Chapter (2)

Armature Reaction and Commutation

Introduction

In a d.c. generator, the purpose of field winding is to produce magnetic field (called main flux) whereas the purpose of armature winding is to carry armature current. Although the armature winding is not provided for the purpose of producing a magnetic field, nevertheless the current in the armature winding will also produce magnetic flux (called armature flux). The armature flux distorts and weakens the main flux posing problems for the proper operation of the d.c. generator. The action of armature flux on the main flux is called armature reaction.

In the previous chapter (Sec 1.19), it was hinted that current in the coil is reversed as the coil passes a brush. This phenomenon is termed as commutation. The criterion for good commutation is that it should be sparkless. In order to have sparkless commutation, the brushes should lie along magnetic neutral axis. In this chapter, we shall discuss the various aspects of armature reaction and commutation in a d.c. generator.

2.1 Armature Reaction

So far we have assumed that the only flux acting in a d.c. machine is that due to the main poles called main flux. However, current flowing through armature conductors also creates a magnetic flux (called armature flux) that distorts and weakens the flux coming from the poles. This distortion and field weakening takes place in both generators and motors. The action of armature flux on the main flux is known as armature reaction.

The phenomenon of armature reaction in a d.c. generator is shown in Fig. (2.1). Only one pole is shown for clarity. When the generator is on no-load, a smal1 current flowing in the armature does not appreciably affect the main flux ϕ_1 coming from the pole [See Fig 2.1 (i)]. When the generator is loaded, the current flowing through armature conductors sets up flux ϕ_1. Fig. (2.1) (ii) shows flux due to armature current alone. By superimposing ϕ_1 and ϕ_2, we obtain the resulting flux ϕ_3 as shown in Fig. (2.1) (iii). Referring to Fig (2.1) (iii), it is clear that flux density at; the trailing pole tip (point B) is increased while at the leading pole tip (point A) it is decreased. This unequal field distribution produces the following two effects:

(i) The main flux is distorted.

(ii) Due to higher flux density at pole tip B, saturation sets in. Consequently, the increase in flux at pole tip B is less than the decrease in flux under pole tip A. Flux ϕ_3 at full load is, therefore, less than flux ϕ_1 at no load. As we shall see, the weakening of flux due to armature reaction depends upon the position of brushes.

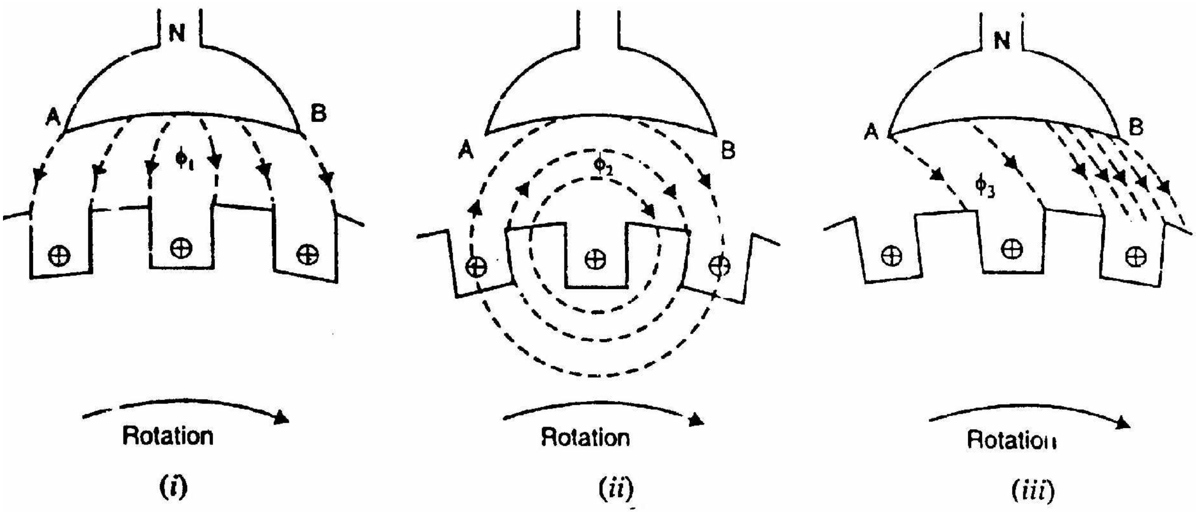

Fig. (2.1)

2.2 Geometrical and Magnetic Neutral Axes

(i) The geometrical neutral axis (G.N.A.) is the axis that bisects the angle between the centre line of adjacent poles [See Fig. 2.2 (i)]. Clearly, it is the axis of symmetry between two adjacent poles.

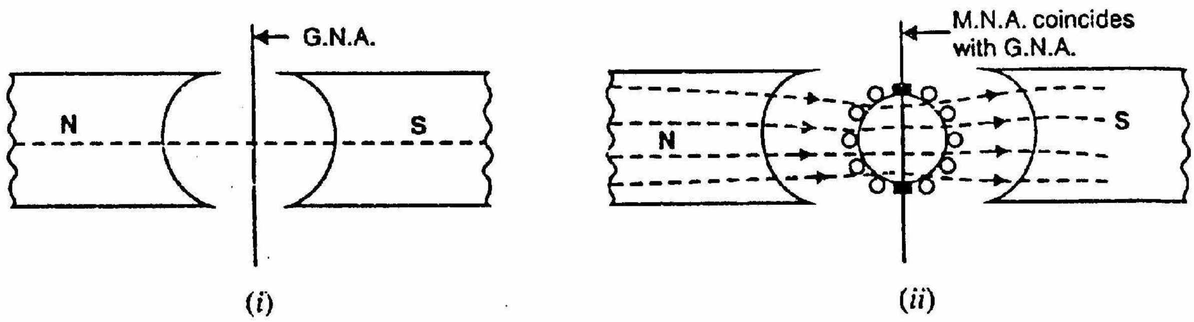

Fig. (2.1)

(ii) The magnetic neutral axis (M. N. A.) is the axis drawn perpendicular to the mean direction of the flux passing through the centre of the armature. Clearly, no e.m.f. is produced in the armature conductors along this axis because then they cut no flux. With no current in the armature conductors, the M.N.A. coincides with G, N. A. as shown in Fig. (2.2).

(ii). In order to achieve sparkless commutation, the brushes must lie along M.N.A.

2.3 Explanation of Armature Reaction

With no current in armature conductors, the M.N.A. coincides with G.N.A. However, when current flows in armature conductors, the combined action of main flux and armature flux shifts the M.N.A. from G.N.A. In case of a generator, the M.N.A. is shifted in the direction of rotation of the machine. In order to achieve sparkless commutation, the brushes have to be moved along the new M.N.A. Under such a condition, the armature reaction produces the following two effects:

1. It demagnetizes or weakens the main flux.
2. It cross-magnetizes or distorts the main flux.

Let us discuss these effects of armature reaction by considering a 2-pole generator (though the following remarks also hold good for a multipolar generator).

(i) Fig. (2.3) (i) shows the flux due to main poles (main flux) when the armature conductors carry no current. The flux across the air gap is uniform. The m.m.f. producing the main flux is represented in magnitude and direction by the vector OF_m in Fig. (2.3) (i). Note that OF_m is perpendicular to G.N.A.

