MEC 3102 – PRODUCTION ENGINEERING I AND ELECTRICITY & ELECTRONICS II

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2nd Series Lecture 3[1]

D.C. and A.C Machines

- DC. Generator
- A.C. Generator
- D.C. Motor
- Induction Motor

i. Electromechanical Energy Conversion Devices

- **Definition**: The conversion of electrical energy into mechanical energy or vise-versa is referred to as Electromechanical Energy Conversion
- A device (machine) which makes possible the conversion of energy from electrical to mechanical form or from mechanical to electrical form is called an Electromechanical energy conversion device.
- Depending upon the conversion of energy from one from to the other, the electromechanical device can be named as **motor** or **generator**.

1. **Motor**: This is an electromechanical device (electrical machine) which converts electrical energy or power (EI) into mechanical energy or power (ωT) is called a **motor**.

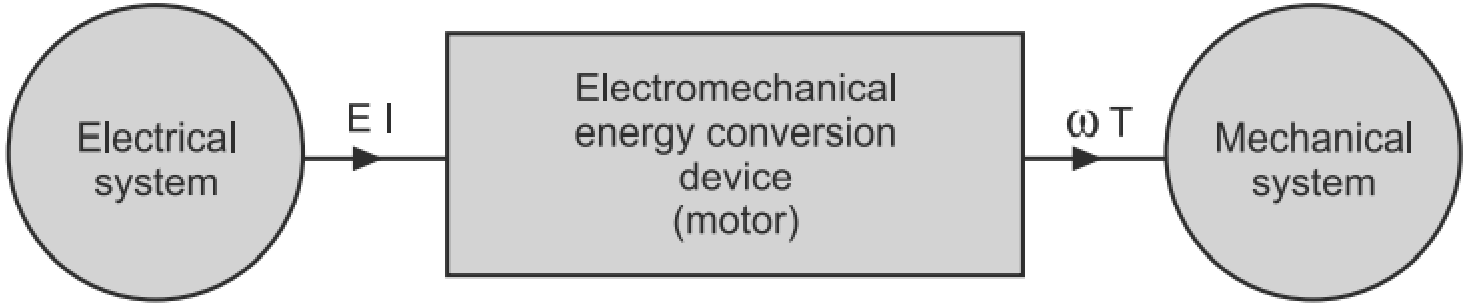


Fig. 1 Motor block diagram of energy conversion

Application:

- driving industrial machines e.g., hammer presses, drilling machines, lathes, shapers, milling machines, blowers for furnaces etc., and
- domestic appliances e.g., refrigerators, fans, water pumps, toys, mixers etc

2. **Generator**: An electro-mechanical device (electrical machine) which converts mechanical energy or power (ωT) into electrical energy or power (EI) is called **generator**.

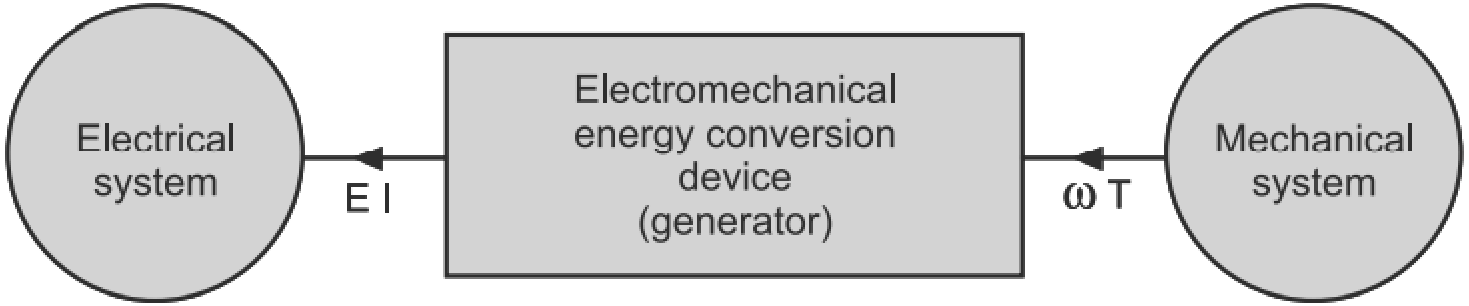


Fig. 2 Generator block diagram of energy conversion

Application:

hydro-electric power plants, steam power plants, diesel power plants, nuclear power plants and in automobiles.

- The same electromechanical device is capable of operating either as a motor or generator depending upon whether the input power is electrical or mechanical. Thus, the motoring and generating action is reversible.

