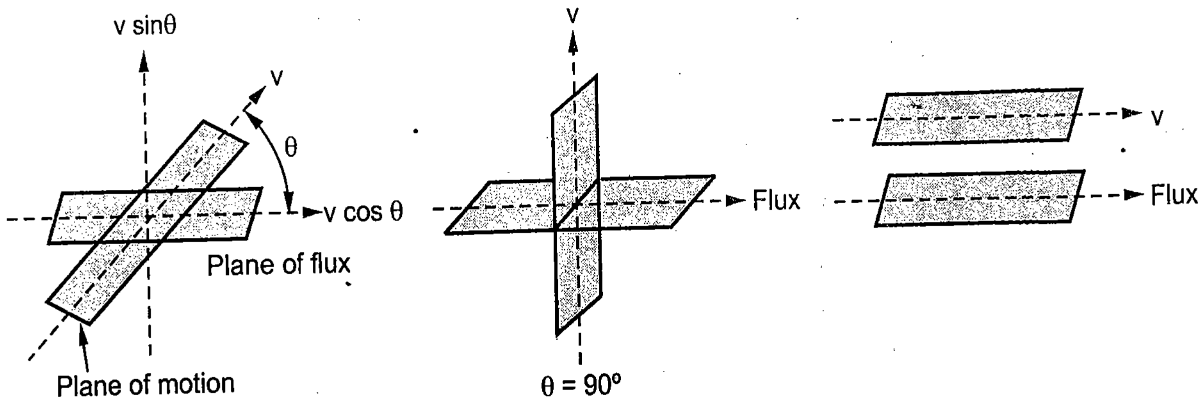


(a) $E \propto v \sin\theta$ (b) Maximum E (c) E = 0

Fig. 2.2.4

From the equation of the induced e.m.f., it can be seen that the basic nature of the induced e.m.f. in a d.c. generator is purely sinusoidal i.e. alternating. To have d.c. voltage, a device is used in a d.c. generator to convert the alternating e.m.f. to unidirectional e.m.f. This device is called **commutator**.

Review Questions

1. *Explain the principle of operation of a d.c. generator.*
   JNTU : May-03, 04, Nov.-04, 07, 12, March-14, Marks 6
2. *Explain Fleming's right hand rule used to decide the direction of an induced e.m.f. in a generator.*

2.3 Constructional Features of a D.C. Machine

JNTU : Nov.-03, 04, 05, 08, 13, May-04, 05, 08, 09, 13, June-04, Dec.-04, Jan.-14, March-06

As stated earlier, whether a machine is **d.c. generator or a motor** the construction basically remains the same as shown in the Fig. 2.3.1. (See Fig. 2.3.1 on next page)

It consists of the following parts :

2.3.1 Yoke

a) Functions :

1. It serves the purpose of outermost cover of the d.c. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.
2. It provides mechanical support to the poles.
   And it Also Acts as the return path for magnetic flux lines
3. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. The low reluctance path is important to avoid wastage of power to provide same flux. Large current and hence the power is necessary if the path has high reluctance, to produce the same flux.

