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وزارة التعليم العالي والبحث العلمي
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قسم هندسة تقنيات القدرة الكهربائية

# DC Machine

# مكائن التيار المستمر

المرحلة الثانية

المحاضرة (2)

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# I. Introduction

**Generator:** An electro-mechanical device (electrical machine) which convert mechanical energy or power (ω T) into electrical energy or power (EI) is called generator.

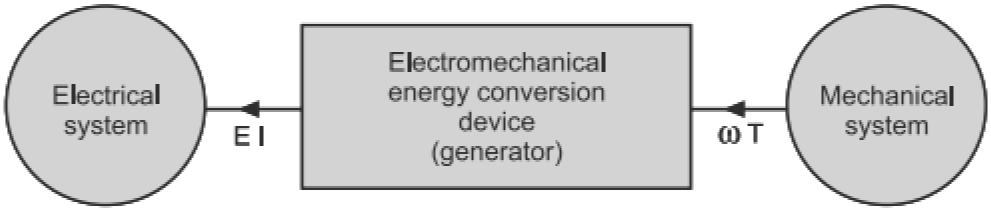


**Figure 1.** Generator

Generators are used in hydro-electric power plants, steam power plants, diesel power plants, nuclear power plants and in automobiles. In the above said power plants various natural sources of energy are first converted into mechanical energy and then it is converted into electrical energy with the help of generators. The block diagram of energy conversion, when the electro-mechanical device works as a generator, is shown in **Fig. 1**.

**Working Principle**

The basic principle of a DC generator is electro-magnetic induction i.e.,
*"When a conductor cuts across the magnetic field, an emf is induced in it."*
Consider **Fig. 2(a)**, here, when a conductor is moved vertically upward or downward, the deflection in the galvanometer clearly shows that an emf is induced in the conductor since flux is cut by the conductor. But, when it is moved horizontally (left or right), there is no deflection in the galvanometer which shows that no emf is induced in the conductor since flux cut is zero and conductor moves just parallel to the magnetic lines of force. In fact, in a generator, a coil is rotated at a constant speed of Z radians per second in a strong magnetic field of constant magnitude as shown in **Fig. 2(b)**. An emf is induced in the coil by the phenomenon of *dynamically induced emf* ($e = Blv\sin\theta$ ; $e\ Direct\ proportion\ with\ \sin\theta$ ). The magnitude and direction of induced emf changes periodically depending upon sine of angle $\theta$. The wave shape of the induced emf is shown in **Fig. 2(c)**, which is AC for internal as well as external load. This AC is converted into DC with the help of commutator, as explained in the sections to follow.

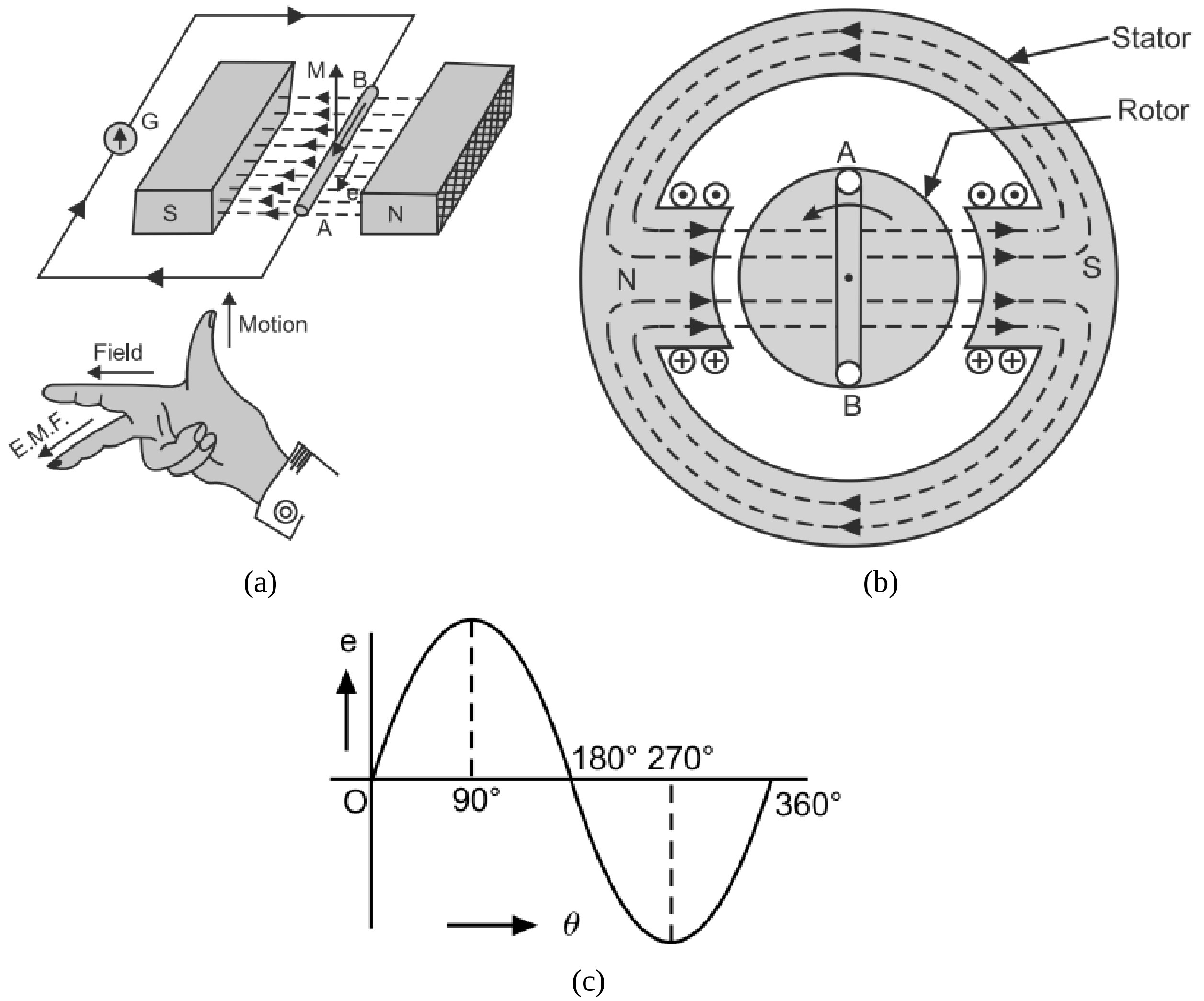


**Figure 2.** Generation of emf (a) Linear motion of conductor in a uniform magnetic field (b) Coil rotating in a uniform magnetic field (c) Wave shape of induced emf.

## 1.1 Main Constructional Features

The complete assembly of various parts in a scattered form of a DC machine is shown in **Fig. 3**.

| | | | |
|---|---|---|---|
| i. Magnetic Frame or Yoke | ii. Pole Core and Pole Shoes | iii. Field or Exciting Coils | iv. Armature Core |
| v. Armature Windings or Conductors | vi. Commutator | vii. Brushes and Bearings | |

A DC machine has a **magnetic circuit** and an **electric circuit,** the magnetic circuit provides the needed magnetic flux and consists of:

i. Magnetic Frame or Yoke

ii. Pole Core

iii. Armature Core

iv. The air gaps between the pole and the armature

The electric circuit consists of:

i. Armature Winding

ii. Field or Exciting Coils

iii. Commutator

iv. Brushes

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**DC Machine**

- Stator
  - Yoke
  - Pole
  - Field Windings
- Rotor
  - Armature
  - Commutator

The essential parts of a DC machine are described below:

1. **Magnetic Frame or Yoke:** The outer cylindrical frame to which main poles and inter poles are fixed is called yoke. It also helps to fix the machine on the foundation. It serves two purposes:
   - It provides mechanical protection to the inner parts of the machine.
   - It provides a low reluctance path for the magnetic flux.

   The yoke is made of cast iron for smaller machines and for larger machines, it is made of cast steel or fabricated rolled steel since these materials have better magnetic properties as compared to cast iron.