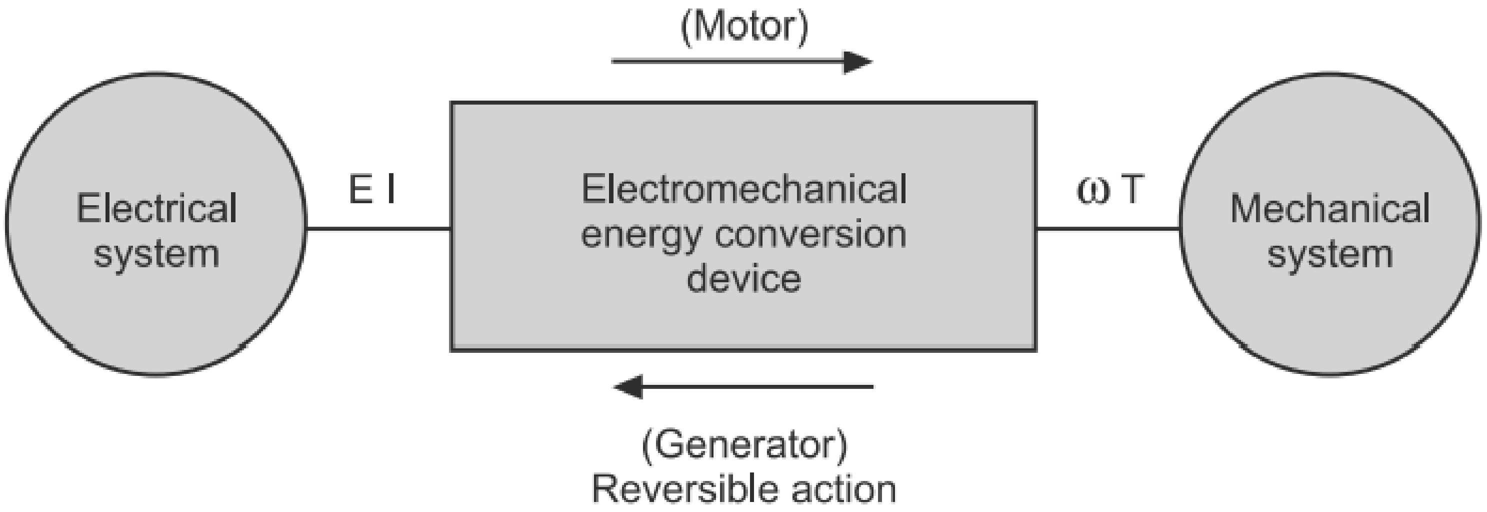


Fig. 3 Same machine can work as a generator or motor

- The conversion of energy either from electrical to mechanical or from mechanical to electrical takes place through magnetic field.

ii. Elementary Concept of Electrical Machines

Operation of Machine as a Generator

- The operation of all rotating electrical machines are based on fundamental electromagnetic laws:
- ✓ When the magnetic flux linking a conductor or coil changes, an e.m.f. is induced in it whose magnitude is given by;

$$e = \frac{Nd\phi}{dt}$$

- Faraday's law

- ✓ When a current-carrying conductor of length l is placed at right angles to a uniform magnetic field (of flux density **B**), experiences a mechanical force (F) whose magnitude is given by;

$$F = Bli$$

- Maxwell's law

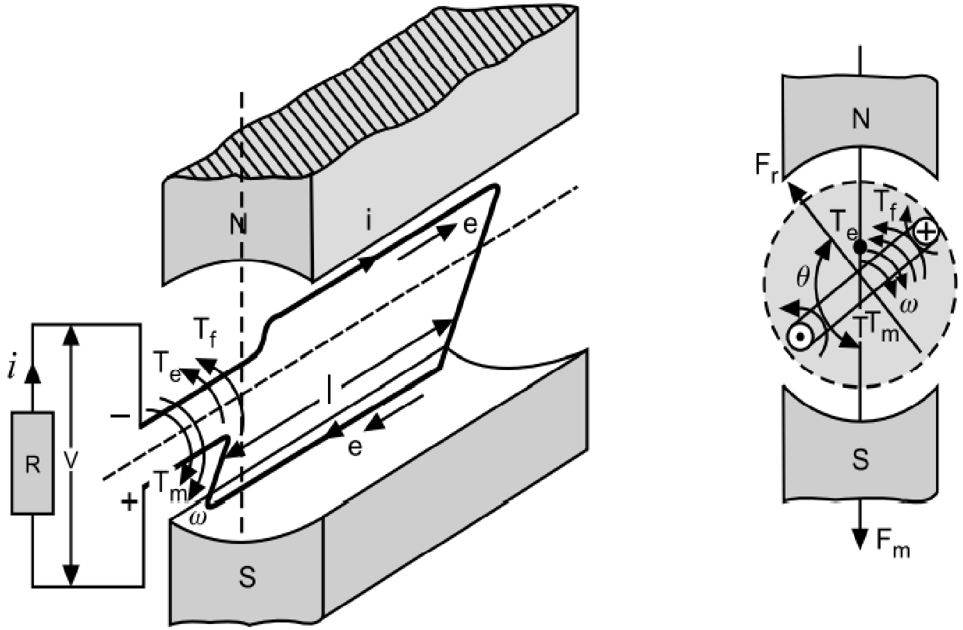


Fig. 4 Concept of generator

Operation of Machine as a Generator

In figure 4:

- The coil is rotated in clockwise direction at an angular velocity of ω radians per second by some outside driving mechanical torque T_m.
- The coil sides cut the magnetic field and emf (e) is induced in the coil.
- The coil is connected to an external load resistor R, therefore current (i) flows through the coil and external load resistor.
- When current flows through the coil conductors, they produce their own magnetic field. The direction of this rotor field is marked by arrowhead F_r.
- The rotor field F_r tries to come in line with the main field F_m and an electromagnetic torque T_e is produced in the opposite direction to that of the rotation.

Torque at no-load

- If the coil circuit is not closed, no current would flow through the coil and hence no electromagnetic torque will be developed (i.e., T_e = 0), under such a condition the opposition is only due to frictional torque (neglecting iron losses).
- Therefore, the mechanical torque Tm applied must be sufficient to overcome the frictional torque. Thus,

$$T_m = T_f$$

Where, T_f is the frictional torque. Frictional torque always acts in opposite direction to the direction of rotation.

Torque at load

- When the load resistance is connected, current flows and electromagnetic torque is produced in opposite direction to that of mechanical torque.
- The mechanical torque T_m must be sufficient to overcome the electromagnetic torque and frictional torque (iron losses neglected). Thus,

$$T_m = T_e + T_f \tag{1}$$

or $$\omega T_m = \omega T_e + \omega T_f \tag{2}$$

or $$\omega T_e = \omega T_m - \omega T_f \tag{3}$$

Where,

$\omega T_m =$ Mechanical input power, $\omega T_f =$ Power losses due to friction, and $\omega T_e =$ Mechanical power developed in the rotor which is converted into electrical power.