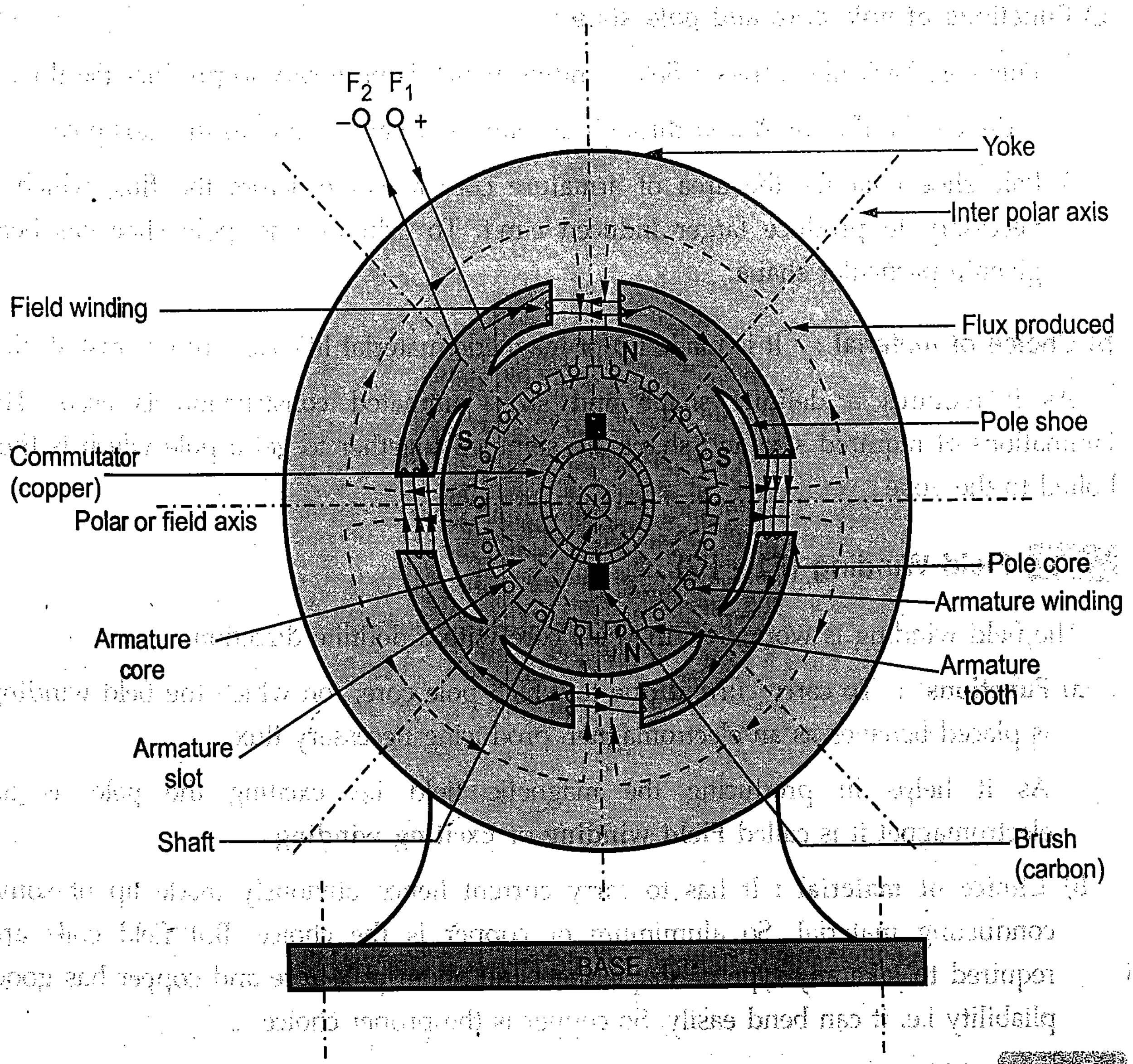


Fig. 2.3.1 A cross-section of typical d.c. machine

b) Choice of material : To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is cheapest. For large machines rolled steel, cast steel, silicon steel is used which provides high permeability i.e. low reluctance and gives good mechanical strength.

2.3.2 Poles

Each pole is divided into two parts namely, I) Pole core and II) Pole shoe

This is shown in the Fig. 2.3.2.

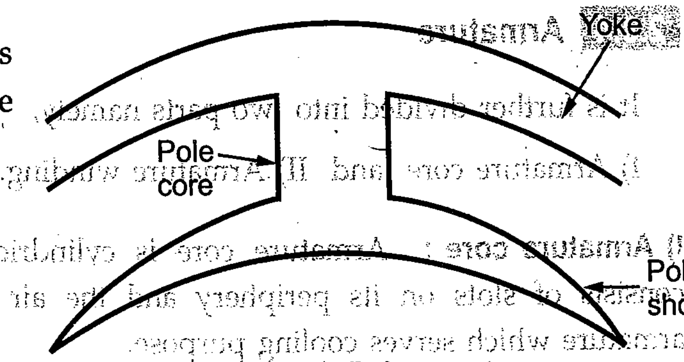


Fig. 2.3.2 Pole structure

a) Functions of pole core and pole shoe :

1. Pole core basically carries a field winding which is necessary to produce the flux.
2. It directs the flux produced through air gap to armature core, to the next pole.
3. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced e.m.f. To achieve this, pole shoe has been given a particular shape.

b) Choice of material : It is made up of magnetic material like cast iron or cast steel.

As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to the yoke.

2.3.3 Field Winding (F1 - F2)

The field winding is wound on the pole core with a definite direction.

a) Functions : To carry current due to which pole core, on which the field winding is placed behaves as an electromagnet, producing necessary flux.

As it helps in producing the magnetic field i.e. exciting the pole as an electromagnet it is called **Field winding** or **Exciting winding.**

b) Choice of material : It has to carry current hence obviously made up of some conducting material. So aluminium or copper is the choice. But field coils are required to take any type of shape and bend about pole core and copper has good pliability i.e. it can bend easily. So copper is the proper choice.

Key Point *Field winding is divided into various coils called field coils. These are connected in series with each other and wound in such a direction around pole cores, such that alternate 'N' and 'S' poles are formed.*

By using right hand thumb rule for current carrying circular conductor, it can be easily determined that how a particular core is going to behave as 'N' or 'S' for a particular winding direction around it. The direction of winding and flux can be observed in the Fig. 2.3.1.

2.3.4 Armature

It is further divided into two parts namely,

I) Armature core and II) Armature winding.

I) Armature core : Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

a) Functions :

1. Armature core provides house for armature winding i.e. armature conductors.
2. To provide a path of low reluctance to the magnetic flux produced by the field winding.

b) Choice of material : As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.

It is made up of laminated construction to keep eddy current loss as low as possible. A single circular lamination used for the construction of the armature core is shown in the Fig. 2.3.3.

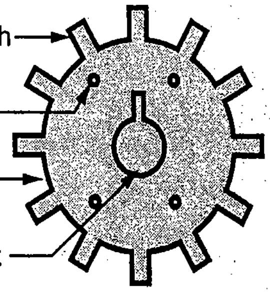


Fig. 2.3.3 Single circular lamination of armature core

II) Armature winding : Armature winding is nothing but the interconnection of the armature conductors, placed in the slots provided on the armature core periphery. When the armature is rotated, in case of generator, magnetic flux gets cut by armature conductors and e.m.f. gets induced in them.

a) Functions :

1. Generation of e.m.f. takes place in the armature winding in case of generators.
2. To carry the current supplied in case of d.c. motors.
3. To do the useful work in the external circuit.

b) Choice of material : As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

Armature winding is generally former wound. The conductors are placed in the armature slots which are lined with though insulating material.

2.3.5 Commutator

We have seen earlier that the basic nature of e.m.f. induced in the armature conductors is alternating. This needs rectification in case of d.c. generator, which is possible by a device called commutator.

a) Functions :

1. To facilitate the collection of current from the armature conductors.
2. To convert internally developed alternating e.m.f. to unidirectional (d.c.) e.m.f.
3. To produce unidirectional torque in case of motors.

b) Choice of material : As it collects current from armature, it is also made up of copper segments.

It is cylindrical in shape and is made up of wedge shaped segments of hard drawn, high conductivity copper. These segments are insulated from each other by thin layer of mica. Each commutator segment is connected to the armature conductor by means of copper lug or strip. This connection is shown in the Fig. 2.3.4.