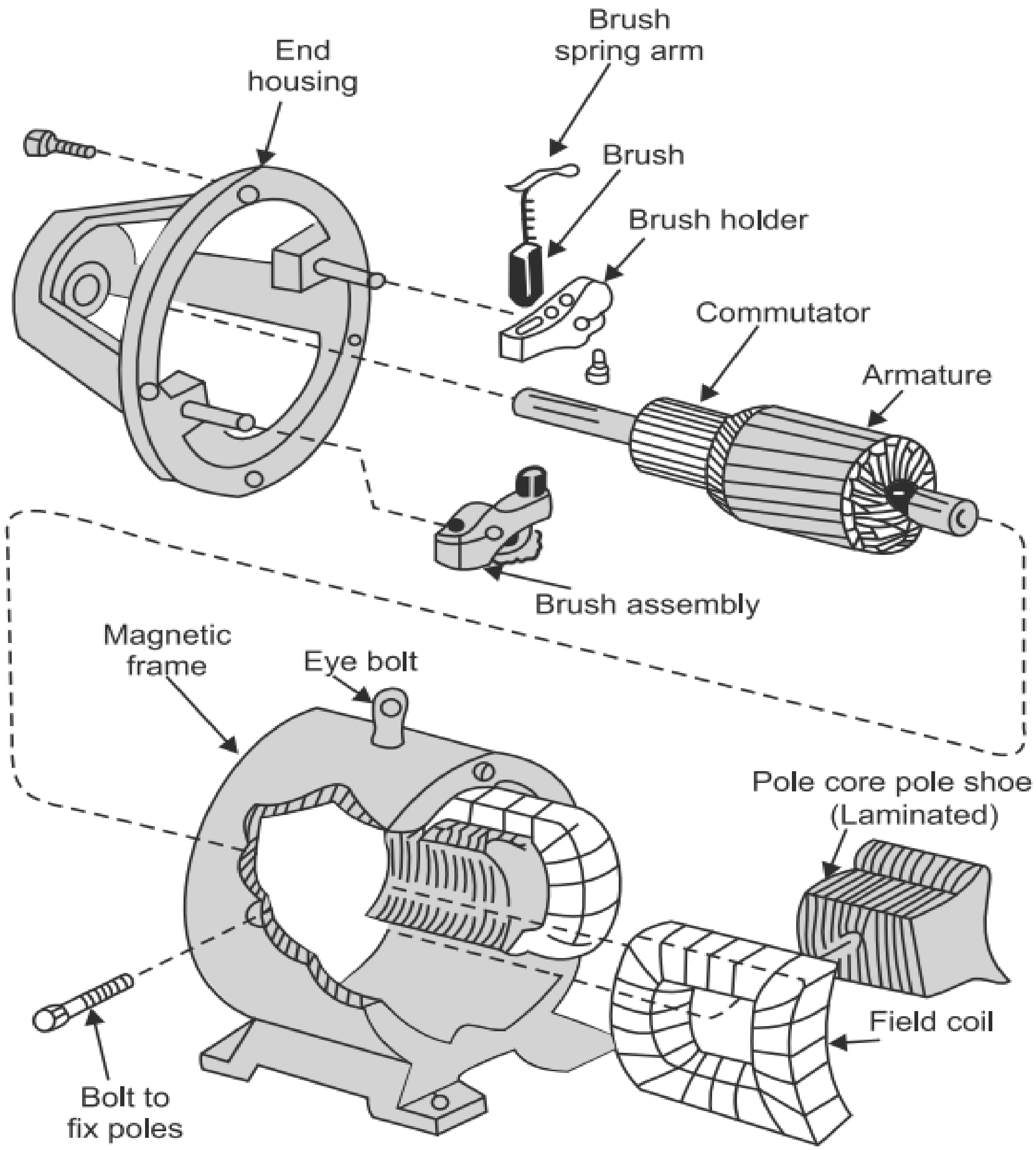


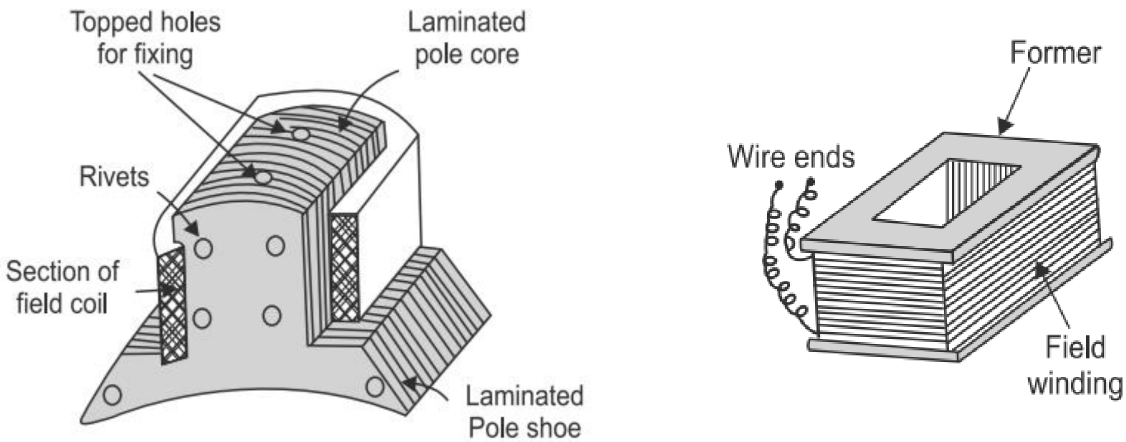

**Figure 3.** DC Machine Parts.

2. **Pole Core and Pole Shoes:** The pole core and pole shoes are fixed to the magnetic frame or yoke by bolts. They serve the following purposes:

- They support the field or exciting coils.
- They spread out the magnetic flux over the armature periphery more uniformly.
- Since pole shoes have larger cross-section, the reluctance of magnetic path is reduced.

Usually, the pole core and pole shoes are made of thin cast steel or wrought iron laminations which are riveted together under hydraulic pressure as shown in **Fig. 4(a)**.

3. **Field or Exciting Coils:** Enamelled copper wire is used for the construction of field or exciting coils. The coils are wound on the former [see **Fig. 4(b)**] and then placed around the pole core as shown in **Fig. 4(a)**. When direct current is passed through the field winding, it magnetizes the poles which produce the required flux. The field coils of all the poles are connected in series in such a way that when current flows through them, the adjacent poles attain opposite polarity as shown in **Fig. 5**.




(a) (b)

**Figure 4.** Pole core, pole shoe and field winding (a) Field winding placed around pole core (b) Field winding.

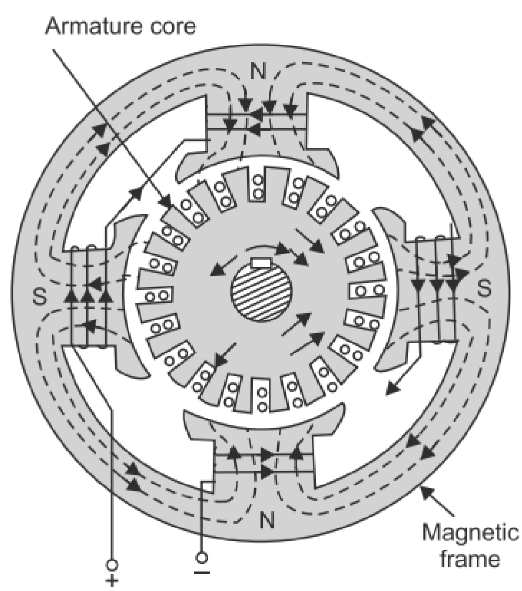



**Figure 5.** Magnetic circuit of DC machine.

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4. **Armature Core:** It is cylindrical is shape and keyed to the rotating shaft. At the outer periphery slots are cut, as shown in **Fig. 6**, which accommodate the armature winding. The armature core shown in **Fig. 6**, serves the following purposes:

- It houses the conductors in the slots.
- It provides an easy path for magnetic flux.