- Induced emf in the coil when conductors move perpendicular to the magnetic field,

$$e = 2Blu \tag{4}$$

Multiplying by current (i) through out,

$$ei = 2Bilu = 2Fu, \text{ since } F = Bil$$

expanding

$$ei = 2F \times radius \times \frac{u}{radius}, T = 2F \times radius, \text{ and } \omega = \frac{u}{radius}$$

Hence,

$$ei = T_e \times \omega$$

$\therefore$

$$ei = \omega T_e \tag{5}$$

If r is the internal resistance of the coil,

$$e = ir + iR$$

multiplying both sides by i, we get,

$$ei = i^2 r + i^2 R \text{ or } ei - i^2 r = vi \tag{6}$$

Where,

$ei =$ electrical power generated, $i^2 r =$ power lost in the resistance of coil, called copper losses, and vi or $i^2 R =$ electrical power output to the load.

Thus, we conclude that out of the input power ($\omega \mathrm{T_m}$), only $\omega \mathrm{T_e}$ is the mechanical power which is converted into electrical power (ei)

The power flow diagram (neglecting iron losses) for the generator

- After subtracting the copper losses (i^2r), the electrical power available at the load is only i^2R. This is how the conversion of power takes place in electrical machine working as a generator.

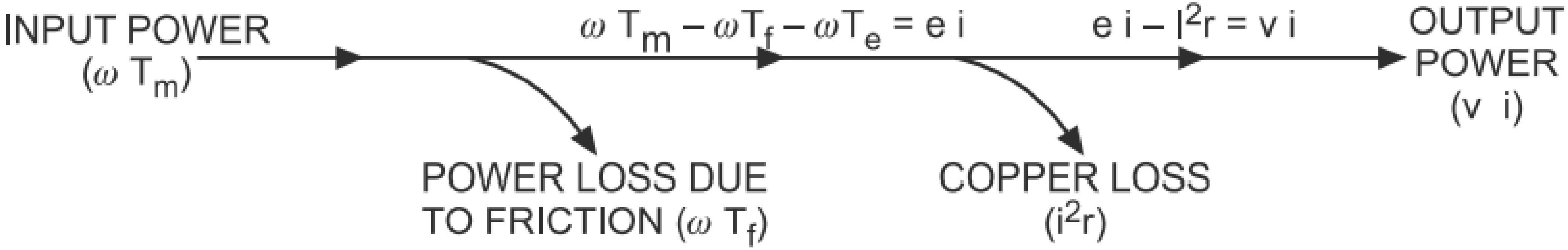


Fig. 5 Power flow in generator action

1. DC Generator

- An electro-mechanical energy conversion device (or electrical machine) that converts mechanical energy or power (ωT) into DC electrical energy or power (EI) is called **D.C. generator**.
- 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.