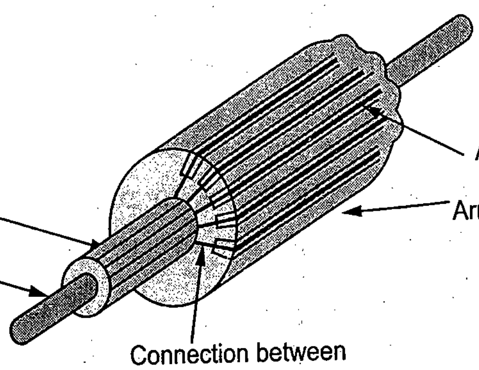


Fig. 2.3.4 Commutator

2.3.6 Brushes and Brush Gear

Brushes are stationary and resting on the surface of the commutator.

a) Function : To collect current from commutator and make it available to the stationary external circuit.

b) Choice of material : Brushes are normally made up of soft material like carbon.

Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called **pig tail** is used to connect the brush to the external circuit. To avoid wear and tear of commutator, the brushes are made up of soft material like carbon.

2.3.7 Bearings

Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

Review Questions

1. *Draw a detailed sketch of a d.c. machine and identify the different parts. Briefly explain the function of each major part.*
   JNTU : Nov.-03, 04, 05, 08, 13, May-04, 05, 09, March-06, Nov.-08, May-09, Marks 14
2. *Name the main parts of a D.C. machine and state the materials of which each part is made.*
   JNTU : Nov.-03, 05, June-04, Dec.-04, May-05, March-06, Marks 13
3. *Explain the purpose of a pole shoe in a d.c. machine with the help of diagrams.*
   JNTU : Jan.-14, Marks 6

2.4 Types of Armature Winding

JNTU : Nov.-04, 08, 09, 12, May-03, 09

We have seen that there are number of armature conductors, which are connected in specific manner as per the requirement, which is called **armature winding.** According to the way of connecting the conductors, armature winding has basically two types namely,

a) Lap winding b) Wave winding.

2.4.1 Lap Winding

In this case, if connection is started from conductor in slot 1 then connections overlap each other as winding proceeds, till starting point is reached again.

Developed view of part of the armature winding in lap fashion is shown in the Fig. 2.4.1.

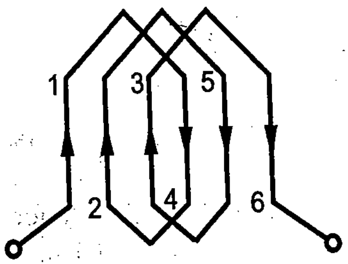


Fig. 2.4.1 Lap winding

As seen from the Fig. 2.4.1, there is overlapping of coils while proceeding.

Key Point *Due to such connection, the total number of conductors get divided into 'P' number of parallel paths, where P = Number of poles in the machine.*

Large number of parallel paths indicate high current capacity of machine hence lap winding is preferred for high current rating generators.

2.4.2 Wave Winding

In this type of connection, winding always travels ahead avoiding overlapping. It travels like a progressive wave hence called wave winding. To get an idea of wave winding a part of armature winding in wave fashion is shown in the Fig. 2.4.2.

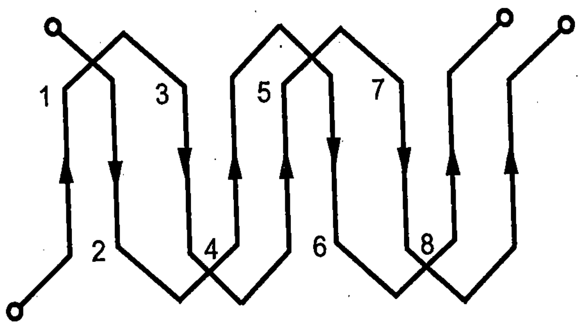


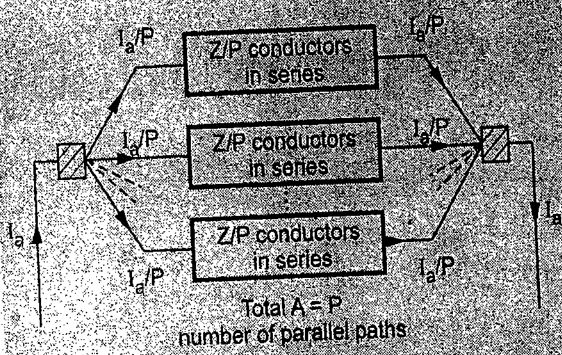
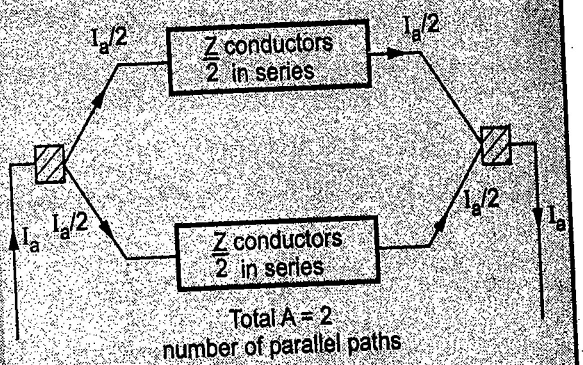
Fig. 2.4.2 Wave winding

Both coils starting from slot 1 and slot 2 are progressing in wave fashion.

Key Point *Due to this type of connection, the total number of conductors get divided into two number of parallel paths always, irrespective of number of poles of the machine. As number of parallel paths are less, it is preferable for low current, high voltage capacity generators.*

The number of parallel paths in which armature conductors are divided due to lap or wave fashion of connection is denoted as A. So **A = P** for **lap** connection and **A = 2** for **wave** connection.