Since armature is a rotating part of the machine, reversal of flux takes place in the core, hence hysteresis losses are produced. To minimize these losses silicon steel material is used for its construction. When it rotates, it cuts the magnetic field and an emf is induced in it. This emf circulates eddy currents which results in eddy current loss in it. To reduce these losses, **armature core is laminated**, in other words we can say that about 0.3 to 0.5 mm thick stampings are used for its construction. Each lamination or stamping is insulated from the other by varnish layer. In small machines, the armature stampings are keyed directly to the shaft. Usually, these laminations are perforated for air ducts which permits axial flow of air through the armature for cooling purposes. Such ventilating channels are clearly visible in the laminations shown in **Fig. 7(a)**. 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 dove-tailed or wedge-shaped to make the laminations self-locking imposition. Up to armature diameters of about one meter, the circular stampings are cut out in one piece as shown in **Fig. 7(a)**. 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 **Fig. 7(b)**.

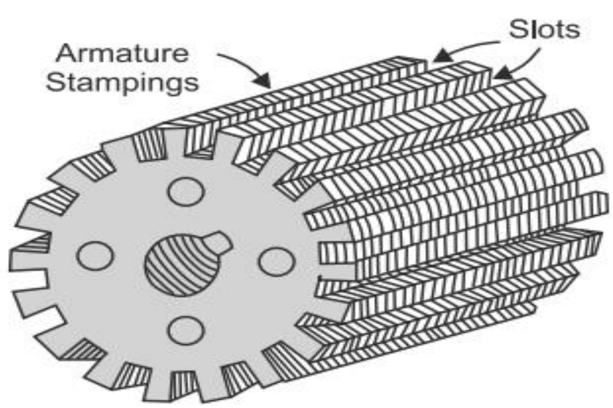
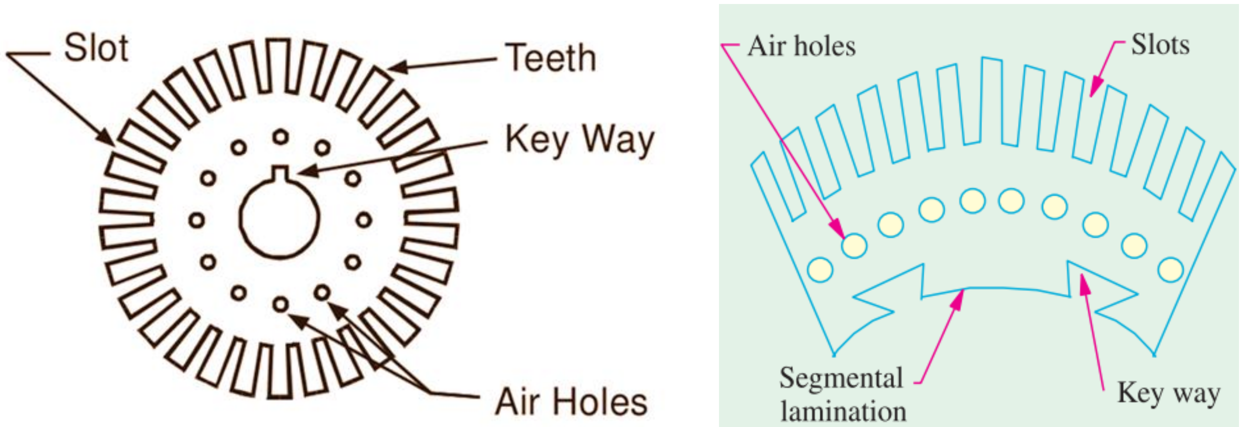



**Figure 6.** Armature core.




(a) (b)

**Figure 7.** Armature core (a) Single circular lamination (b) segment.

5. **Armature Winding:** The insulated conductors housed in the armature slots are suitably connected. The armature winding acts as the heart of a DC machine. It is a place where one form of power is converted to the other form i.e., in case of generator, mechanical power is converted into electrical power and in case of motor, electrical power is converted into mechanical power. On the basis of connections, there are two types of armature windings named (i) Lap winding and (ii) Wave winding (detailed discussions in the coming sections).
6. **Commutator:** It is an important part of a DC machine and serves the following purposes:

- It connects the rotating armature conductors to the stationary external circuit through brushes.
- It converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit in generator action, whereas, it converts the alternating torque into unidirectional (continuous) torque produced in the armature in motor action.

The commutator is of cylindrical shape and is made up of wedge-shaped hard drawn copper segments. The segments are insulated from each other by a thin sheet of mica. The segments are held together by means of two V-shaped rings that fit into the V-grooves cut into the segments. Each armature coil is connected to the commutator segment through riser. The sectional view of the commutator assembly is shown in **Fig. 8**.

$$\text{No. of segments} = \text{No. of armature coils}$$

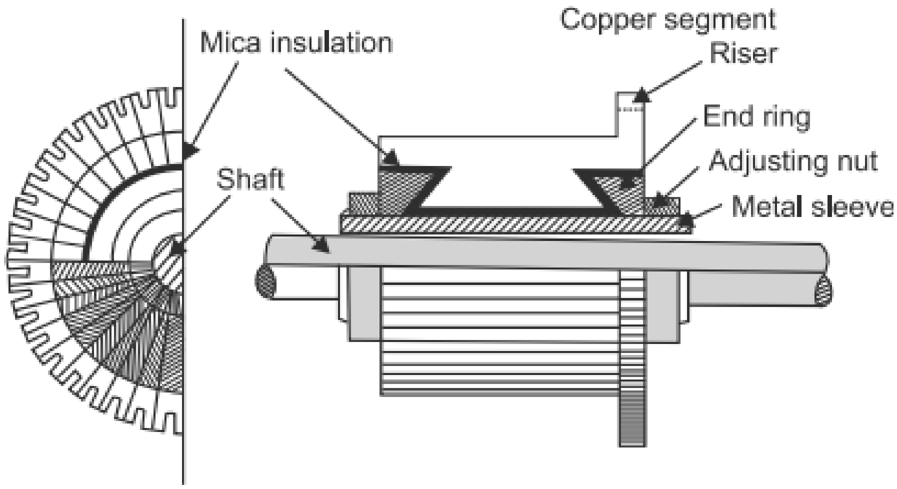
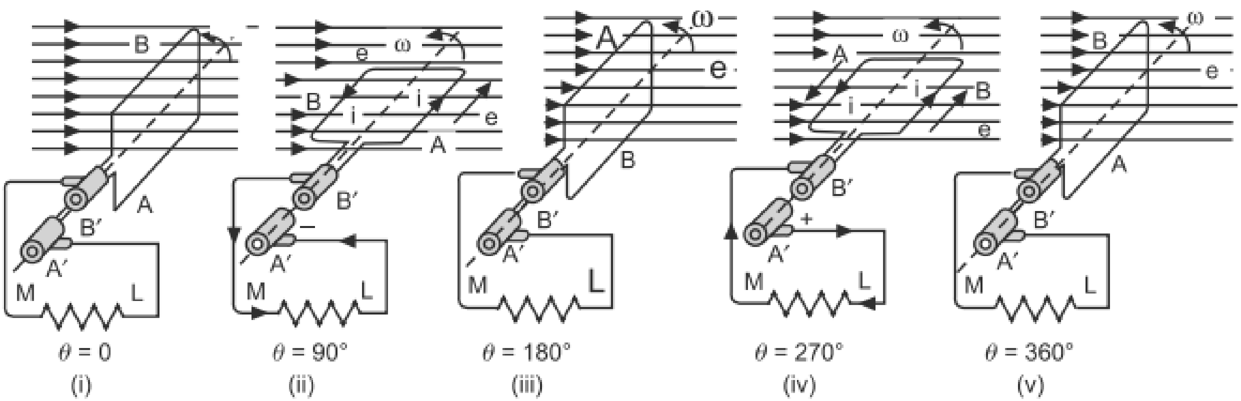