1.1 Simple Loop Generator

Note that e.m.f. generated in the loop is <u>alternating one</u>

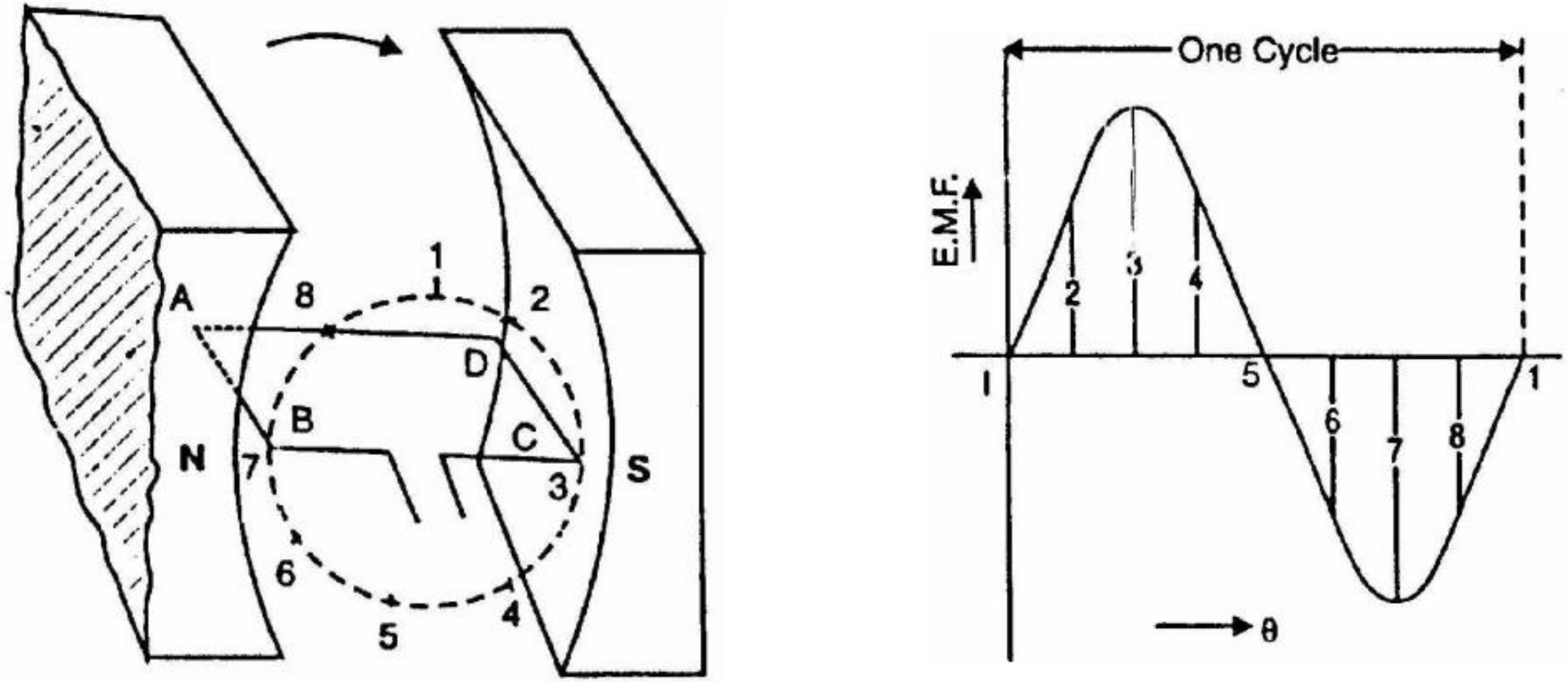


Fig. 1.1 Generated e.m.f.

1.2 Main Constructional Features

The d.c. generators and d.c. motors have the same general construction. Any d.c. generator can be run as a d.c. motor and vice-versa. All d.c. machines have five principal components viz.,

(i) field system

(ii) armature core

(iii) armature winding

(iv) commutator

(v) brushes.

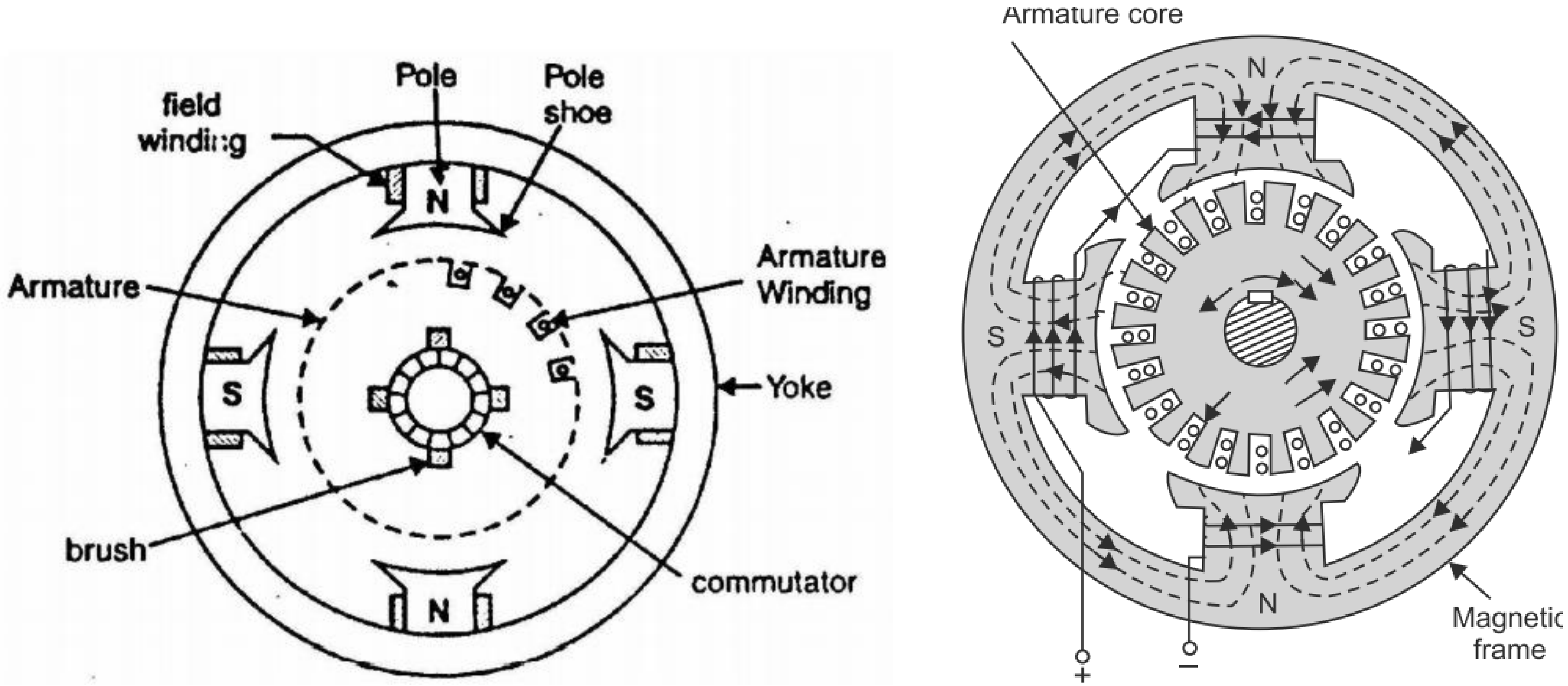

Pole
Pole shoe
field winding
N
Armature
Armature Winding
S
S
Yoke
brush
commutator
N
Armature core
N
S
S
N
+
−
Magnetic frame

Fig. 1.2

i. Field system

The function of the field system is to produce uniform magnetic field within which the armature rotates. It consists of a number of salient poles (of course, even number) bolted to the inside of circular frame (generally called yoke)

ii. Armature core

The armature core is keyed to the machine shaft and rotates between the field poles.

It consists of slotted soft-iron laminations that are stacked to form a cylindrical core.