2.4.3 Comparison of Lap and Wave Type Windings

Sr. No.	Lap winding	Wave winding
1.	Number of parallel paths (A) = poles (P)	Number of parallel paths (A) = 2 (always)
2.	Number of brush sets required is equal to number of poles.	Number of brush sets required is always equal to two.
3.	Preferable for high current, low voltage capacity generators.	Preferable for high voltage, low current capacity generators.
4.	Normally used for generators of capacity more than 500 A.	Preferred for generators of capacity less than 500 A.
5.	If Z = Total number of conductors then, 	If Z = Total number of conductors then, 

2.4.4 Winding Terminologies

a) Conductor : It is the actual armature conductor which is under the influence of the magnetic field, placed in the armature slot.

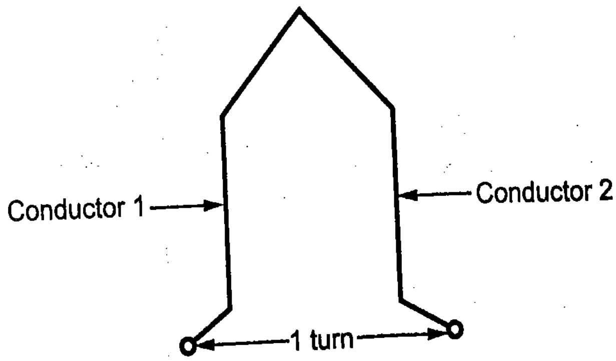


Fig. 2.4.3 Single turn

b) Turn : The two conductors placed in different slots when connected together, forms a turn. While describing armature winding the number of turns may be specified from which, the number of conductors can be decided.

$$Z = 2 \times \text{Number of turns}$$

3.1 Introduction

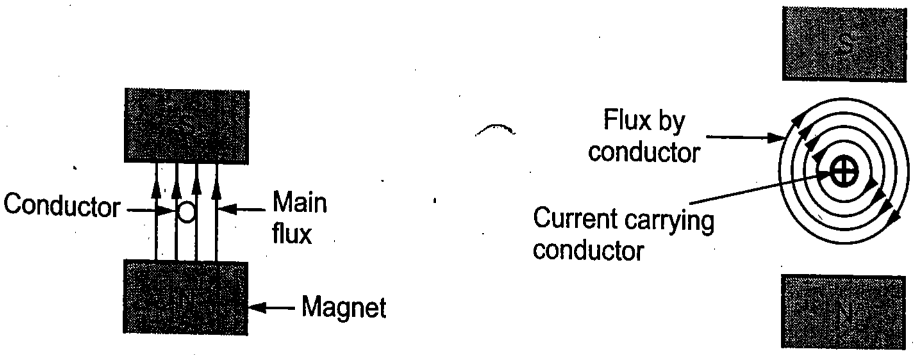
An electric motor is a device which converts an electrical energy into mechanical energy. In a d.c. motor, input electrical energy is supplied by a d.c. supply. The basic construction of d.c. machine is same whether it is a motor or a generator.

3.2 Principle of Operation of a D.C. Motor

JNTU : Nov.-03, 08, May-05

The principle of operation of a d.c. motor can be stated in a single statement as 'when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force'. In a practical d.c. motor, field winding produces a required magnetic field while armature conductors play a role of a current carrying conductors and hence armature conductors experience a force. As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a **torque**. The torque is the product of force and the radius at which this force acts. So overall armature experiences a torque and starts rotating. Let us study this motoring action in detail.

Consider a single conductor placed in a magnetic field as shown in the Fig. 3.2.1 (a). The magnetic field is produced by a permanent magnet but in a practical d.c. motor it is produced by the field winding when it carries a current.



(a) Conductor in a magnetic field **(b) Flux produced by current carrying conductor**

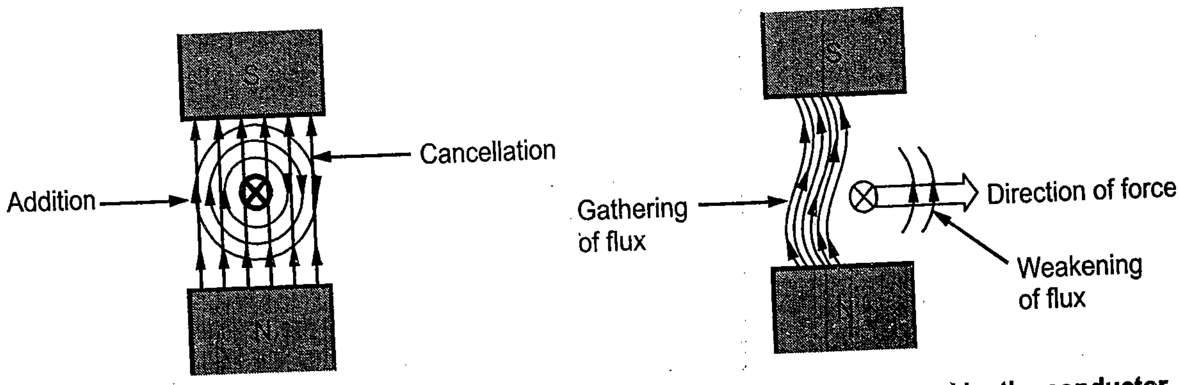
Fig. 3.2.1

Now this conductor is excited by a separate supply so that it carries a current in a particular direction. Consider that it carries a current away from an observer as shown in the Fig. 3.2.1 (b). Any current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux, around. The direction of this flux can be determined by right hand thumb rule. For direction of current considered, the direction of flux around a conductor is clockwise. For simplicity of understanding, the main flux produced by the permanent magnet is not shown in the Fig. 3.2.1 (b).