**Figure 8.** Commutator.

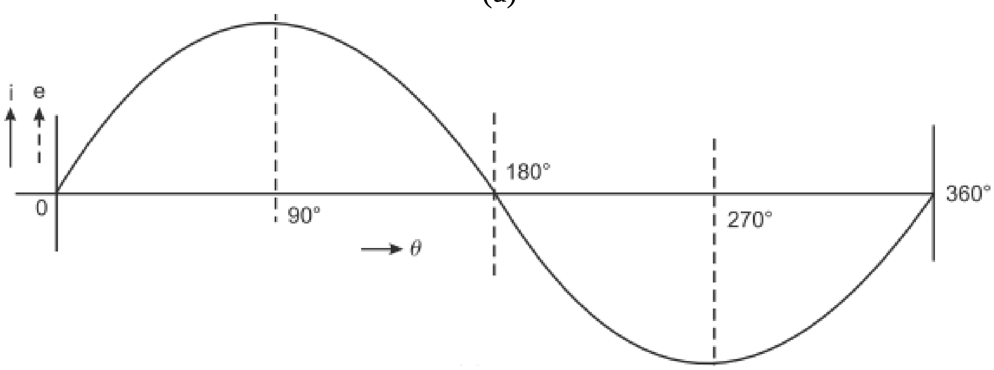
7. **Brushes:** The brushes whose function is to collect current from commutator. The brushes are rectangular in shape and are made of carbon or graphite. Brushes at equal potential are connected by internal wires. The current is led to or from the brushes by flexible wires. The brushes are held in contact with the commutator by means of brush holders and springs, whose tension may be adjusted. Usually the brush holders are of the box type and it is always mounted on an insulating material and attached to the stator frame. The brush holder is located such that the brush always contacts a commutator segment connected to a coil in which no voltage is induced.
8. **Bearings:** The bearings may be ball or roller bearings these are fitted in the end housings. Their function is to reduce friction between the rotating and stationary parts of the machine. Mostly high carbon steel is used for the construction of bearings as it is very hard material.
9. **Air Gap:** It is the space between the pole face and the armature core. It should be big enough to allow safe mechanical rotation and small enough to minimize the reluctance of the magnetic circuit.

## 1.2 Simple Loop Generator and Function of Commutator

For simplicity, consider only one coil AB placed in the strong magnetic field. The two ends of the coil are joined to slip rings A' and B' respectively. Two brushes rest on these slip rings as shown in **Fig. 9**. When this coil is rotated in counter clockwise direction at an angular velocity of ω radius per second, the magnetic flux is cut by the coil and an emf is induced in it. The position of the coil at various instants is shown in **Fig. 9(a)** and the corresponding value of the induced emf and its direction is shown in **Fig. 9(b)**. The induced emf is alternating and the current flowing through the external resistance is also alternating i.e., at second instant current flows in external resistance from *M* to *L*, whereas, at fourth instant it flows from *L* to *M* as shown in **Fig. 9(b)**.




(a)



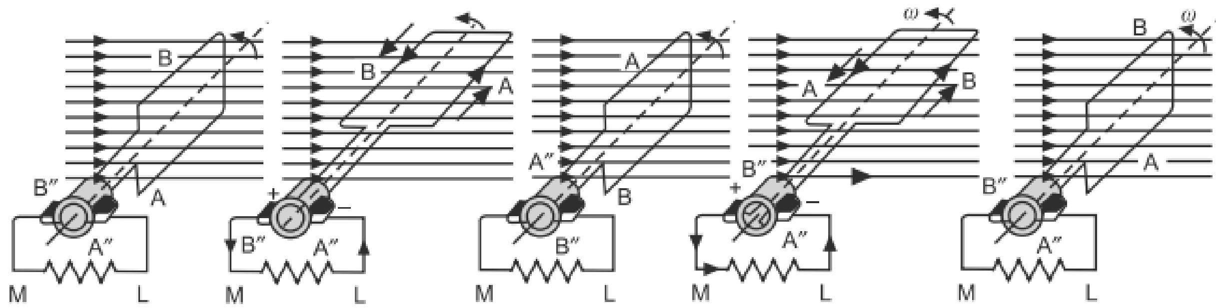

(b)

**Figure 9.** Generated emf for external circuit connected through slip rings (a) Load connected through slip-rings (b) Wave diagram.

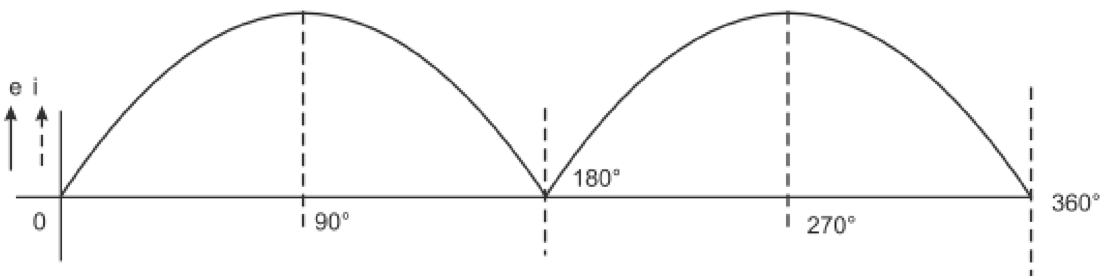
**Commutator Action:** Now, consider that the two ends of the coil are connected to only one slip ring split into two parts (segment) i.e., A'' and B''. Each part is insulated from the other by a mica layer. Two brushes rest on these parts of the ring as shown in **Fig. 10(a)**.

In this case when the coil is rotated is counter clockwise direction at an angular velocity of ω radians per second, the magnetic flux is cut by the coil and an emf is induced in it. The magnitude of emf induced in the coil at various instants will remain the same as shown in **Fig. 9(b)**.

However, the flow of current in the external resistor or circuit will become unidirectional i.e., at second instant the flow of current in the external resistor is from M to L as well as the flow of current in the external resistor is from M to L in the fourth instant, as shown in **Fig. 10(a)**. Its wave shape is shown in **Fig. 10(b)**.




(a)




(b)

**Figure 10.** Generated emf for external circuit connected through split ring (a) Generated emf for external circuit connected through slip rings (b) Wave diagram.

Hence, *an alternating current is converted into unidirectional current in the external circuit with the help of a* **split ring** (i.e., **commutator**)

In an actual machine, there are number of coils connected to the number of segments of the ring called commutator. The emf or current delivered by these coils to the external load is shown in Fig. 4.10(a). The actual flow of current flowing in the external load is shown by the firm line which fluctuates slightly. The number of coils placed on the armature is even much more than this and a pure direct current is obtained at the output as shown in Fig. 4.10(b).

Thus, *in actual machine working as a generator, the function of commutator is to convert the* **alternating current** *produced in the armature into* **direct current** *in the external circuit*.

## 1.3 Armature Winding

The different terms related to armature windings are conductor, turn, coil, coil side, overhang coil span etc. These terms are briefly described below.

1. **Pole pitch:** It is the distance between the centers of two adjacent poles and is equivalent to $180_{ed}$ and is measured in terms of number of slots i.e.

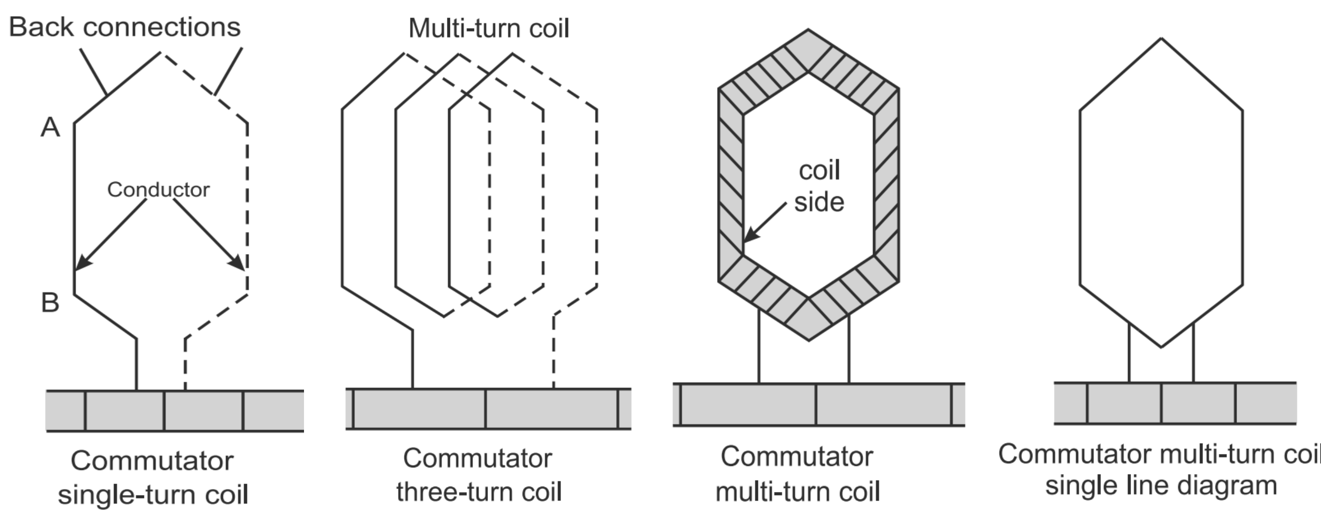
$$\text{Pole Pitch} = \frac{\text{No. of slots}}{\text{No. of poles}}$$