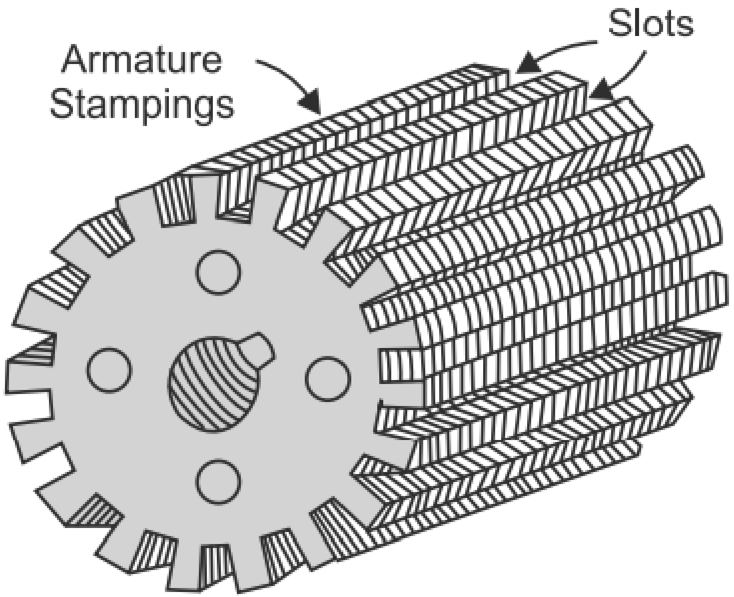


Fig. 1.3 Armature core

iii. Armature winding

The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as *armature winding*. This is the winding in which “working” e.m.f. is induced. There are two types of armature windings named (a) Lap winding and (b) Wave winding

a) Lap winding

In this winding, the connections are such that the number of parallel paths is equal to number of poles.

b) Wave winding

In this winding, the connections are such that the numbers of parallel paths are only two irrespective of the number of poles.

iv. Commutator

A *commutator* is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes.

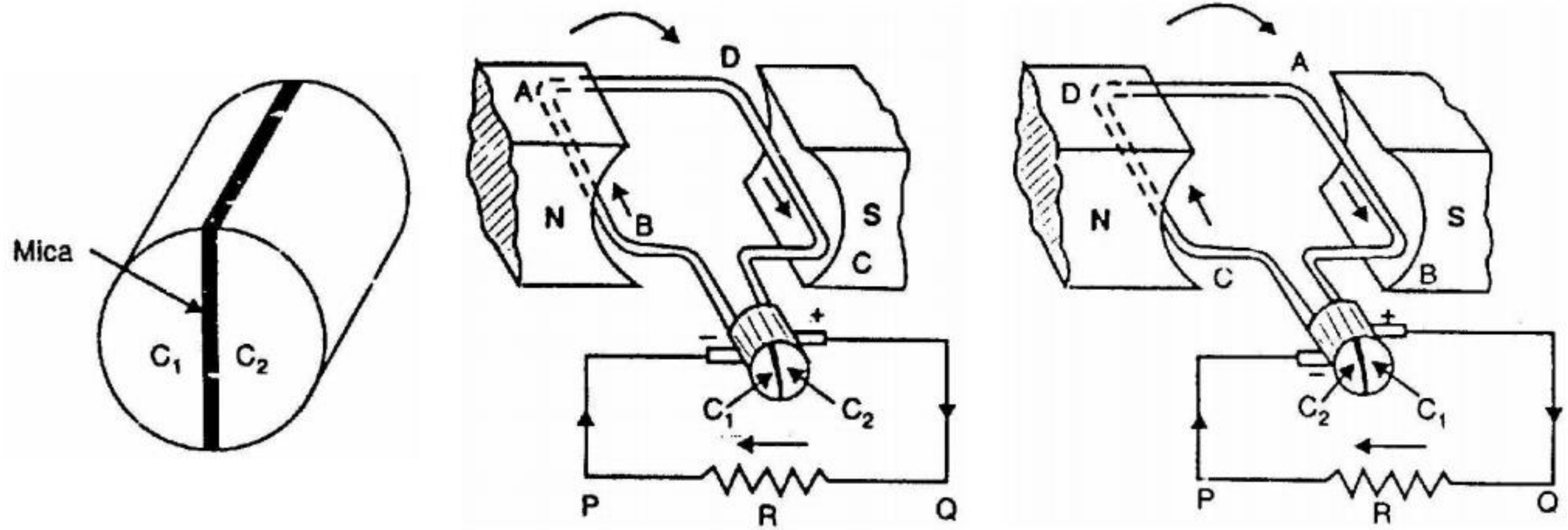


Fig. 1.4 Action of commutator

In Fig. 1.4:

- Shows a commutator having two segments C_1 and C_2
- The ends of coil sides AB and CD are connected to the segments C_1 and C_2 respectively.
- Two stationary carbon brushes rest on the commutator and lead current to the external load.
- The commutator at all times connects the coil side under S-pole to the +ve brush and that under N-pole to the -ve brush.
- The variation of voltage across the brushes with the angular displacement of the loop will be as shown in Fig. 1.5.