(ii) Fig. (2.3) (ii) shows the flux due to current flowing in armature conductors alone (main poles unexcited). The armature conductors to the left of G.N.A. carry current "in" (×) and those to the right carry current "out" (•). The direction of magnetic lines of force can be found by cork screw rule. It is clear that armature flux is directed downward parallel to the brush axis. The m.m.f. producing the armature flux is represented in magnitude and direction by the vector OF_A in Fig. (2.3) (ii).

(iii) Fig. (2.3) (iii) shows the flux due to the main poles and that due to current in armature conductors acting together. The resultant m.m.f. OF is the vector sum of OF_m and OF_A as shown in Fig. (2.3) (iii). Since M.N.A. is always perpendicular to the resultant m.m.f., the M.N.A. is shifted through an angle θ. Note that M.N.A. is shifted in the direction of rotation of the generator.

(iv) In order to achieve sparkless commutation, the brushes must lie along the M.N.A. Consequently, the brushes are shifted through an angle θ so as to lie along the new M.N.A. as shown in Fig. (2.3) (iv). Due to brush shift, the m.m.f. F_A of the armature is also rotated through the same angle θ. It is because some of the conductors which were earlier under N-pole now come under S-pole and vice-versa. The result is that armature m.m.f. F_A will no longer be vertically downward but will be rotated in the direction of rotation through an angle θ as shown in Fig. (2.3) (iv). Now F_A can be resolved into rectangular components F_c and F_d.

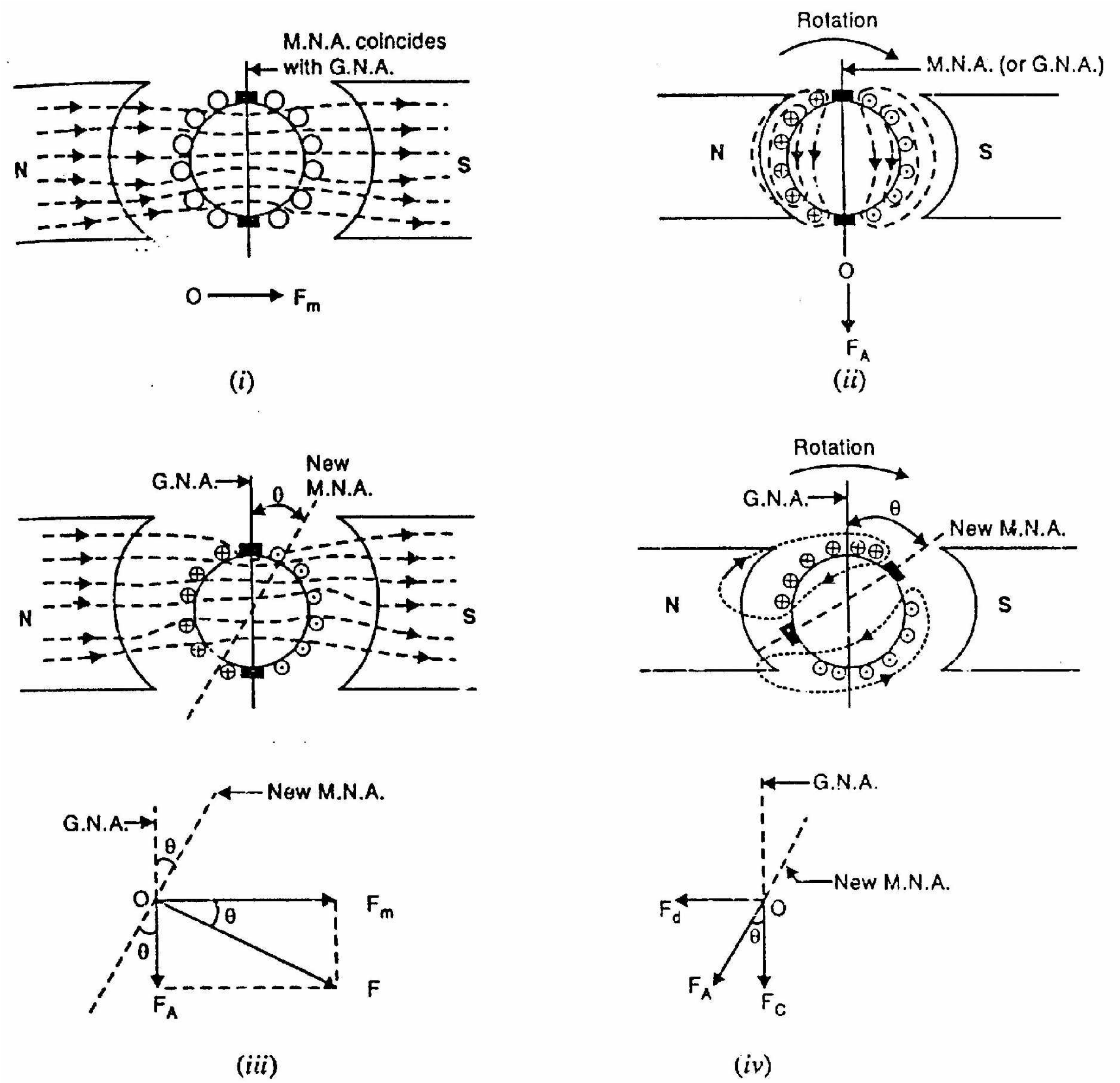

Fig. (2.3)

(a) The component F_d is in direct opposition to the m.m.f. OF_m due to main poles. It has a demagnetizing effect on the flux due to main poles. For this reason, it is called the demagnetizing or weakening component of armature reaction.

(b) The component F_c is at right angles to the m.m.f. OF_m due to main poles. It distorts the main field. For this reason, it is called the cross-magnetizing or distorting component of armature reaction.

It may be noted that with the increase of armature current, both demagnetizing and distorting effects will increase.

Conclusions

(i) With brushes located along G.N.A. (i.e., $\theta = 0°$), there is no demagnetizing component of armature reaction ($F_d = 0$). There is only distorting or cross-magnetizing effect of armature reaction.

(ii) With the brushes shifted from G.N.A., armature reaction will have both demagnetizing and distorting effects. Their relative magnitudes depend on the amount of shift. This shift is directly proportional to the armature current.

(iii) The demagnetizing component of armature reaction weakens the main flux. On the other hand, the distorting component of armature reaction distorts the main flux.

(iv) The demagnetizing effect leads to reduced generated voltage while cross-magnetizing effect leads to sparking at the brushes.

2.4 Demagnetizing and Cross-Magnetizing Conductors

With the brushes in the G.N.A. position, there is only cross-magnetizing effect of armature reaction. However, when the brushes are shifted from the G.N.A. position, the armature reaction will have both demagnetizing and cross-magnetizing effects. Consider a 2-pole generator with brushes shifted (lead) θ_m mechanical degrees from G.N.A. We shall identify the armature conductors that produce demagnetizing effect and those that produce cross-magnetizing effect.