Now there are two fluxes present,

1. The flux produced by the permanent magnet called main flux.
2. The flux produced by the current carrying conductor.

These are shown in the Fig. 3.2.2 (a). From this, it is clear that on one side of the conductor, both the fluxes are in the same direction. In this case, on the left of the conductor there is gathering of the flux lines as two fluxes help each other. As against this, on the right of the conductor, the two fluxes are in opposite direction and hence try to cancel each other. Due to this, the density of the flux lines in this area gets weakened. So on the left, there exists high flux density area while on the right of the conductor there exists low flux density area as shown in the Fig. 3.2.2 (b).



(a) Interaction of two fluxes

(b) Force experienced by the conductor

Fig. 3.2.2

This flux distribution around the conductor acts like a stretched rubber band under tension. This exerts a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e. from left to right for the case considered as shown in the Fig. 3.2.2 (b).

Key Point *In the practical d.c. motor, the permanent magnet is replaced by a field winding which produces the required flux called main flux and all the armature conductors, mounted on the periphery of the armature drum, get subjected to the mechanical force. Due to this, overall armature experiences a twisting force called torque and armature of the motor starts rotating.*

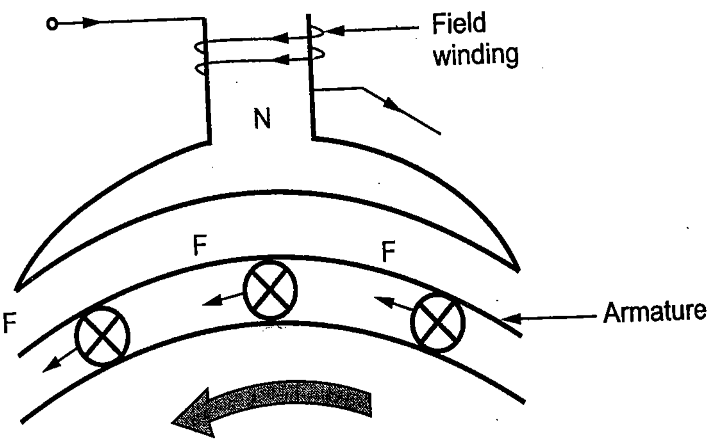


Fig. 3.2.3 Torque exerted on armature

Review Question

1. *Explain the working principle of a d.c. motor.* **JNTU : Nov.-03, 08, May-05, Marks 8**

conductor reverses its direction. However if both the directions are reversed, the direction of the force experienced remains the same.

Key Point *So in a practical motor, to reverse its direction of rotation, either direction of main field produced by the field winding is reversed or direction of the current passing through the armature is reversed.*

The direction of the main field can be reversed by changing the direction of current passing through the field winding, which is possible by interchanging the polarities of supply which is given to the field winding. In short, to have a motoring action two fluxes must exist, the interaction of which produces a torque.

Review Questions

1. *How to decide the direction of rotation of a d.c. motor ?*
2. *Explain clearly how the direction of rotation of a d.c. motor can be reversed.*

JNTU : Nov.-04, March-06, Marks 4

3.4 Significance of Back E.M.F.

JNTU : May-04, 05, Nov.-04, 06, March-06

It is seen in the generating action, that when a conductor cuts the lines of flux, e.m.f. gets induced in the conductor. The question is obvious that in a d.c. motor, after a motoring action, armature starts rotating and armature conductors cut the main flux. So is there a generating action existing in a motor ? The answer to this question is 'Yes'.

After a motoring action, there exists a generating action. There is an induced e.m.f. in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced e.m.f. in the armature always acts in the opposite direction of the supply voltage. This is according to the **Lenz's law** which states that the direction of the induced e.m.f. is always so as to oppose the cause producing it. In a d.c. motor, electrical input i.e. the supply voltage is the cause and hence this induced e.m.f. opposes the supply voltage. This e.m.f. tries to set up a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor.

So as this e.m.f. always opposes the supply voltage, it is called **back e.m.f.** and denoted as E_b. Though it is denoted as E_b, basically it gets generated by the generating action which we have seen earlier in case of generators. So its magnitude can be determined by the e.m.f. equation which is derived earlier. So,

$$E_b = \frac{\phi P N Z}{60 A} \text{ volts}$$

where all symbols carry the same meaning as seen earlier.

3.17.1 Three Point Starter

The Fig. 3.17.2 shows this type of starter.