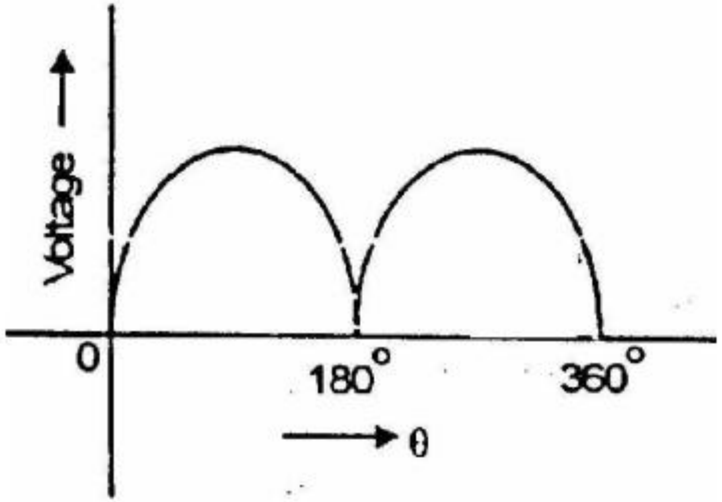
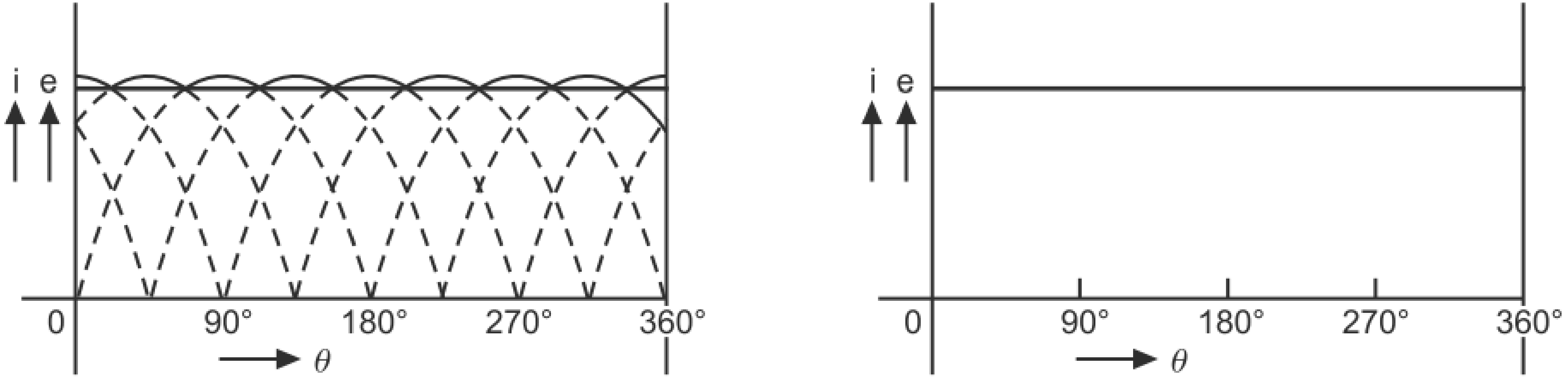


Fig. 1. 5 Generated emf for external circuit connected through split ring

- In an actual machine, there are a number of coils connected to the number of segments of the ring called armature winding.
- The emf or current delivered by these coils to the external load is shown in Fig. 1.6.



(a) Wave shape of output delivered by number of coils (b) True wave shape of output delivered by a dc generator

Fig. 1.6 Wave shape of output delivered by a DC generator

v. Brushes

- The purpose of brushes is to ensure electrical connections between the rotating commutator and stationary external load circuit. The brushes are made of carbon and rest on the commutator. The brush pressure is adjusted by means of adjustable springs.
- Multipole machines have as many brushes as they have poles. For example, a 4- pole machine has 4 brushes

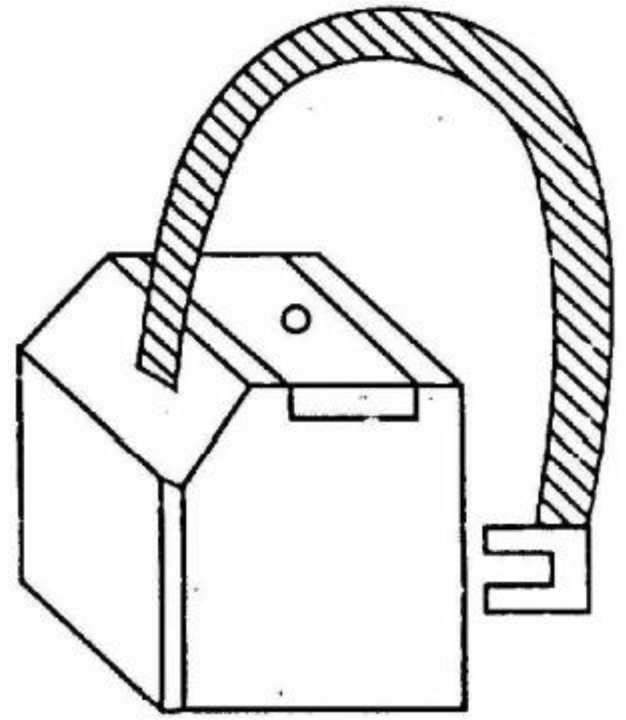


Fig. 1.7 Brush

1.3 Armature Winding

Conductor: The length of wire embedded in armature core and lying within the magnetic field is called the conductor. Total number of conductors in the armature winding are represented by the symbol Z.

Turn: Two conductors lying in a magnetic field connected in series at the back, as shown in Fig. 1.8, so that emf induced in them is additive is known as a **turn.**

Coil: may be a single turn coil having only two conductors, or it may be a multi-turn coil having more than two conductors.