(i) The armature conductors θ_m on either side of G.N.A. produce flux in direct opposition to main flux as shown in Fig. (2.4) (i). Thus the conductors lying within angles AOC = BOD = $2\theta_m$ at the top and bottom of the armature produce demagnetizing effect. These are called demagnetizing armature conductors and constitute the demagnetizing ampere-turns of armature reaction (Remember two conductors constitute a turn).

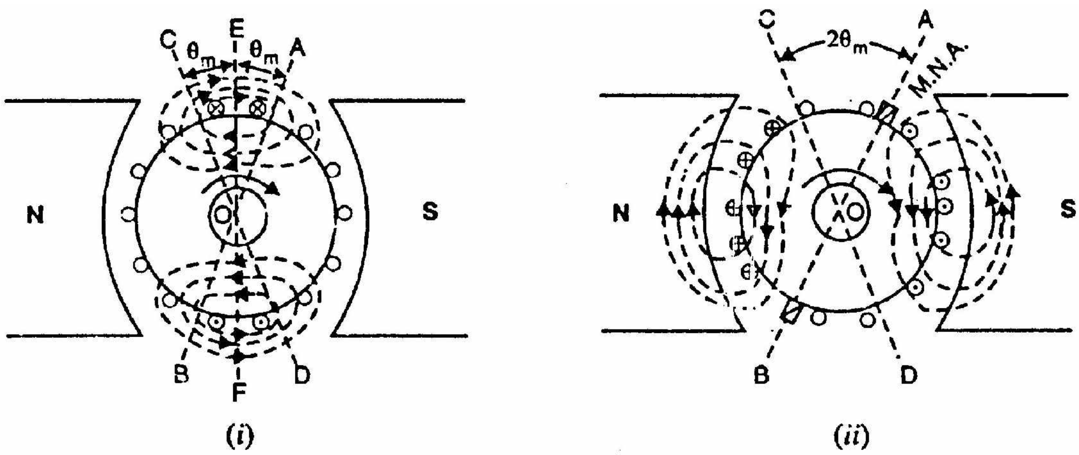

Fig.(2.4)

(ii) The axis of magnetization of the remaining armature conductors lying between angles AOD and COB is at right angles to the main flux as shown in Fig. (2.4) (ii). These conductors produce the cross-magnetizing (or distorting) effect i.e., they produce uneven flux distribution on each pole. Therefore, they are called cross-magnetizing conductors and constitute the cross-magnetizing ampere-turns of armature reaction.

2.5 Calculation of Demagnetizing Ampere-Turns Per Pole (AT_d/Pole)

It is sometimes desirable to neutralize the demagnetizing ampere-turns of armature reaction. This is achieved by adding extra ampere-turns to the main field winding. We shall now calculate the demagnetizing ampere-turns per pole (AT_d/pole).

Let Z = total number of armature conductors

I = current in each armature conductor

$= I_a/2$ ... for simplex wave winding

$= I_a/P$ ... for simplex lap winding

θ_m = forward lead in mechanical degrees

Referring to Fig. (2.4) (i) above, we have,

Total demagnetizing armature conductors

$$= \text{Conductors in angles AOC and BOD} = \frac{4\theta_m}{360} \times Z$$

Since two conductors constitute one turn,

$$\therefore \quad \text{Total demagnetizing ampere-turns} = \frac{1}{2}\left[\frac{4\theta_m}{360} \times Z\right] \times I = \frac{2\theta_m}{360} \times ZI$$

These demagnetizing ampere-turns are due to a pair of poles.

$$\therefore \quad \text{Demagnetizing ampere-turns/pole} = \frac{\theta_m}{360} \times ZI$$

i.e., $$AT_d / \text{pole} = \frac{\theta_m}{360} \times ZI$$

As mentioned above, the demagnetizing ampere-turns of armature reaction can be neutralized by putting extra turns on each pole of the generator.

$$\therefore \quad \text{No. of extra turns/pole} = \frac{AT_d}{I_{sh}} \quad \text{for a shunt generator}$$

$$= \frac{AT_d}{I_a} \quad \text{for a series generator}$$

Note. When a conductor passes a pair of poles, one cycle of voltage is generated. We say one cycle contains 360 electrical degrees. Suppose there are P poles in a generator. In one revolution, there are 360 mechanical degrees and 360 × P/2 electrical degrees.

$$\therefore \quad 360° \text{ mechanical} = 360 \times \frac{P}{2} \text{ electrical degrees}$$

or $$1° \text{ Mechanical} = \frac{P}{2} \text{ electrical degrees}$$

$$\therefore \quad \theta \text{ (mechanical)} = \frac{\theta(\text{electrical})}{\text{Pair of pols}}$$

or $$\theta_m = \frac{\theta_e}{P/2} \qquad \therefore \quad \theta_m = \frac{2\theta_e}{P}$$

2.6 Cross-Magnetizing Ampere-Turns Per Pole (AT_c/Pole)

We now calculate the cross-magnetizing ampere-turns per pole (AT_c/pole).

Total armature reaction ampere-turns per pole

$$= \frac{Z/2}{P} \times I = \frac{Z}{2P} \times I \qquad (\because \text{ two conductors make one turn})$$

Demagnetizing ampere-turns per pole is given by;

$$AT_d / \text{pole} = \frac{\theta_m}{360} \times ZI$$

(found above)

$\therefore$ Cross-magnetizing ampere-turns/pole are

$$AT_d / \text{pole} = \frac{Z}{2P} \times I - \frac{\theta_m}{360} \times ZI = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

$$\therefore \quad AT_d / \text{pole} = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

2.7 Compensating Windings

The cross-magnetizing effect of armature reaction may cause trouble in d.c. machines subjected to large fluctuations in load. In order to neutralize the cross-magnetizing effect of armature reaction, a compensating winding is used.

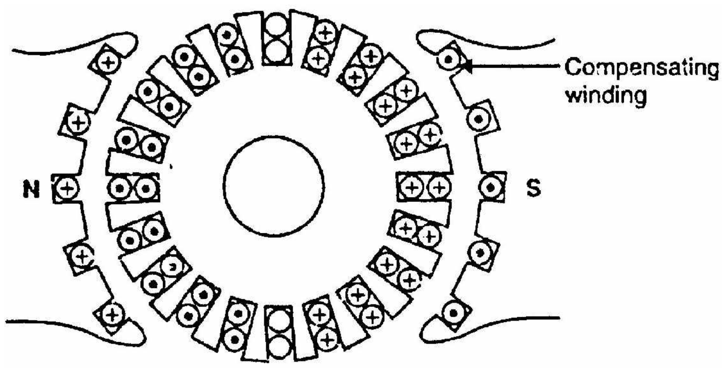

Fig. (2.5)

A compensating winding is an auxiliary winding embedded in slots in the pole faces as shown in Fig. (2.5). It is connected in series with armature in a manner so that the direction of current through the compensating conductors in any one pole face will be opposite to the direction of the current through the adjacent armature conductors [See Fig. 2.5]. Let us now calculate the number of compensating conductors/ pole face. In calculating the conductors per pole face required for the compensating winding, it should be remembered that the current in the compensating conductors is the armature current I_a whereas the current in armature conductors is I_a/A where A is the number of parallel paths.