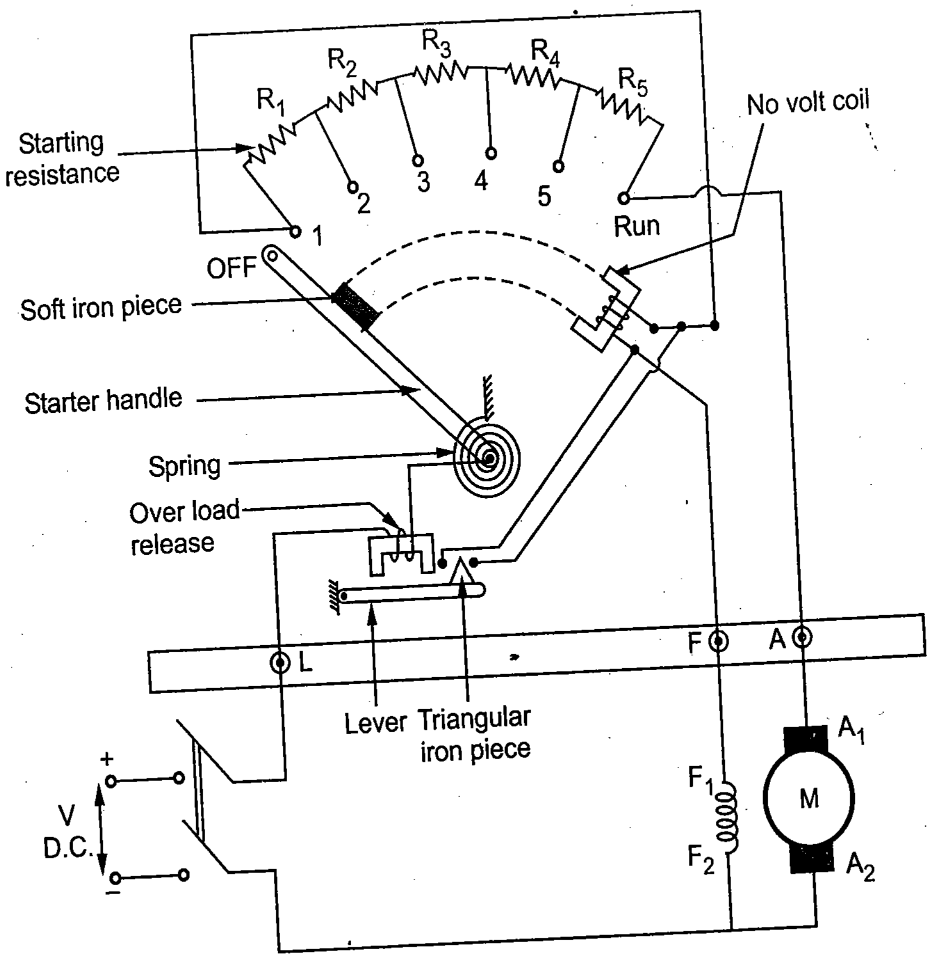


Fig. 3.17.2 Three point starter

The starter is basically a variable resistance, divided into number of sections. The contact points of these sections are called **studs** and brought out separately shown as OFF, 1, 2, ... upto RUN. There are three main points of this starter :

1. 'L' → Line terminal to be connected to positive of supply.
2. 'A' → To be connected to the armature winding.
3. 'F' → To be connected to the field winding.

Point 'L' is further connected to an electromagnet called **Overload Release** (OLR). The second end of 'OLR' is connected to a point where handle of the starter is pivoted. This handle is free to move from its other side against the force of the spring. This spring brings back the handle to the OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to the another electromagnet called **No Volt Coil** (NVC). The NVC is further connected to terminal 'F'. The starting resistance is entirely in series with the armature. The OLR and NVC are the two protecting devices of the starter.

Operation : Initially the handle is in the OFF position. The d.c. supply to the motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding gets supply through the parallel path provided to starting resistance, through NVC. While entire starting resistance comes in series with the armature and armature current which is high at start, gets limited. As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., cutting out the starting resistance gradually from the armature circuit. Finally when the starter handle is in 'RUN' position, the entire starting resistance gets removed from the armature circuit and motor starts operating with normal speed. The handle is moved manually, and the obvious question is how handle will remain in the 'RUN' position, as long as motor is running ?

Let us see the action of NVC which will give the answer to this question along with some other functions of NVC.

3.17.1.1 Functions of No Volt Coil

1. The supply to the field winding is derived through NVC. So when field current flows, it magnetises the NVC. When the handle is in the 'RUN' position, soft iron piece connected to the handle gets attracted by the magnetic force produced by NVC. Design of NVC is such that it holds the handle in 'RUN' position against the force of the spring as long as supply to the motor is proper. Thus NVC holds the handle in the 'RUN' position and hence also called **hold on coil.**
2. Whenever there is supply failure or if field circuit is broken, the current through NVC gets affected. It looses its magnetism and hence not in a position to keep the soft iron piece on the handle, attracted. Under the spring force, handle comes back to OFF position, switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problem. The entire starting resistance comes back in series with the armature when attempt is made to start the motor everytime. This prevents the damage of the motor caused due to accidental starting.
3. NVC performs the similar action under low voltage conditions and protects the motor from such dangerous supply conditions as well.

3.17.1.2 Action of Over Load Release

The current through the motor is taken through the OLR, an electromagnet. Under overload condition, high current is drawn by the motor from the supply which passes through OLR. Below this magnet, there is an arm which is fixed at its fulcrum and normally resting in horizontal position. Under overloading, high current though OLR produces enough force of attraction to attract the arm upwards. Normally magnet is so designed that up to a full load value of current, the force of attraction produced is just enough to balance the gravitational force of the arm and hence not lifting it up. At the end of this arm, there is a triangular iron piece fitted. When the arm is pulled upwards the triangular piece touches to the two points which are connected to the two ends of NVC. This shorts the NVC and voltage across NVC becomes zero due to which NVC looses its magnetism. So under the spring force, handle comes back to the OFF position, disconnecting the motor from the supply. Thus motor gets saved from the overload conditions.

In this starter, it can be observed that as handle is moved from different studs one by one, the part of the starting resistance which gets removed from the armature circuit, gets added to the field circuit. As the value of starting resistance is very small as compared to the field winding resistance, this hardly affects the field winding performance. But this addition of the resistance in the field circuit can be avoided by providing a brass arc or copper arc connected just below the stud, the end of which is connected to NVC, as shown in the Fig. 3.17.3.