One pole pitch = $180_{ed} = 360_{md}$ /p

2. **Conductor:** The length of wire embedded in armature core and lying within the magnetic field is called the conductor (see **Fig. 11(a)**, where AB is a conductor). It may be having one or more parallel strands. Total number of conductors in the armature winding are represented by the symbol *Z*.

$$\text{No. of conductor} = 2 \times \text{No. of turn}$$

3. **Turn:** Two conductors lying in a magnetic field connected in series at the back, as shown in **Fig. 11(a)**, so that emf induced in them is additive is known as a turn.
4. **Coil:** A coil may be a single turn coil having only two conductors, as shown in **Fig. 11(a)**, or it may be a multi-turn coil having more than two conductors as shown in **Fig. 11(b)**. In **Fig. 11(b)**, a three-turn coil is shown. The bunch of three conductors may be wrapped by the cotton tape, as shown in **Fig. 11(c)**, before placing in the slot of armature. A multi-turn coil can be represented by single line diagram as shown in **Fig. 11(d)**. Multi-turn coils are used to develop higher voltages. When the armature conductors are more, it is not feasible to use single turn coils because it will require large number of commutator segments and if used it will not give spark-less commutation. Moreover, it will not be economical due to use of more copper in the end connections. The total number of coils in the armature winding are represented by symbol 'C'.




(a) (b) (c) (d)

**Figure 11.** Representation of a coil.

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5. **Coil side:** Each coil (single turn or multi-turn) has two sides called coil sides. Both the coil sides are embedded in two different slots as per the winding design (nearly a pole pitch apart).
6. **Winding:** When number of coil groups are arranged on the armature in a particular fashion as per the design, it is called an armature winding.
7. **Over Hang:** The winding length required to connect the two conductors at the end of machine is known as overhang of the winding.
8. **Coil Span or coil pitch ($Y_s$):** The peripheral distance between two slots in which the two sides of a coil are placed is called coil span. It is generally expressed in terms of number of slots or conductors. Thus, if the coil span is 9 slots, it means one side of the coil is in slot 1 and the other side in slot 10.
9. **Full Pitch Coil:** When the two coil sides of a coil are placed in the slots over the periphery of armature exactly a pole pitch apart then the coil is called full pitch coil. In full pitch coil, the coil span is equal to the pole pitch of the machine. It means that coil span is 180 electrical degrees. In this case, the coil sides lie under opposite poles, hence the induced e.m.f in them are additive.

   For instance, consider Fig. 4.19. where pole pitch is said 4. One side of coil-A is placed is slot No. 1 and the other side is placed in slot No. 5, then the coil span is 5-1 = 4 which is equal to pole pitch hence coil-A is called a full-pitched coil. Whereas, in case of coil-B, the coil span is 6–3 = 3 which is less than pole pitch, this coil is called a short-pitched coil.

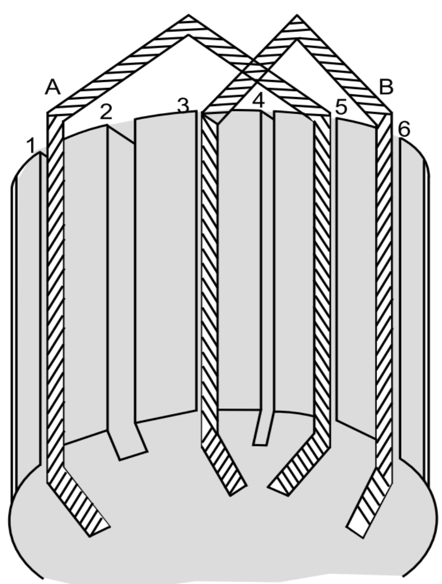
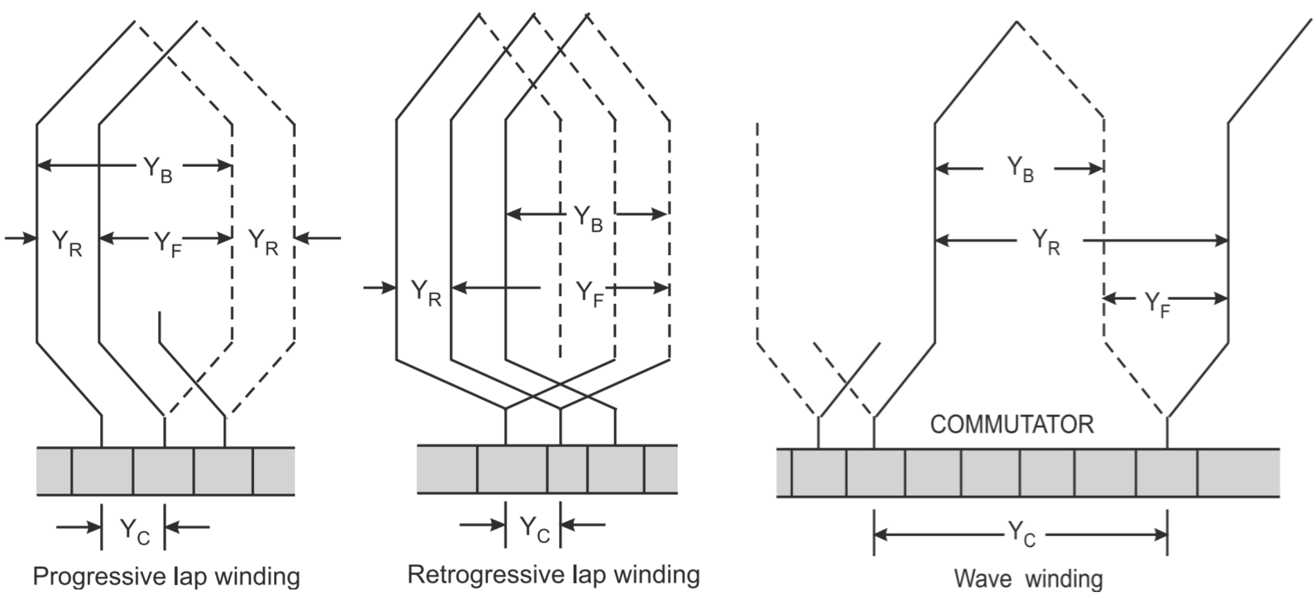



**Figure 12.** Full Pitch Coil.

10. **Front-end and Back-end connectors:** A wire that is used to connect end of a coil at the front to the commutator segment is called a front-end connector. Whereas, a wire that is used to connect one coil side to the other coil side at the back is called back-end connector.
11. **Back pitch:** The distance in terms of number of armature conductors between first and last conductor of the same coil i.e., the distance between two coil sides of the same coil is called back pitch. It is also called the coil span or coil spread and is denoted by $Y_B$, as shown in **Figs. 13 (a), (b) and (c).**
12. **Front pitch.** The distance in terms of number of armature conductors or number of slots between second conductor of one coil and the first conductor of the next coil which are connected to the same commutator segment on the front is called front pitch. It is denoted by $Y_F$, as shown in **Figs. 13 (a), (b) and (c)**.
13. **Resultant pitch:** The distance in terms of number of armature conductors or number of slots between the start of one coil and the start of the next coil to which it is connected is called resultant pitch. It is denoted by $Y_R$ as shown in **Figs. 13 (a), (b) and (c).**
14. **Commutator pitch:** The distance measured in terms of commutator segments between the segments to which the two ends of a coil are connected is called commutator pitch. It is denoted by $Y_C$ as shown in **Figs. 13 (a), (b) and (c)**.