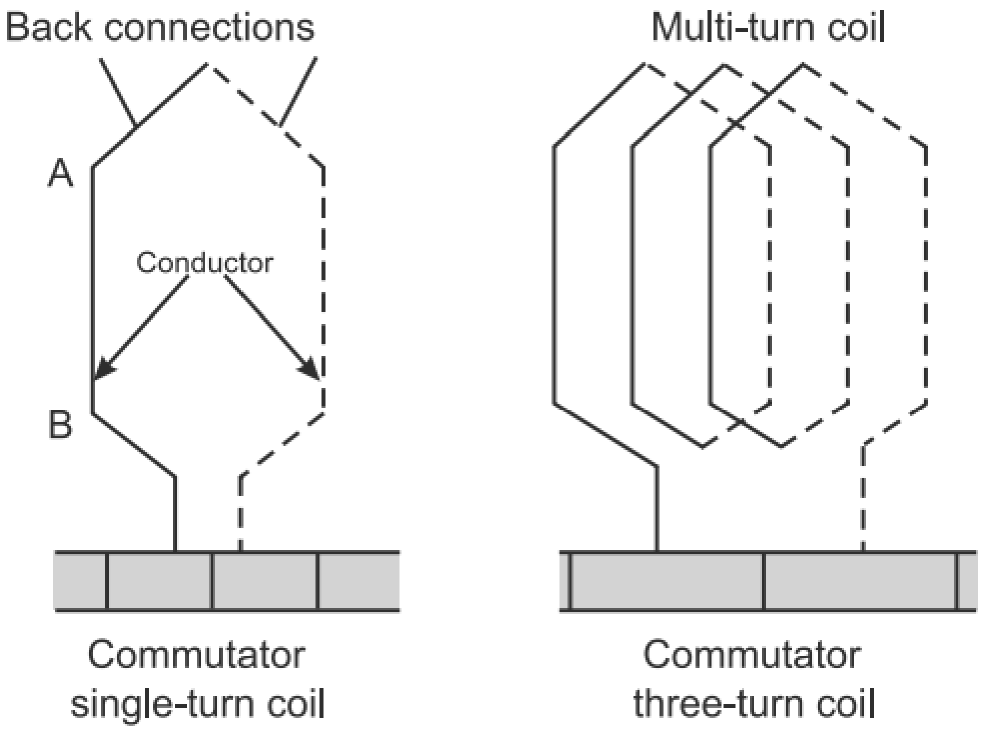


Fig. 1.8 Representation of a coil.

Commutator Pitch (Y_C): The commutator pitch is the number of commutator segments spanned by each coil of the winding. It is denoted by YC.

Pole-Pitch*: It is the distance measured in terms of number of armature slots (or armature conductors) per pole. Thus if a 4-pole generator has 16 coils, then number of slots = 16.

$$\text{Pole pitch} = \frac{16}{4} = 4 \text{ slots}$$

Also,

$$\text{Pole pitch} = \frac{\text{Number of conductors}}{\text{number of poles}}$$

$$= \frac{16 \times 2}{4} = 8 \text{ conductors}$$

Coil Span or Coil Pitch (Y_S): It is the distance measured in terms of the number of armature slots (or armature conductors) spanned by a coil. 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.

Full-Pitched Coil: If the coil-span or coil pitch is equal to pole pitch, it is called full-pitched coil. Therefore, e.m.f. induced in the coil is maximum.

- **Fractional pitched coil**. If the coil span or coil pitch is less than the pole pitch (coil pitch less than 180° electrical), then it is called fractional pitched coil. Fractional pitch winding requires less copper but if the pitch is too small, an appreciable reduction in the generated e.m.f. results.

1.4 Lap Winding

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.

Where:

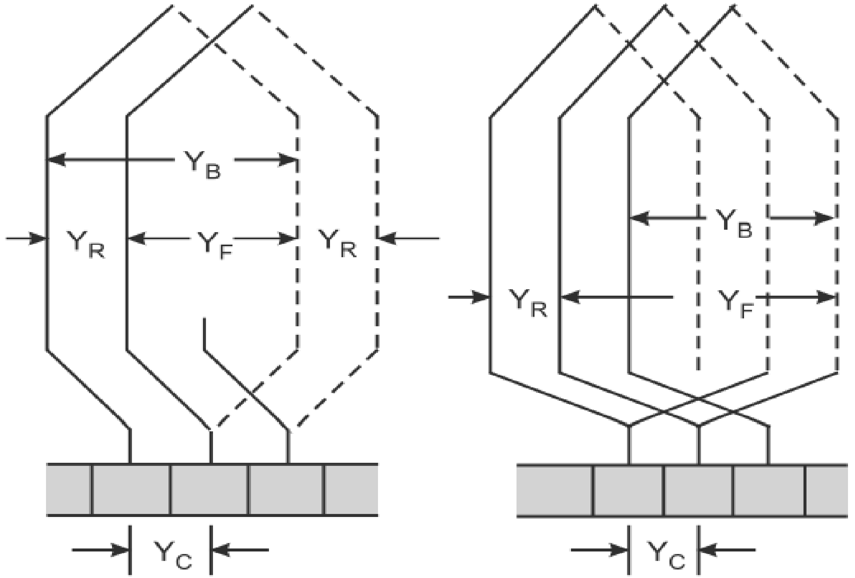
Back Pitch(Y_B) is the distance between two sides of a coil at the back of the armature.

Front Pitch (Y_F) is the distance between two sides attached to any one commutator segment.

Resultant Pitch (Y_R) is the distance between the beginning of one coil and the beginning of the next coil to which it is connected.

Progressive winding: as you trace through the winding, the connection to the commutator will progress around the machine in the same direction as being traced along the path of each individual coil.

Retrogressive winding: the connection to the commutator will progress around the machine in the opposite direction to that which is being traced along the path of each individual coil.



