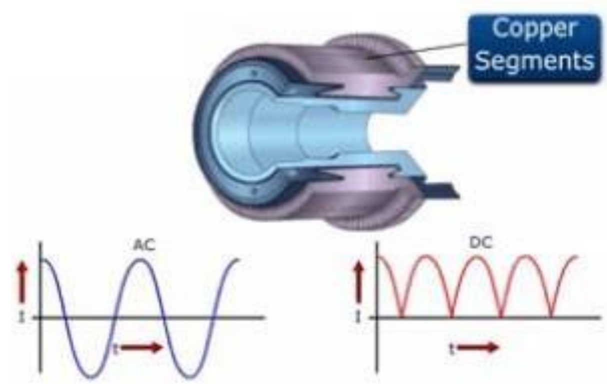


Figure 5: Commutator of DC machine

Armature Winding Terminology:

Now we are going to discuss about armature winding in details. Before going through this section, we should understand some basic terms related to armature winding of DC generator.

Pole Pitch:

The pole pitch is defined as peripheral distance between centers of two adjacent poles in DC machine. This distance is measured in term of armature slots or armature conductor come between two adjacent pole centers. Pole Pitch is naturally equal to the total number of armature slots divided by the number of poles in the machine.

If there are 96 slots on the armature periphery and 4 numbers of poles in the machine, the numbers of armature slots come between two adjacent poles centres would be 96/4 = 24. Hence, the pole pitch of that DC machine would be 24.

As we have seen that, pole pitch is equal to total numbers of armature slots divided by total numbers of poles, we alternatively refer it as armature slots per pole.

Coil side:

Coil of dc machine is made up of one turn or multi turns of the conductor. If the coil is made up of single turn or a single loop of conductor, it is called single turn coil. If the coil is made up of more than one turn of a conductor, we refer it as a multi-turn coil. A single turn coil will have one conductor per side of the coil whereas, in multi turns coil, there will be multiple conductors per side of the coil. Whatever may be the number of conductors per side of the coil, each coil side is placed inside one armature slot only. That means all conductors of one side of a particular coil must be placed in one single slot only. Similarly, we place all conductors of opposite side of the coil in another single armature slot.

Coil Span

Coil span is defined as the peripheral distance between two sides of a coil, measured in term of the number of armature slots between them. That means, after placing one side of the coil in a particular slot, after how many conjugative slots, the other side of the same coil is placed on the armature. This number is known as coil span.

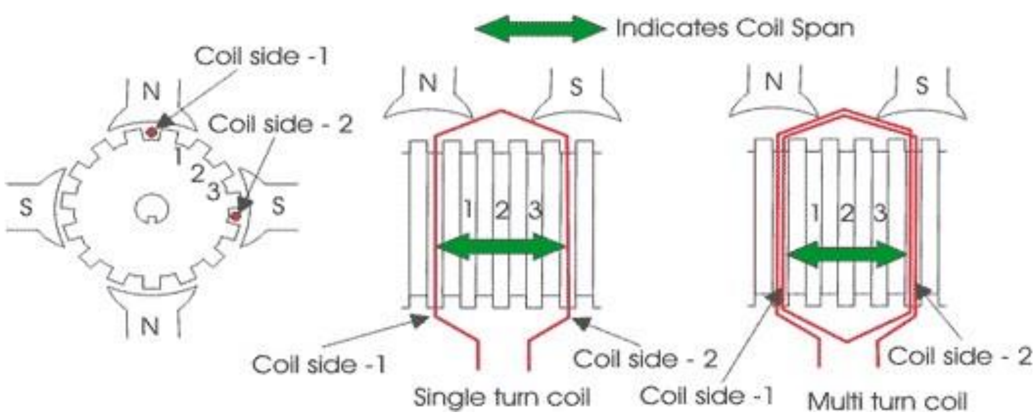


Figure: Armature windings

If the coil span is equal to the pole pitch, then the armature winding is said to be full - pitched. In this situation, two opposite sides of the coil lie under two opposite poles. Hence emf induced in one side of the coil will be in 180° phase shift with emf induced in the other side of the coil. Thus, the total terminal voltage of the coil will be nothing but the direct arithmetic sum of these two emfs. If the coil span is less than the pole pitch, then the winding is referred as fractional pitched. In this coil, there will be a phase difference between induced emf in two sides, less than 180o. Hence resultant terminal voltage of the coil is vector sum of these two emf's and it is less than that of full-pitched coil.