(a) (b) (c)

**Figure 13.** Terms used in coils.

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## Single Layer and Double Layer Winding

- **Single Layer:** When the whole slot of the machine is accommodated by one side coil of only one coil, the winding is known as single layer winding. Single layer winding is normally not used due to commutation problems.
- **Double Layer:** When upper portion of a slot (top layer and nearer to air gap) is occupied by the upper coil side of a coil and the lower portion (bottom layer) of the same slot is occupied by the lower coil side of another coil, winding is known as double layer winding. The two layers of the windings in the same slot are insulated by an insulation strip' called separator. Double layer windings are most commonly used in d.c. machines. It gives satisfactory arrangement of end connections. For double layer winding, the number of armature slots is equal to the number of coils in the armature winding. But in larger machines, the number of coils may become larger and number of slots may be limited due to design considerations. In such machines, the slot may accommodate two or more than two coil sides. The numbering of conductors should be done in such a way that odd numbered conductors should occupy top layers of the slot portion and even numbers should occupy the bottom layer of slot portion **Fig. 14** shows the slots with 2, 4 and 6 conductors.

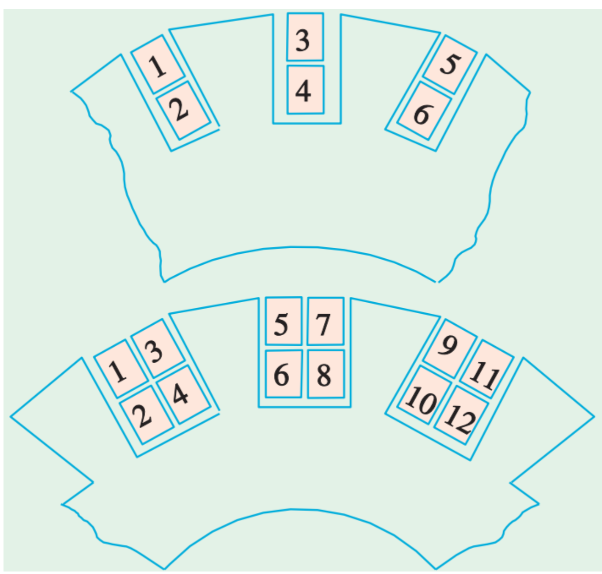



**Figure 14.** Double Layer Winding.

# 1.4 Types of Armature Winding

All the coils in one parallel path are connected in series and so the emfs induced in these coils are added to get the resultant emf, which is equal to voltage rating of machine. Generally, two types of windings are used in d.c. machines and they are lap winding and wave winding.

## 1.4.1 Lap Winding

Single turn lap winding is shown in Figs. 4.21(a) and (b). In lap winding a coil side under one pole is connected directly to the coil side of another coil which occupies nearly the corresponding position under the next pole and the finish end of other coil is connected to a commutator segment and to the start end of the adjacent coil situated under the same pole and all coils are connected similarly forming a closed loop. Since the sides of successive coils overlap each other, it is called a lap winding. Lap winding may be further classified as a simplex (single) or multiplex (double or triple) windings.

- **Simplex lap winding:** In this winding, there are as many parallel paths as there are field poles on the machine.
- **Double or duplex lap winding:** In this case, two similar simplex windings are placed in alternate slots on the armature and connected to alternate commutator segments. Thus, each winding carries half of the armature current.
- **Triple or triplex lap winding:** In this case, three similar simplex windings are placed to occupy every third slot and connected to every third commutator segment. Thus, each winding carries one third of the armature current. Similarly, there can be multiplex lap winding having even more than three simplex winding as per the requirement.

The above explanation clearly shows that the sole purpose of employing multiplex lap winding is to increase the number of parallel** paths enabling the armature to carry a large total current, at the same time reducing the conductor current to improve commutation conditions.

Following points regarding lap winding should be carefully noted:

**i.** The back and front pitches are odd and are of opposite signs. They differ numerically by

$$Y_B = Y_F \pm 2$$
$$Y_B = Y_F + 2 \quad \text{for progressive winding}$$
$$Y_B = Y_F - 2 \quad \text{for retrogressive winding}$$

**ii.** Both $Y_B$ and $Y_F$ should be nearly equal to pole pitch.

**iii.** The average pitch $Y_A = \frac{Y_F+Y_B}{2}$ . It is equal to pole pitch $\frac{Z}{P}$

Commutator pitch, $Y_C = \pm 1$

$Y_C = +1$ for progressive winding
$Y_C = -1$ for retrogressive winding

**iv.** Resultant pitch YR is always even, being the arithmetical difference of two odd numbers, i.e., YR = YB – YF. It is equal to 2 m where m is multiplicity of winding.

**v.** For a two-layer winding, the number of slots and number of commutator segments are equal to the number of coils (i.e., half the number of coil sides).

**vi.** If Z = number of armature conductors and P = number of poles, then pole pitch $\frac{Z}{P}$

Since $Y_B$ and $Y_F$ both must be about one pole pitch and differ numerically by 2,

$$\left.\begin{aligned} Y_B &= \frac{Z}{P} + 1 \\ Y_F &= \frac{Z}{P} - 1 \end{aligned}\right\} \text{for progressive winding}$$

$$\left.\begin{aligned} Y_B &= \frac{Z}{P} - 1 \\ Y_F &= \frac{Z}{P} + 1 \end{aligned}\right\} \text{for retrogressive winding}$$

It is clear that $Z/P$ must be even number to make the winding possible.

**<u>Example 1:</u>** A 4-pole, simplex lap – wound armature contains 16 slots and has two coil sides per slot. Find **back pitch**, **front pitch** and **commutator pitch** for **(i)** progressive winding **(ii)** retrogressive winding.

**<u>Sol:</u>**

$$\text{pole pitch} = \frac{Z}{P} = \frac{16*2}{4} = 8 \text{ conductors}$$

**(i)** progressive winding

$$Y_B = \frac{Z}{P} + 1 = 8 + 1 = 9 \text{ conductors}$$
$$Y_F = \frac{Z}{P} - 1 = 8 - 1 = 7 \text{ conductors}$$
$$Y_C = +1 \text{ for progressive winding}$$

**(ii)** retrogressive winding

$$Y_B = \frac{Z}{P} - 1 = 8 - 1 = 7 \text{ conductors}$$
$$Y_F = \frac{Z}{P} + 1 = 8 + 1 = 9 \text{ conductors}$$
$$Y_C = -1 \text{ for retrogressive winding}$$

**Example 2:** Draw a developed winding diagram of a simple two-layer lap-winding for a four-pole generator with 16 coils. Also draw the equivalent ring diagram with position of brushes and diagram representing parallel circuits thus formed.