Let Z_c = No. of compensating conductors/pole face
Z_a = No. of active armature conductors
I_a = Total armature current
I_a/A = Current in each armature conductor

$$\therefore \quad Z_c I_a = Z_a \times \frac{I_a}{A}$$

or $$Z_c = \frac{Z_a}{A}$$

The use of a compensating winding considerably increases the cost of a machine and is justified only for machines intended for severe service e.g., for high speed and high voltage machines.

2.8 AT/Pole for Compensating Winding

Only the cross-magnetizing ampere-turns produced by conductors under the pole face are effective in producing the distortion in the pole cores. If Z is the total number of armature conductors and P is the number of poles, then,

$$\text{No. of armature conductors/pole} = \frac{Z}{P}$$

$$\text{No. of armature turns/pole} = \frac{Z}{2P}$$

$$\text{No. of armature turns under pole face} = \frac{Z}{2P} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

If I is the current through each armature conductor, then,

$$\text{AT/pole required for compensating winding} = \frac{ZI}{2P} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

$$= \text{Armature AT/pole} \times \frac{\text{Pole arc}}{\text{Pole pitch}}$$

2.9 Commutation

Fig. (2.6) shows the schematic diagram of 2-pole lap-wound generator. There are two parallel paths between the brushes. Therefore, each coil of the winding carries one half ($I_a/2$ in this case) of the total current (I_a) entering or leaving the armature.

Note that the currents in the coils connected to a brush are either all towards the brush (positive brush) or all directed away from the brush (negative brush). Therefore, current in a coil will reverse as the coil passes a brush. This reversal of current as the coil passes & brush is called commutation.

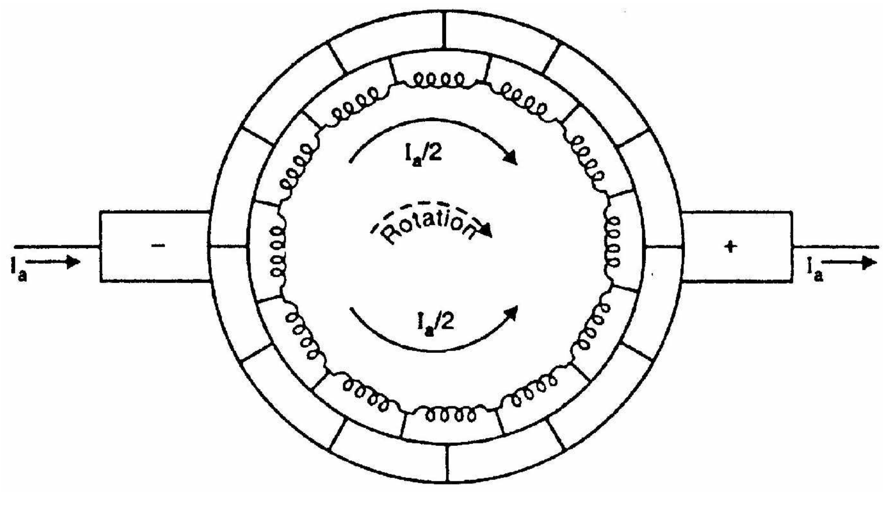

Fig. (2.6)

The reversal of current in a coil as the coil passes the brush axis is called commutation.

When commutation takes place, the coil undergoing commutation is short-circuited by the brush. The brief period during which the coil remains short-circuited is known as commutation period T_c. If the current reversal is completed by the end of commutation period, it is called ideal commutation. If the current reversal is not completed by that time, then sparking occurs between the brush and the commutator which results in progressive damage to both.

Ideal commutation

Let us discuss the phenomenon of ideal commutation (i.e., coil has no inductance) in one coil in the armature winding shown in Fig. (2.6) above. For this purpose, we consider the coil A. The brush width is equal to the width of one commutator segment and one mica insulation. Suppose the total armature current is 40 A. Since there are two parallel paths, each coil carries a current of 20 A.

(i) In Fig. (2.7) (i), the brush is in contact with segment 1 of the commutator. The commutator segment 1 conducts a current of 40 A to the brush; 20 A from coil A and 20 A from the adjacent coil as shown. The coil A has yet to undergo commutation.

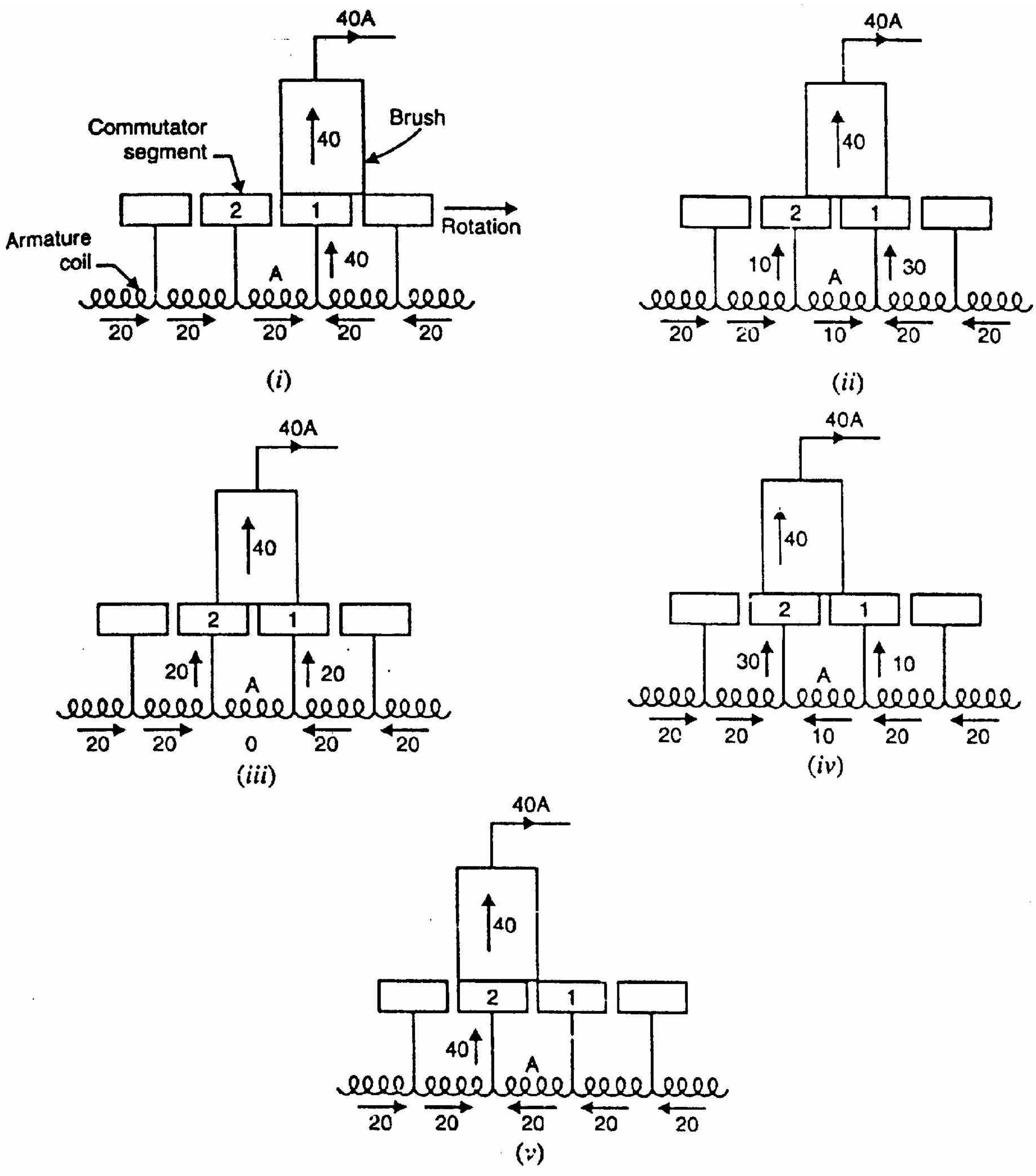

Fig. (2.7)