(a) Progressive lap winding (b) Retrogressive lap winding

Fig. 1.9 Lap winding connections

1.5 Wave Winding

In the wave winding the coil side is not connected back rather progresses forward to another coil side placed under the next pole. In this way, the winding progresses, passing successively every North and South pole till it returns to the coil side from where it was started

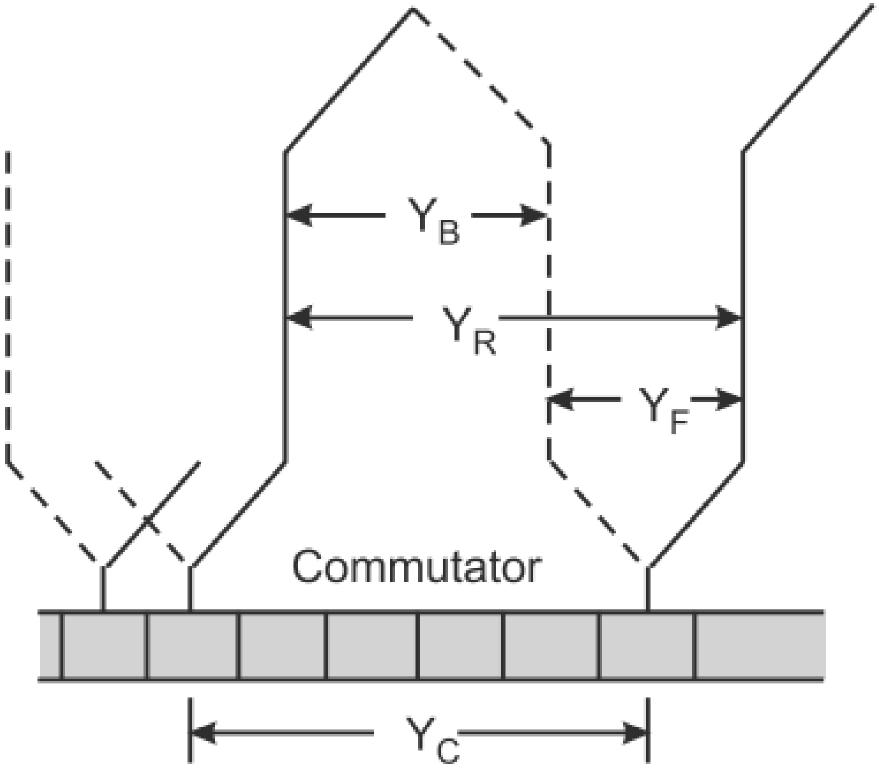


Fig. 1.10. Wave winding connection

1.6 E.M.F. Equation of a D.C. Generator

❖Derivation of an expression for the e.m.f generated in a d.c. generator.

Let $\mathrm{P} =$ Number of poles of the machine.

$\emptyset =$ Flux per pole in Wb

$\mathrm{Z} =$ Total number of armature conductors.

$\mathrm{N} =$ Speed of armature in rpm

$E_g =$ e.m.f. of the generator $=$ e.m.f./parallel path

$A =$ number of parallel paths= 2 ... for wave winding

$=$ P ... for lap winding.

Flux cut by one conductor in one revolution of the armature,

$$d\emptyset = P\emptyset \text{ Wb}$$

Time taken to complete one revolution,

$$dt = 60/N \text{ second}$$

Average induced emf in one conductor,

$$e = \frac{d\emptyset}{dt} = \frac{P\emptyset \times N}{60} \text{ Volts}$$

∴ Average induced emf across each parallel path or across the armature terminals,

$E_g =$ (e.m.f/conductor) × No. of conductors in series per parallel path

$$E_g = \frac{P\emptyset N}{60} \times \frac{Z}{A} = \frac{PZ\emptyset N}{60A} \quad \text{Volts} \qquad (1.1)$$

Or

$$E_g = \frac{PZ\emptyset n}{A} \qquad (1.2)$$

For,

$$n = \frac{N}{60}$$

Note the following:

1. Equation (1.1) is also valid for a d.c. motor. Only that the induced voltage is called counter e.m.f. or back e.m.f. E_b(= $PZ\emptyset N$/60A)
2. For a given machine, the number of poles and number of conductors per parallel path (Z/A) are constant.

$$E_g = K\emptyset n, \text{ where } K = \frac{PZ}{A} \text{ is a constant or } E_g \propto \emptyset n$$

$$E_g \propto \emptyset\omega, \text{ where } \omega = \frac{2\pi N}{60} \text{ is the angular velocity in radian/second}$$

- Thus, we can conclude that the induced e.m.f is directly proportional to flux per pole and speed.
- This induced e.m.f is fundamental phenomenon to all DC machines whether they are working as generator or motor. However, when the machine is working as a generator, this induced emf is called generated emf and is represented as E_g.
- Whereas, in case the machine is working as a motor, this induced emf is called back emf as it acts opposite to the supply voltage V. Then

$$E_b = \frac{PZ\emptyset N}{60A} \text{ Volts}$$

Examples:

1. A 6-pole lap-wound d.c. generator has 600 conductors on its armature. The flux per pole is 0.02 Wb. Calculate:

i. The speed at which the generator must be run in order to gerate 300 V.

ii. What would be the speed if the generator were wave-wound?

Solution.

i. Lap-wound: A = P

$$E_g = \frac{PZ\emptyset N}{60A}$$

$$\therefore \quad N = \frac{60A\times Eg}{PZ\phi} = \frac{60\times6\times300}{6\times600\times0.02} = \mathbf{1500\ r.p.m}$$

ii. Wave-wound:

$$N = \frac{60A\times Eg}{PZ\phi} = \frac{60\times2\times300}{6\times600\times0.02} = \mathbf{500\ r.p.m}$$

2. A 6-pole, 600 r.p.m. lap-wound generator has an armature with 90 slots. If each coil has 4 turns, Calculate the flux per pole required to generate an e.m.f of 288 volts.

Solution:

Given, $P = 6, N = 600 \text{ rpm}, E_g = 288\,V, \quad \emptyset = ?$

Each turn has two active conductors and 90 coils are required to fill all the 90 slots.

$\therefore \qquad Z = 90 \times 4 \times 2 = 720$

But, $\qquad E_g = \frac{PZ\emptyset N}{60A}$

=> $\qquad \phi = \frac{E_g \times 60A}{PZN} = \frac{288 \times 60 \times 6}{6 \times 720 \times 600} = \mathbf{0.04\,Wb}$