**Sol:**

Number of armature conductors = 2×16 = 32

pole pitch $= \frac{Z}{P} = \frac{32}{4} = 8 \text{ conductors}$

**Let us design the progressive lap winding. For progressive winding:

$$Y_B = \frac{Z}{P} + 1 = 8 + 1 = 9 \text{ conductors}$$
$$Y_F = \frac{Z}{P} - 1 = 8 - 1 = 7 \text{ conductors}$$
$$Y_C = +1 \text{ for progressive winding}$$

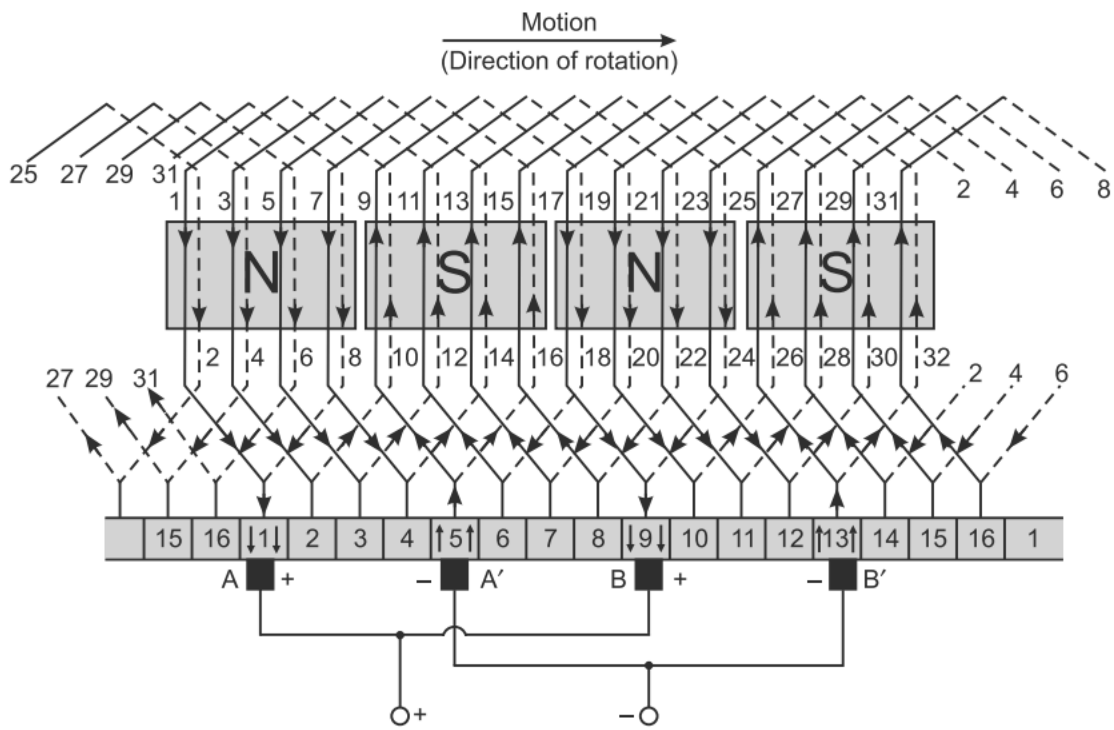
Figure below shows the winding table

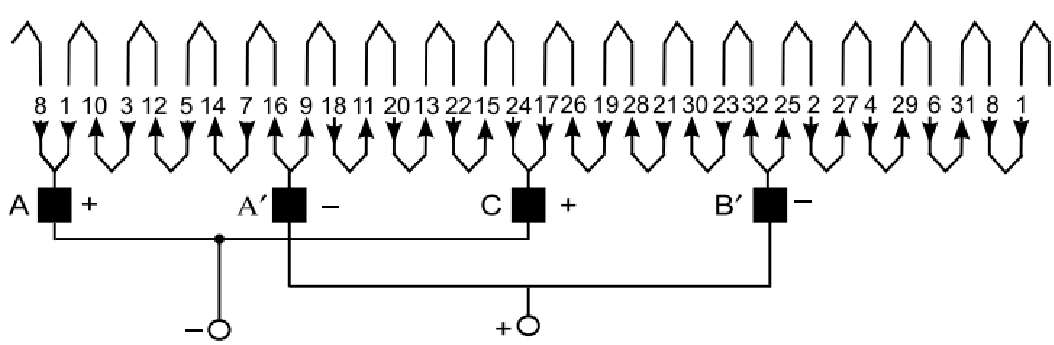
| Back connections | | Front connections |
|---|---|---|
| $1 \text{ to } (1+9) = 10$ | → | $10 \text{ to } (10-7) = 3$ |
| $3 \text{ to } (3+9) = 12$ | → | $12 \text{ to } (12-7) = 5$ |
| $5 \text{ to } (5+9) = 14$ | → | $14 \text{ to } (14-7) = 7$ |
| $7 \text{ to } (7+9) = 16$ | → | $16 \text{ to } (16-7) = 9$ |

$$9 \text{ to } (9+9) = 18 \quad \longrightarrow \quad 18 \text{ to } (18-7) = 11$$
$$11 \text{ to } (11+9) = 20 \quad \longrightarrow \quad 20 \text{ to } (20-7) = 13$$
$$13 \text{ to } (13+9) = 22 \quad \longrightarrow \quad 22 \text{ to } (22-7) = 15$$

……………………………………………..

$$25 \text{ to } (25+9) = 34 = (34-32) = 2 \quad \longrightarrow \quad 2 \text{ to } (34-7) = 27$$
$$27 \text{ to } (27+9) = 36 = (36-32) = 4 \quad \longrightarrow \quad 4 \text{ to } (36-7) = 29$$
$$29 \text{ to } (29+9) = 38 = (38-32) = 8 \quad \longrightarrow \quad 6 \text{ to } (38-7) = 31$$
$$31 \text{ to } (31+9) = 40 = (40-32) = 8 \quad \longrightarrow \quad 8 \text{ to } (8-7) = 1$$




LECTURE 2

**Example 3:** Design a 4-pole, simplex lap winding suitable for an armature containing 20 slots. Assume single turn coils with 2 conductors per slot.

**Sol:**

Number of commutator segments = number of slots =20
Number of armature coils = number of slots = 20

Number of armature conductors = 2×20 = 40

pole pitch $= \frac{Z}{P} = \frac{40}{4} = 10$ conductors

**Let us design the progressive lap winding. For progressive winding:

$$Y_B = \frac{Z}{P} + 1 = 10 + 1 = 11 \text{ conductors}$$
$$Y_F = \frac{Z}{P} - 1 = 10 - 1 = 9 \text{ conductors}$$
$Y_C = +1$ for progressive winding

Figure below shows the winding table

| Back connections | | Front connections |
|---|---|---|
| 1 to $(1 + 11) = 12$ | → | 12 to $(12 - 9) = 3$ |
| 3 to $(3 + 11) = 14$ | → | 14 to $(14 - 9) = 5$ |
| 5 to $(5 + 11) = 16$ | → | 16 to $(16 - 9) = 7$ |
| 7 to $(7 + 11) = 18$ | → | 18 to $(18 - 9) = 9$ |
| 9 to $(9 + 11) = 20$ | → | 20 to $(20 - 9) = 11$ |
| 11 to $(11 + 11) = 22$ | → | 22 to $(22 - 9) = 13$ |
| 13 to $(13 + 11) = 24$ | → | 24 to $(24 - 9) = 15$ |
| | ……………………………………….. | |
| 31 to $(31 + 11) = 42$ $= (42 - 40) = 2$ | → | 2 to $(42 - 9) = 33$ |
| 33 to $(33 + 11) = 44$ $= (44 - 40) = 4$ | → | 4 to $(44 - 9) = 35$ |
| | ……………………………………….. | |
| 37 to $(37 + 11) = 48$ $= (48 - 40) = 8$ | → | 8 to $(48 - 9) = 39$ |

$$39 \text{ to } (39 + 11) = 50 \qquad \longrightarrow \qquad 10 \text{ to } (10 - 9) = 1$$
$$= (50 - 40) = 10$$

### 1.4.2 Wave winding

Wave windings can be classified into single wave winding and multiplex wave winding. **Fig. 15** shows a portion of wave winding with single turn coil with coils *A* and *B*. The end *A2* of coil a which lies in south pole is connected to *B1* the starting of coil *B*, which lies in north pole. Other coils are connected in similar fashion. The wave winding may be classified as progressive wave winding or retrogressive wave winding.

- **Simple wave winding:** Armature winding with wave winding and having only one closed circuit is known as simple wave winding. The commutator pitch for simple wave winding depends upon the number of poles and commutator segments. The number of parallel circuits (parallel paths) in simple wave winding is always 2 irrespective of number of poles.

Number of parallel paths (a) = 2

- **Duplex winding:** is equivalent to two simple wave winding is used in d.c. machines where simplex-winding is not suitable. The number of parallel circuits (parallel path) in duplex wave winding is always 4 irrespective of number of poles (double of parallel path in simple wave winding).