(ii) As the armature rotates, the brush will make contact with segment 2 and thus short-circuits the coil A as shown in Fig. (2.7) (ii). There are now two parallel paths into the brush as long as the short-circuit of coil A exists. Fig. (2.7) (ii) shows the instant when the brush is one-fourth on segment 2 and three-fourth on segment 1. For this condition, the resistance of the path through segment 2 is three times the resistance of the path through segment 1 (**n** contact resistance varies inversely as the area of contact of brush with the segment). The brush again conducts a current of 40 A; 30 A through segment 1 and 10 A through segment 2. Note that current in coil A (the coil undergoing commutation) is reduced from 20 A to 10 A.

(iii) Fig. (2.7) (iii) shows the instant when the brush is one-half on segment 2 and one-half on segment 1. The brush again conducts 40 A; 20 A through segment 1 and 20 A through segment 2 (**n** now the resistances of the two parallel paths are equal). Note that now. current in coil A is zero.

(iv) Fig. (2.7) (iv) shows the instant when the brush is three-fourth on segment 2 and one-fourth on segment 1. The brush conducts a current of 40 A; 30 A through segment 2 and 10 A through segment 1. Note that current in coil A is 10 A but in the reverse direction to that before the start of commutation. The reader may see the action of the commutator in reversing the current in a coil as the coil passes the brush axis.

(v) Fig. (2.7) (v) shows the instant when the brush is in contact only with segment 2. The brush again conducts 40 A; 20 A from coil A and 20 A from the adjacent coil to coil A. Note that now current in coil A is 20 A but in the reverse direction. Thus the coil A has undergone commutation. Each coil undergoes commutation in this way as it passes the brush axis. Note that during commutation, the coil under consideration remains short-circuited by the brush.

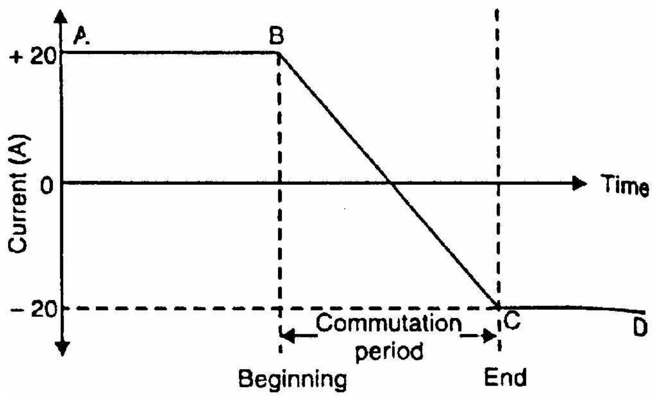

Fig. (2.8)

Fig. (2.8) shows the current-time graph for the coil A undergoing commutation. The horizontal line AB represents a constant current of 20 A upto the beginning of commutation. From the finish of commutation, it is represented by another horizontal line CD on the opposite side of the zero line and the same distance from it as AB i.e., the current has exactly reversed (– 20 A). The way in which current changes from B to C depends upon the conditions under which the coil undergoes commutation. If the current changes at a uniform rate (i.e., BC is a straight line), then it is called ideal commutation as shown in Fig. (2.8). Under such conditions, no sparking will take place between the brush and the commutator.

Practical difficulties

The ideal commutation (i.e., straight line change of current) cannot be attained in practice. This is mainly due to the fact that the armature coils have appreciable inductance. When the current in the coil undergoing commutation changes, self-induced e.m.f. is produced in the coil. This is generally called reactance voltage. This reactance voltage opposes the change of current in the coil undergoing commutation. The result is that the change of current in the coil undergoing commutation occurs more slowly than it would be under ideal commutation. This is illustrated in Fig. (2.9). The straight line RC represents the ideal commutation whereas the curve BE represents the change in current when self-inductance of the coil is taken into account. Note that current CE (= 8A in Fig. 2.9) is flowing from the commutator segment 1 to the brush at the instant when they part company. This results in sparking just as when any other current-carrying circuit is broken. The sparking results in overheating of commutator-brush contact and causing damage to both.

Fig. (2.10) illustrates how sparking takes place between the commutator segment and the brush. At the end of commutation or short-circuit period, the current in coil A is reversed to a value of 12 A (instead of 20 A) due to inductance of the coil. When the brush breaks contact with segment 1, the remaining 8 A current jumps from segment 1 to the brush through air causing sparking between segment 1 and the brush.

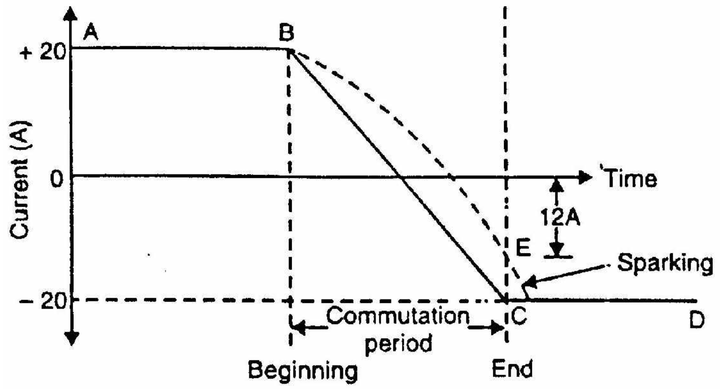

Fig. (2.9)

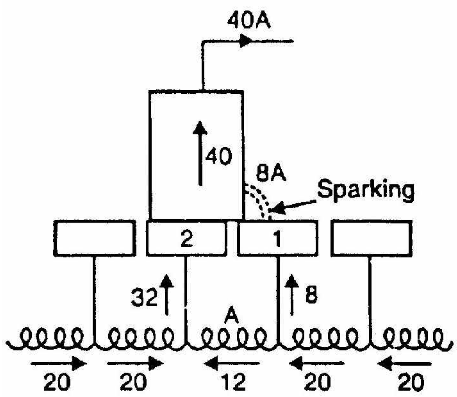

Fig. (2.10)

2.10 Calculation of Reactance Voltage

Reactance voltage = Coefficient of self-inductance × Rate of change of current

When a coil undergoes commutation, two commutator segments remain short-circuited by the brush. Therefore, the time of short circuit (or commutation period T_c) is equal to the time required by the commutator to move a distance equal to the circumferential thickness of the brush minus the thickness of one insulating strip of mica.