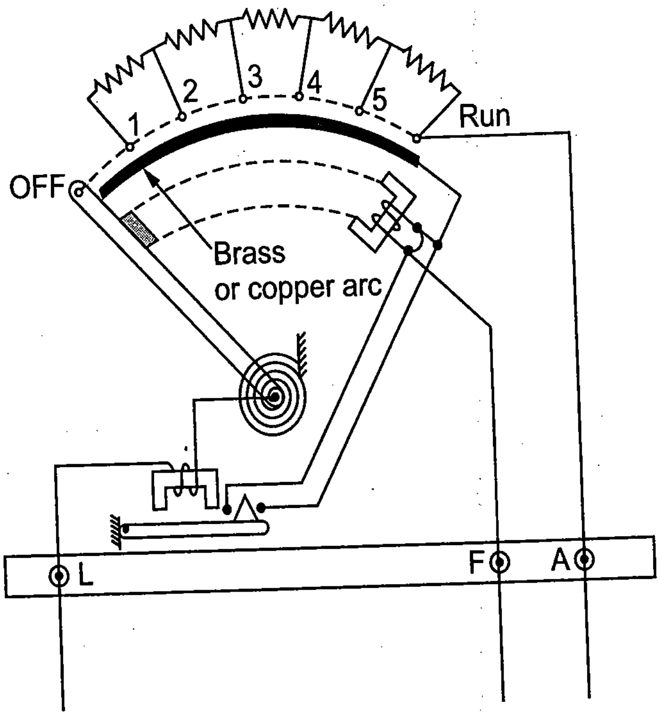


Fig. 3.17.3 Three point starter with brass arc

The handle moves over this arc, supplying the field current directly bypassing the starting resistance. When such an arc is provided, the connection used earlier to supply field winding, is removed.

3.17.1.3 Disadvantage

In this starter, the NVC and the field winding are in series. So while controlling the speed of the motor above rated, field current is reduced by adding an extra resistance in series with the field winding. Due to this, the current through NVC also reduces. Due to this, magnetism produced by NVC also reduces. This may release the handle from its RUN position switching off the motor. To avoid the dependency of NVC and the field winding, four point starter is used, in which NVC and the field winding are connected in parallel.

3.19 Speed Control of D.C. Shunt Motor

JNTU : Dec.-03, May-04, 05, 08, 09, Nov.-03, 04, 05, 08, March-06

Out of the three methods, let us study flux control method.

3.19.1 Flux Control

As indicated by the speed equation, the speed is inversely proportional to the flux. The flux is dependent on the current through the shunt field winding. Thus flux can be controlled by adding a rheostat (variable resistance) in series with the shunt field winding, as shown in the Fig. 3.19.1.

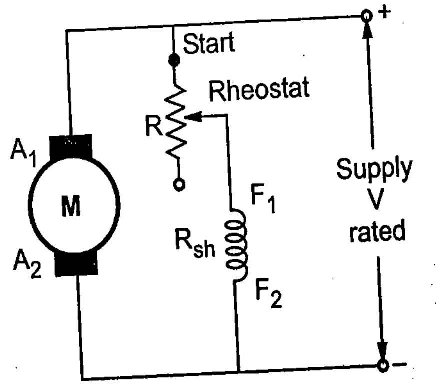


Fig. 3.19.1 Flux control of shunt motor

At the beginning the rheostat R is kept at minimum indicated as start in the Fig. 3.19.1. The supply voltage is at its rated value. So current through shunt field winding is also at its rated value. Hence the speed is also rated speed also called normal speed. Then the resistance R is increased due to which shunt field current I_{sh} decreases, decreasing the flux produced. As $N \propto (1/\phi)$, the speed of the motor increases beyond its rated value.

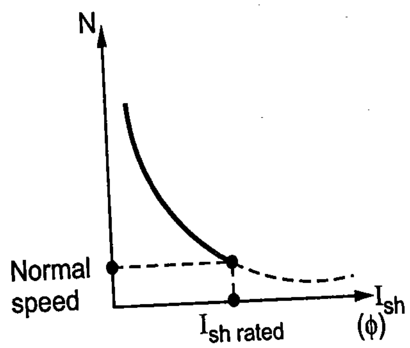


Fig. 3.19.2 N Vs I_{sh} (ϕ) for shunt motor

Thus by this method, the speed control above rated value is possible. This is shown in the Fig. 3.19.2, by speed against field current curve. The curve shows the inverse relation between N and ϕ as its nature is rectangular hyperbola.

It is mentioned that the rated values of electrical parameters should not be exceeded but the speed which is mechanical parameter can be increased upto twice its rated value.

3.19.1.1 Advantages of Flux Control Method

1. It provides relatively smooth and easy control.
2. Speed control above rated speed is possible.
3. As the field winding resistance is high, the field current is small. Hence power loss (I_{sh}^2 R) in the external resistance is very small, which makes the method more economical and efficient.
4. As the field current is small, the size of the rheostat required is small.

3.19.1.2 Disadvantages of Flux Control Method

1. The speed control below normal rated speed is not possible as flux can be increased only upto its rated value.
2. As flux reduces, speed increases. But high speed affects the commutation making motor operation unstable. So there is limit to the maximum speed above normal, possible by this method.

3.19.2 Armature Voltage Control Method or Rheostatic Control

The speed is directly proportional to the voltage applied across the armature. As the supply voltage is normally constant, the voltage across the armature can be controlled by adding a variable resistance in series with the armature as shown in the Fig. 3.19.3.