Number of parallel paths = 2m

Where (m) is the multiplicity of the winding

Duplex wave winding is single re-entrant when commutator bars are odd and it is doubly re-entrant if the commutator bars are even.

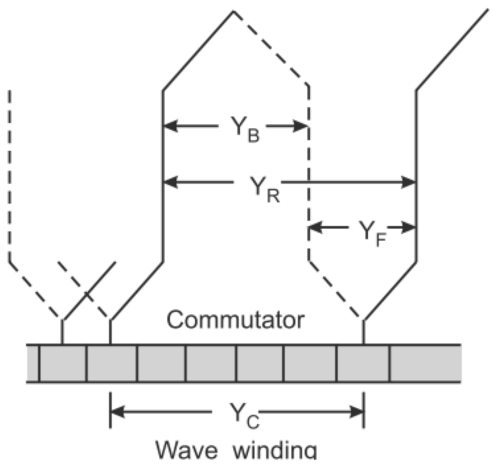



**Figure 15.** Wave winding.

***Design of simplex wave winding***

- **i.** Both pitches YB and YF are odd and of the same sign
- **ii.** Back and front pitches are nearly equal to the pole pitch and may be equal or differ by 2, in which case, they are respectively one more or one less than the average pitch.
- **iii.** $Number\ of\ coil = \frac{Z}{2}$
- **iv.** The even number of coils are not used for wave winding
- v. Resultant pitch $Y_R = Y_F + Y_B$
- **vi.** Commutator pitch, $Y_C = Y_A$ (in lap winding $Y_C = \pm 1$)

$$\text{Also, } Y_C = \frac{\text{No. of Commutator bars} \pm 1}{\text{No. of pair of poles}}$$

- **vii.** The average pitch which must be an integer is given by

$$Y_A = \frac{Z \pm 2}{P} = \frac{\frac{Z}{2} + 1}{P/2} = \frac{\text{No. of Commutator bars } \pm 1}{\text{No. of pair of poles}}$$

**<u>Example 4:</u>** A 4-pole armature has 30 armature conductors. The armature is to be simplex wave-wind with single-turn coils. Determine for a retrogressive winding **(i)** back pitch **(ii)** front pitch **(iii)** commutator pitch.

**<u>Sol:</u>**

For a retrogressive winding, average pitch $Y_A = \frac{Z-2}{P} = \frac{30-2}{4} = 7$ conductors

$$Y_B = 7 \text{ conductors}$$

$$Y_A = \frac{Y_B + Y_F}{2} = 7 = \frac{7 + Y_F}{2}$$

$$Y_F = 7 \text{ conductors}$$

$$Y_C = Y_A = 7 \text{ conductor segments}$$

**<u>Example 4:</u>** Draw a developed winding diagram showing position of poles, direction of rotation, polarity and position of brushes of a simplex two-layer wave winding for a four-pole DC generator with 30 armature conductors. Hence point out the characteristics of a simple wave winding.

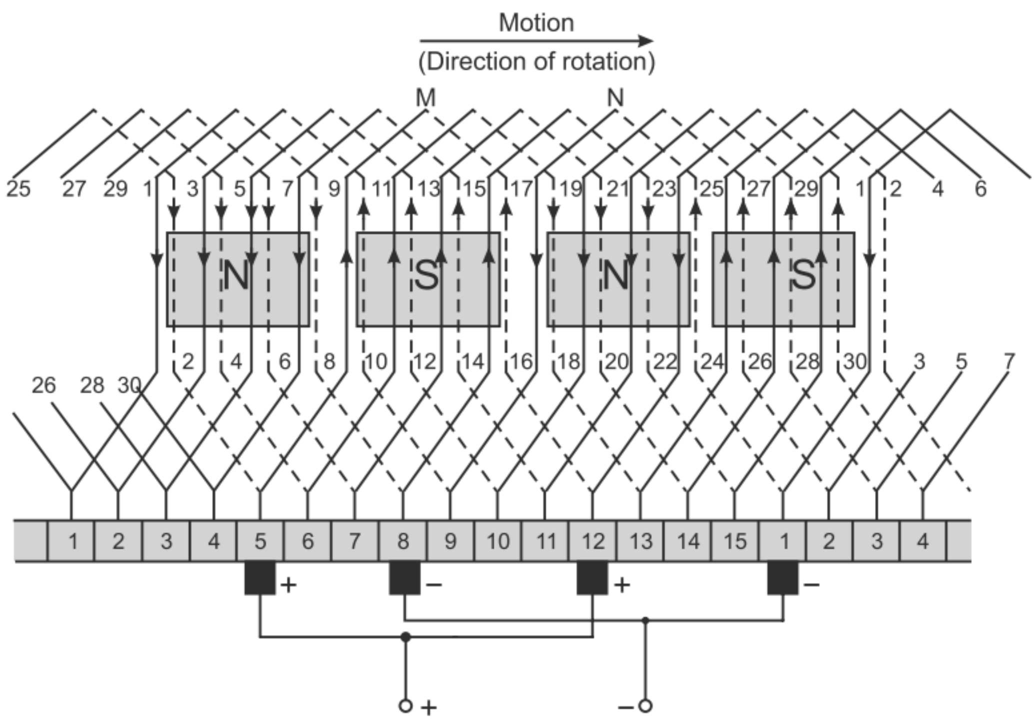
**Sol:**

$P= 4$, $Z= 30$

For a retrogressive winding, average pitch $Y_A = \frac{Z-2}{P} = \frac{30-2}{4} = 7$ conductors

If $Y_A$ is taken odd i.e., 7, then $Y_B = Y_F$

| Back-end Connections | Front-end Connections | Through Segment No. |
|---|---|---|
| 1 to (1 + 7) = 8 | 8 to (8 + 7) = 15 | 8 |
| 15 to (15 + 7) = 22 | 22 to (22 + 7) = 29 | 15 |
| 29 to (29 + 7) = 36 = 6 | 6 to (6 + 7) = 13 | 7 |
| 13 to (13 + 7) = 20 | 20 to (20 + 7) = 27 | 14 |
| 27 to (27 + 7) = 34 = 4 | 4 to (4 + 7) = 11 | 6 |
| 11 to (11 + 7) = 18 | 18 to (18 + 7) = 25 | 13 |
| 25 to (25 + 7) = 32 = 2 | 2 to (2 + 7) = 9 | 5 |
| 9 to (9 + 7) = 16 | 16 to (16 + 7) = 23 | 12 |
| 23 to (23 + 7) = 30 | 30 to (30 + 7) = 37 = 7 | 4 |
| 7 to (7 + 7) = 14 | 14 to (14 + 7) = 21 | 11 |
| 21 to (21 + 7) = 28 | 28 to (28 + 7) = 35 = 5 | 3 |
| 5 to (5 + 7) = 12 | 12 to (12 + 7) = 19 | 10 |
| 19 to (19 + 7) = 26 | 26 to (26 + 7) = 33 = 3 | 2 |
| 3 to (3 + 7) = 10 | 10 to (10 + 7) = 17 | 9 |
| 17 to (17 + 7) = 24 | 24 to (24 + 7) = 31 = 1 | 1 |




### 1.4.3 Uses of Lap and Wave Windings

The advantage of the wave winding is that, for a given number of poles and armature conductors, it gives more e.m.f. than the lap winding. Conversely, for the same e.m.f., lap winding would require large number of conductors which will result in higher winding cost and less efficient utilization of space in the armature slots. Hence, wave winding is suitable for small generators especially those meant for 500-600 V circuits. Another advantage is that in wave winding, equalizing connections are not necessary whereas in a lap winding they definitely are. It is so because each of the two paths contains conductors lying under all the poles whereas in lap-wound armatures, each of the P parallel paths contains conductors which lie under one pair of poles. Any inequality of pole fluxes affects two paths equally, hence their induced e.m.fs. are equal. In lap-wound armatures, unequal voltages are produced which set up a circulating current that produces sparking at brushes.

However, when large currents are required, it is necessary to use lap winding, because it gives more parallel paths.

Hence, lap winding is suitable for comparatively low-voltage but high-current generators whereas wave-winding is used for high-voltage, low-current machines.