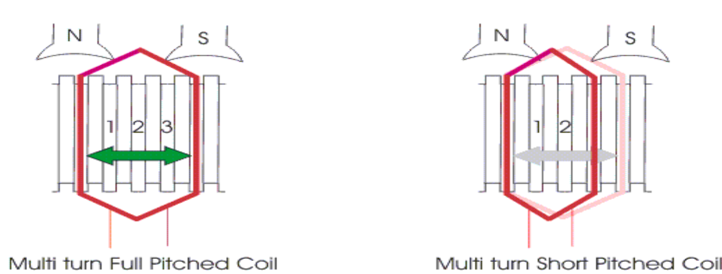
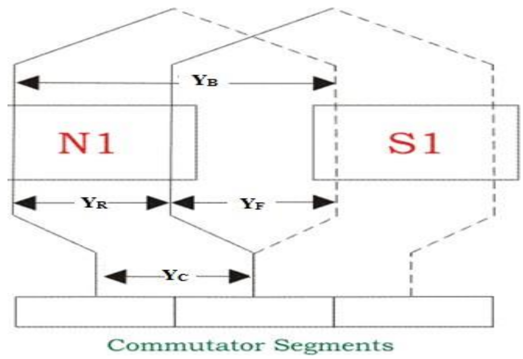


Figure: full pitched and half pitched coils

In practice, coil pitch (or Span) as low as eight tenth of a Pole Pitch, is employed without much serious reduction in emf. Fractional pitched windings are purposely used to effect substantial saving in copper of the end connection and for improving commutation.

Pitch of Armature Winding



Back Pitch (Y_B)

A coil advances on the back of the armature. This advancement is measured in terms of armature conductors and is called back pitch. It is equal to the number difference of the conductor connected to a given segment of the commutator.

Front Pitch (Y_F)

The number of armature conductors or elements spanned by a coil on the front is called front pitch. Alternatively, we define the front-pitch as the distance between the second conductor of the next coil which connects the front, i.e., commutator end of the armature. In other words, it is the number difference of the conductors connected together at the back end of the armature. We are showing both front and back pitches for a lap, and a wave windings in the figure below.

Resultant Pitch (Y_R)

It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected. As a matter of precautions, we should keep in mind that all these pitches, though normally stated concerning armature conductors, are also times of armature slots or commutator bars.

Commutator Pitch (Y_C)

Commutator pitch is defined as the distance between two commutator segments which two ends of same armature coil are connected. We measure commutator pitch in term of commutator bars or segment.

Single Layer Armature Winding

We place armature coil sides in the armature slots differently. In some arrangement, each one side of an armature coil occupies a single slot. In other words, we place one coil side in each armature slot. We refer this arrangement as single layer winding.

Two Layer Armature Winding

In other types of armature winding, arrangement two coil sides occupy every armature slot; one occupies upper half, and another one occupies the lower half of the slot. We so place the coils in two layers winding that if one side occupies upper half, then another side occupies the lower half of some other slot at a distance of one coil pitch away.

<u>Armature Winding of A DC Machine</u>

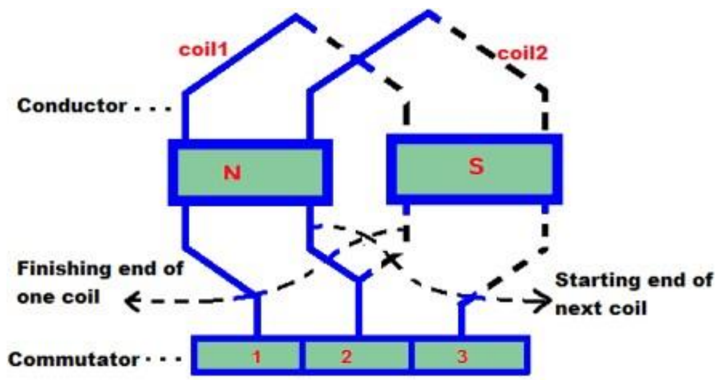
Based on type of winding connections we classified armature winding of a dc machine into two types. These winding connections are same for DC generator & DC motor.

Types of Windings in DC Machine,

1. Lap winding.
2. Wave winding.

Lap winding of a DC Machine

In this type of winding the completing end of one coil is connected to a commutator segment and to the start end of adjacent coil located under the same pole and similarly all coils are connected. This type of winding is known as lap because the sides of successive coils overlap each other.



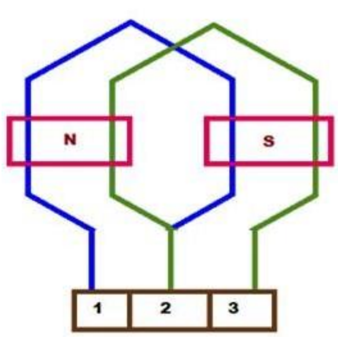
LAP winding

Lap winding may be simplex (single) or multiplex (duplex or triplex) winding. In simplex lap winding the connection of the winding is that there are as many parallel paths as there are number of poles.

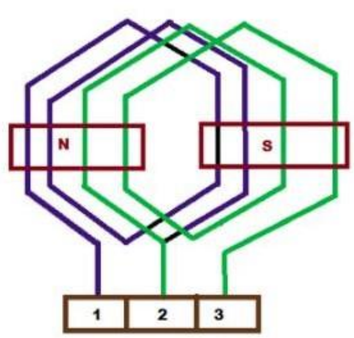
Whereas for duplex, the number of parallel paths are equal to twice that of the number of poles and for triplex it is thrice. For this reason, the lap winding is called multiple or parallel winding. The sole purposes of such type of windings are,

(a) To increase the number of parallel paths enabling the armature current to increase i.e., for high current output.

(b) To improve commutation as the current per conductor decreases.