Let W_b = brush width in cm; W_m = mica thickness in cm

v = peripheral speed of commutator in cm/s

$$\therefore \quad \text{Commutation period, } T_c = \frac{W_b - W_m}{v} \quad \text{seconds}$$

The commutation period is very small, say of the order of 1/500 second.

Let the current in the coil undergoing commutation change from + I to – I (amperes) during the commutation. If L is the inductance of the coil, then reactance voltage is given by;

Reactance Voltage $$E_R = L \times \frac{2I}{T_c}$$ for linear commutation

2.11 Methods of Improving Commutation

Improving commutation means to make current reversal in the short-circuited coil as sparkless as possible. The following are the two principal methods of improving commutation:

(i) Resistance commutation
(ii) E.M.F. commutation

We shall discuss each method in turn.

2.12 Resistance Commutation

The reversal of current in a coil (i.e., commutation) takes place while the coil is short-circuited by the brush. Therefore, there are two parallel paths for the current as long as the short circuit exists. If the contact resistance between the brush and the commutator is made large, then current would divide in the inverse ratio of contact resistances (as for any two resistances in parallel). This is the key point in improving commutation. This is achieved by using carbon brushes (instead of Cu brushes) which have high contact resistance. This method of improving commutation is called resistance commutation.

Figs. (2.11) and (2.12) illustrates how high contact resistance of carbon brush improves commutation (i.e., reversal of current) in coil A. In Fig. (2.11) (i), the brush is entirely on segment 1 and, therefore, the current in coil A is 20 A. The coil A is yet to undergo commutation. As the armature rotates, the brush short-circuits the coil A and there are two parallel paths for the current into the brush. Fig. (2.11) (ii) shows the instant when the brush is one-fourth on segment 2 and three-fourth on segment 1. The equivalent electric circuit is shown in Fig. (2.11) (iii) where R_1 and R_2 represent the brush contact resistances on segments 1 and 2. A resistor is not shown for coil A since it is assumed that the coil resistance is

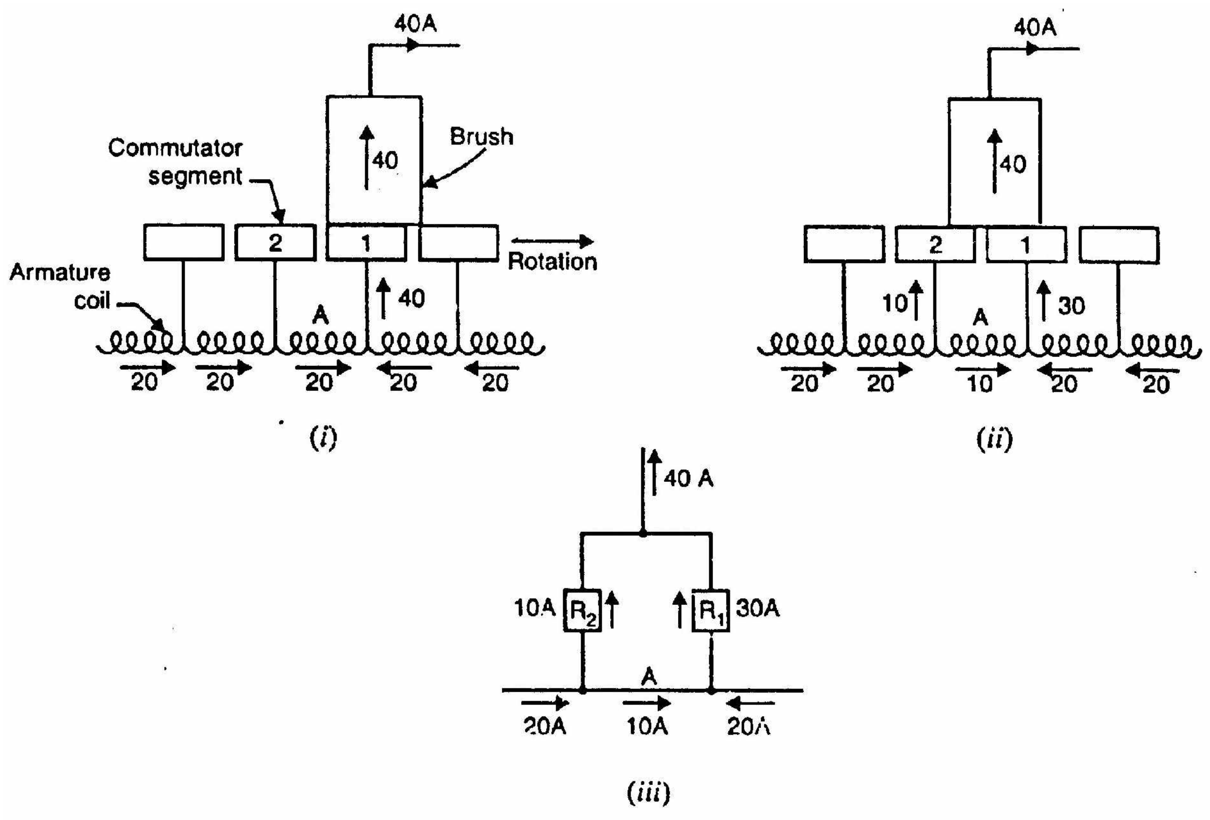

Fig. (2.11)