Simplex lap winding



Duplex lap winding

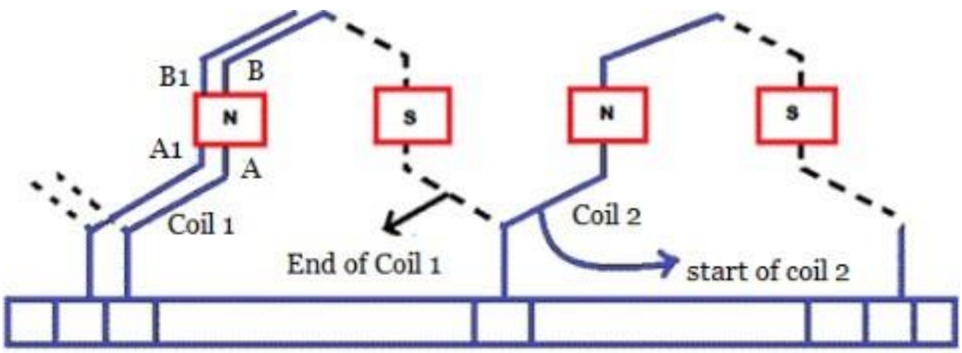
Notes on Lap winding

1. The coil or back pitch Y_B must be approximately equal to pole pitch i.e., $Y_B = Z/P$.

2. The back pitch and front pitch are odd and are of opposite sign. They differ from each other by 2m, where m = 1,2,3 for simplex, duplex, and triplex respectively.
   i.e., $Y_B = Y_F \pm 2m$
   When $Y_B > Y_F$ i.e., $Y_F + 2m$ then the winding progresses from left to right and such a winding is known as progressive winding. If $Y_B < Y_F$ i.e., $Y_B = Y_F - 2m$ then the winding progresses from right to left and such a winding is known as retrogressive winding.
3. The average pitch, $Y_{AVE}=(Y_B + Y_F)/2$.
4. Resultant pitch, Y_R is always even as difference between two odd numbers is even and is equal to 2m.
5. Commutator pitch, Y_C = m i.e., , 2, 3, 4 etc. for simplex, duplex, triplex, quadruplex etc.
6. Number of parallel paths = mP. Where, m = multiplicity.
   Example: For instance, the number of parallel paths for a 6-pole duplex lap winding is given by 6 x 2 = 12 paths.
7. The total number of poles are equal to the total number of brushes.
8. If Ia is the total armature current, then current per parallel path is Ia /P.
9. Lap winding is used for low voltage and high current machines.

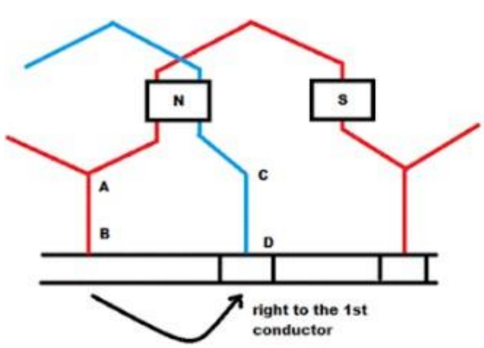
Wave winding of a DC Machine

In wave winding the coils which are carrying current in one direction are connected in series circuit and the carrying current in opposite direction are connected in another series circuit. A wave winding is shown in figure.

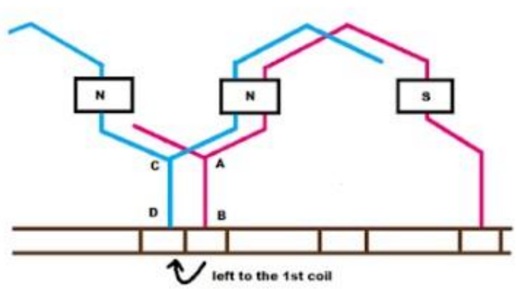


Wave Winding

If after passing once around the armature the winding falls in a slot to the left of its starting point then winding is said to be retrogressive. If it fails one slot to the right it is progressive.



Progressive Wave winding



Retrogressive wave winding

Notes on Wave winding

The following are the important points to be remembered pertaining to wave winding,

1. Both pitches Y_B and Y_F are odd and of same sign.
2. Back and front pitches may be equal or differ by 2 and are merely equal to pole pitch.
3. Resultant pitch, $Y_R = Y_F + Y_B = (Z \pm 2)/2$

P = Number of poles

Z = Total number of conductors.

4. Commutator pitch, $Y_C = Y_A$ (Average pitch)

Y_C =(Number of commutator bars ± 1)/(Number of pair of poles).

5. Number of parallel paths are equal to 2m,where m is the multiplicity.
6. The number of brushes required are two irrespective of the number of poles.
7. If Ia is the total armature current then current carried by each path or conductor is Ia/2.
8. Since a wave winding is a series winding, it is used for high voltage and low current machine.

Emf Equation of a DC Generator

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called the Generated emf or Armature emf and is denoted as Er = Eg. In the case of a motor, the emf of rotation is known as Back emf or Counter emf and represented as Er = Eb. The expression for emf is same for both the operations. I.e., for Generator as well as for Motor

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

Let,

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

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

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

Time taken to complete one revolution is given as

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

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

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

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