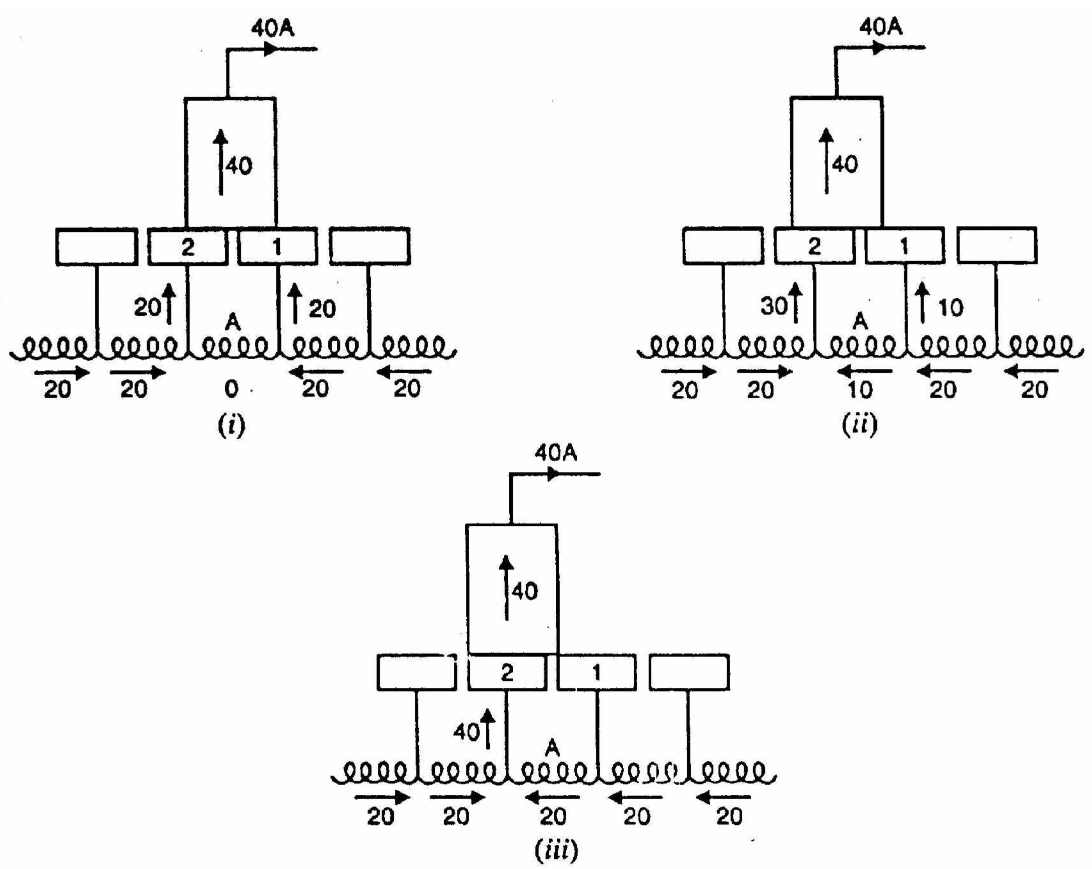

Fig.(2.12)

negligible as compared to the brush contact resistance. The values of current in the parallel paths of the equivalent circuit are determined by the respective resistances of the paths. For the condition shown in Fig. (2.11) (ii), resistor R_2 has three times the resistance of resistor R_1. Therefore, the current distribution in the paths will be as shown. Note that current in coil A is reduced from 20 A to 10 A due to division of current in (he inverse ratio of contact resistances. If the Cu brush is used (which has low contact resistance), R_1 R_2 and the current in coil A would not have reduced to 10 A.

As the carbon brush passes over the commutator, the contact area with segment 2 increases and that with segment 1 decreases i.e., R_2 decreases and R_1 increases. Therefore, more and more current passes to the brush through segment 2. This is illustrated in Figs. (2.12) (i) and (2.12) (ii), When the break between the brush and the segment 1 finally occurs [See Fig. 2.12 (iii)], the current in the coil is reversed and commutation is achieved.

It may be noted that the main cause of sparking during commutation is the production of reactance voltage and carbon brushes cannot prevent it. Nevertheless, the carbon brushes do help in improving commutation. The other minor advantages of carbon brushes are:

(i) The carbon lubricates and polishes the commutator.
(ii) If sparking occurs, it damages the commutator less than with copper brushes and the damage to the brush itself is of little importance.

2.13 E.M.F. Commutation

In this method, an arrangement is made to neutralize the reactance voltage by producing a reversing voltage in the coil undergoing commutation. The reversing voltage acts in opposition to the reactance voltage and neutralizes it to some extent. If the reversing voltage is equal to the reactance voltage, the effect of the latter is completely wiped out and we get sparkless commutation. The reversing voltage may be produced in the following two ways:

(i) By brush shifting
(ii) By using interpoles or compoles

(i) By brush shifting

In this method, the brushes are given sufficient forward lead (for a generator) to bring the short-circuited coil (i.e., coil undergoing commutation) under the influence of the next pole of opposite polarity. Since the short-circuited coil is now in the reversing field, the reversing voltage produced cancels the reactance voltage. This method suffers from the following drawbacks:

(a) The reactance voltage depends upon armature current. Therefore, the brush shift will depend on the magnitude of armature current which keeps on changing. This necessitates frequent shifting of brushes.

(b) The greater the armature current, the greater must be the forward lead for a generator. This increases the demagnetizing effect of armature reaction and further weakens the main field.

(ii) By using interpoles or compotes

The best method of neutralizing reactance voltage is by, using interpoles or compoles. This method is discussed in Sec. (2.14).

2.14 Interpoles or Compoles

The best way to produce reversing voltage to neutralize the reactance voltage is by using interpoles or compoles. These are small poles fixed to the yoke and spaced mid-way between the main poles (See Fig. 2.13). They are wound with comparatively few turns and connected in series with the armature so that they carry armature current. Their polarity is the same as the next main pole ahead in the direction of rotation for a generator (See Fig. 2.13). Connections for a d.c. generator with interpoles is shown in Fig. (2.14).

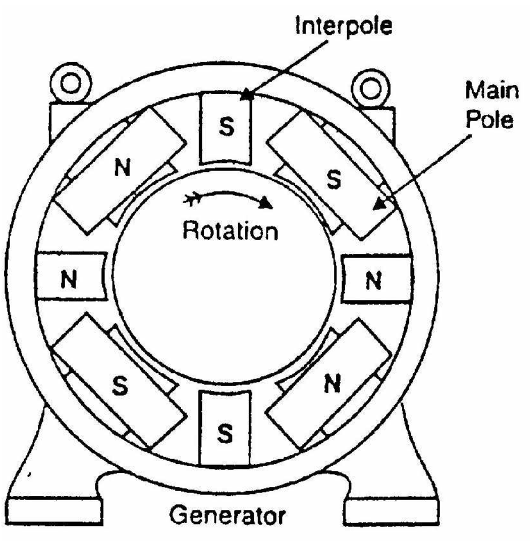

Fig. (2.13)

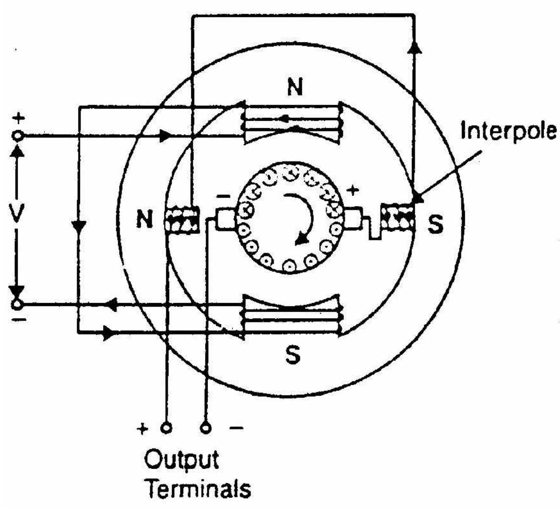

Fig. (2.14)

Functions of Interpoles

The machines fitted with interpoles have their brushes set on geometrical neutral axis (no lead). The interpoles perform the following two functions:

(i) As their polarity is the same as the main pole ahead (for a generator), they induce an e.m.f. in the coil (undergoing commutation) which opposes reactance voltage. This leads to sparkless commutation. The e.m.f. induced by compoles is known as commutating or reversing e.m.f. Since the interpoles carry the armature current and the reactance voltage is also proportional to armature current, the neutralization of reactance voltage is automatic.

(ii) The m.m.f. of the compoles neutralizes the cross-magnetizing effect of armature reaction in small region in the space between the main poles. It is because the two m.m.f.s oppose each other in this region.

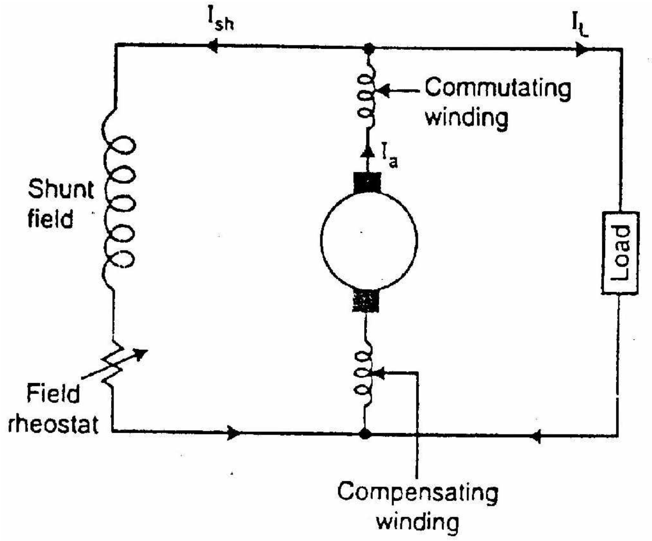

Fig. (2.15)

Fig. (2.15) shows the circuit diagram of a shunt generator with commutating winding and compensating winding. Both these windings are connected in series with the armature and so they carry the armature current. However, the functions they perform must be understood clearly. The main function of commutating winding is to produce reversing (or commutating) e.m.f. in order to cancel the reactance voltage. In addition to this, the m.m.f. of the commutating winding neutralizes the cross-magnetizing ampere-turns in the space between the main poles. The compensating winding neutralizes the cross-magnetizing effect of armature reaction under the pole faces.

2.15 Equalizing Connections

We know that the armature circuit in lap winding of a multipolar machine has as many parallel paths as the number of poles. Because of wear in the bearings, and for other reasons, the air gaps in a generator become unequal and, therefore, the flux in some poles becomes greater than in others. This causes the voltages of the different paths to be unequal. With unequal voltages in these parallel paths, circulating current will flow even if no current is supplied to an external load. If these currents are large, some of the brushes will be required to carry a greater current at full load than they were designed to carry and this will cause sparking. To relieve the brushes of these circulating currents, points on the armature that are at the same potential are connected together by means of copper bars called equalizer rings. This is achieved by connecting to the same equalizer ring the coils that occupy the same positions relative to the poles (See Fig. 2.16). Thus referring to Fig. (2.16), the coil consisting of conductor 1 and conductor 8 occupies the same position relative to the poles as the coil consisting of conductors 13 and 20. Therefore, the two coils are connected to the same equalizer ring. The equalizers provide a low resistance path for the circulating current. As a result, the circulating current due to the slight differences in the voltages of the various parallel paths passes through the equalizer rings instead of passing through the brushes. This reduces sparking.

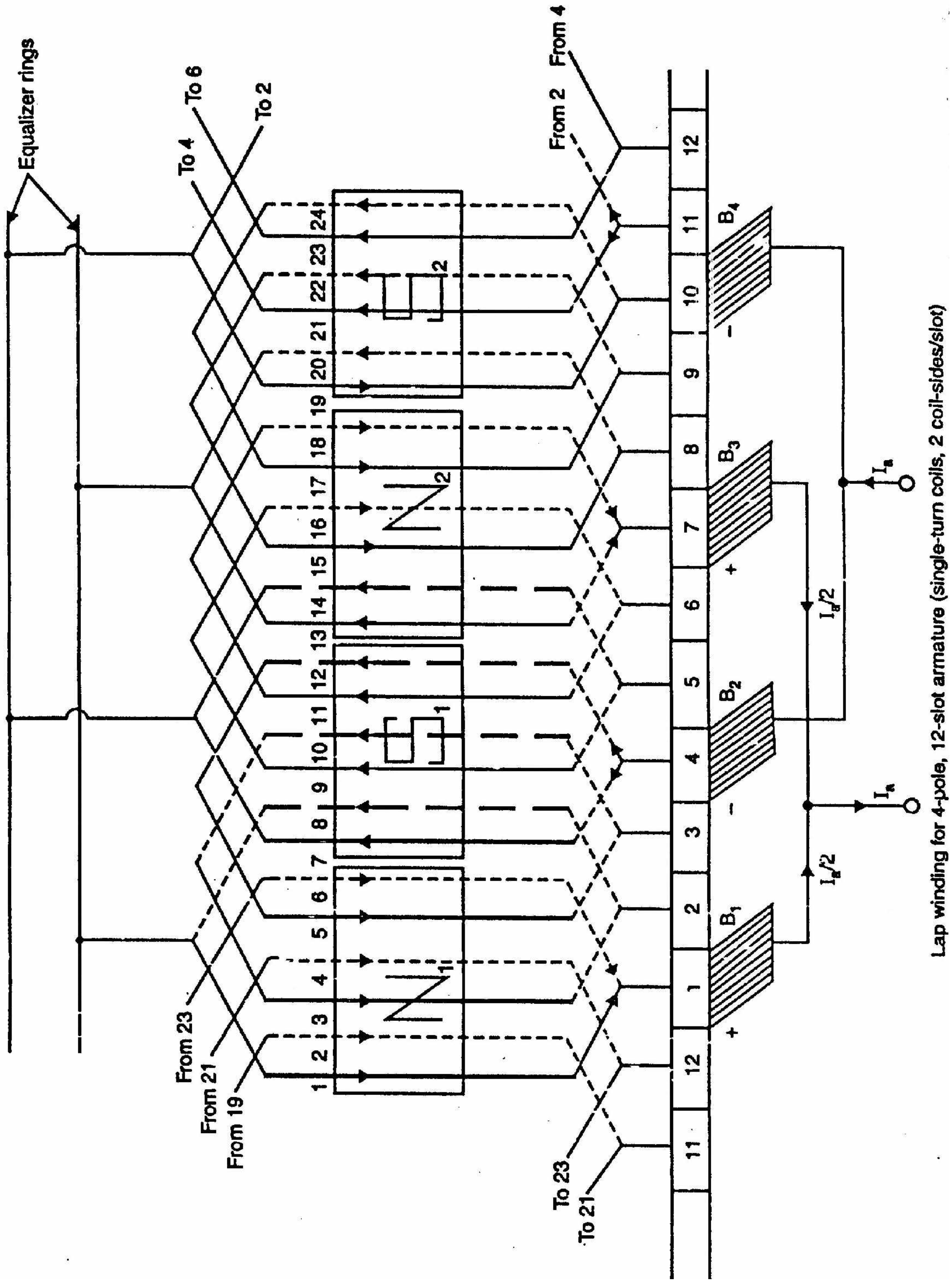

Fig. (2.16)

Equalizer rings should be used only on windings in which the number of coils is a multiple of the number of poles. For best results, each coil should be connected to an equalizer ring but this is seldom done. Satisfactory results are obtained by connecting about every third coil to an equalizer ring. In order to distribute the connections to the equalizer rings equally, the number of coils per pole must be divisible by the connection pitch.

Note. Equalizer rings are not used in wave winding because there is no imbalance in the voltages of the two parallel paths. This is due to the fact that conductors in each of the two paths pass under all N and S poles successively (unlike a lap winding where all conductors in any parallel path lie under one pair of poles). Therefore, even if there are inequalities in pole flux, they will affect each path equally.