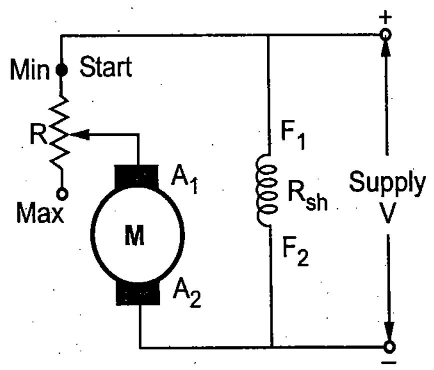


Fig. 3.19.3 Rheostatic control of shunt motor

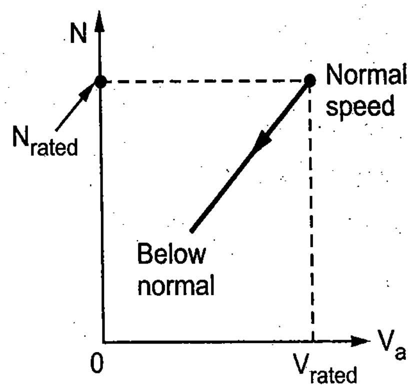


Fig. 3.19.4 N Vs voltage across armature

The field winding is excited by the normal voltage hence I_{sh} is rated and constant in this method. Initially the rheostat position is minimum and rated voltage gets applied across the armature. So speed is also rated. For a given load, armature current is fixed. So when extra resistance is added in the armature circuit, I_a remains same and there is voltage drop across the resistance added (I_a R). Hence voltage across the armature decreases, decreasing the speed below normal value. By varying this extra resistance, various speeds below rated value can be obtained.

So for a **constant load torque**, the speed is directly proportional to the voltage across the armature. The relationship between speed and voltage across the armature is shown in the Fig. 3.19.4.

3.19.2.1 Potential Divider Control

The main disadvantage of the above method is, the speed upto zero is not possible as it requires a large rheostat in series with the armature which is practically impossible. If speed control from zero to the rated speed is required, by rheostatic method then voltage across the armature can be varied by connecting rheostat in a potential divider arrangement as shown in the Fig. 3.19.5.

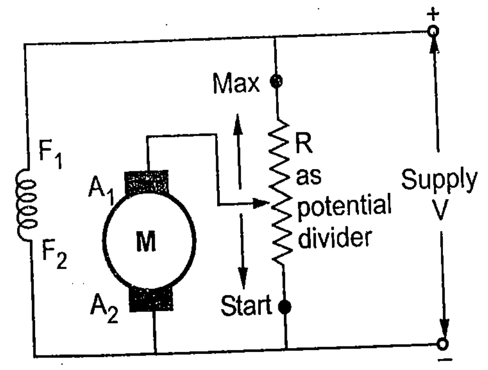


Fig. 3.19.5 Potential divider arrangement

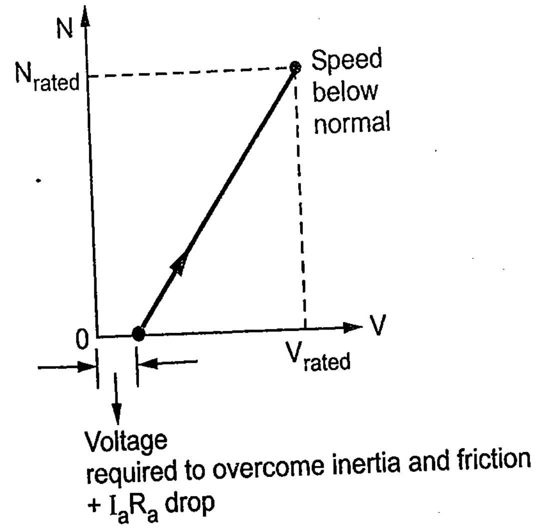


Fig. 3.19.6 N Vs V

When the variable rheostat position is at 'start' point shown, voltage across the armature is zero and hence speed is zero. As rheostat is moved towards 'maximum' point shown, the voltage across the armature increases, increasing the speed. At maximum point the voltage is maximum i.e. rated hence maximum speed possible is rated speed. The relationship is shown in the Fig. 3.19.6.

When the voltage across the armature starts increasing, as long as motor does not overcome inertial and frictional torque, the speed of the motor remains zero. The motor requires some voltage to start hence the graph of voltage and the speed does not pass through the origin as shown in the Fig. 3.19.6.

3.19.2.2 Advantages of Rheostatic Control

1. Easy and smooth speed control below normal is possible.
2. In potential divider arrangement, rheostat can be used as a starter.

3.19.2.3 Disadvantages of Rheostatic Control

1. As the entire armature current passes through the external resistance, there are tremendous power losses.
2. As armature current is more than field current, rheostat required is of large size and capacity.
3. Speed above rated is not possible by this method.
4. Due to large power losses, the method is expensive, wasteful and less efficient.
5. The method needs expensive heat dissipation arrangements.

3.19.3 Applied Voltage Control

Multiple voltage control : In this technique the shunt field of the motor is permanently connected to a fixed voltage supply, while the armature is supplied with various voltages by means of suitable switch gear arrangements.

The Fig. 3.19.7 shows a control of motor by two different working voltages which can be applied to it with the help of switch gear.

In large factories, various values of armature voltages and corresponding arrangement can be used to obtain the speed control.

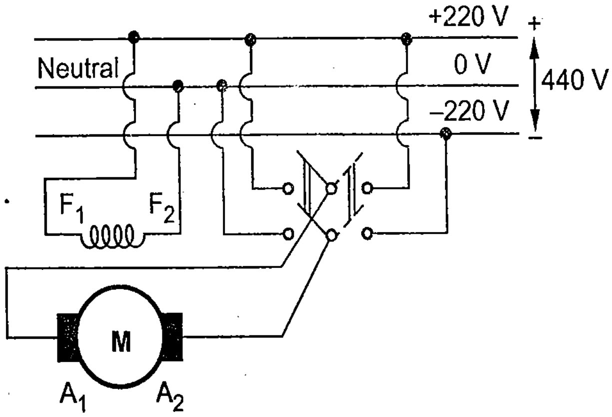


Fig. 3.19.7 Multiple voltage control

3.19.3.1 Advantages of Applied Voltage Control

1. Gives wide range of speed control.
2. Speed control in both directions can be achieved very easily.
3. Uniform acceleration can be obtained.

3.19.3.2 Disadvantages of Applied Voltage Control

1. Arrangement is expensive as provision of various auxiliary equipments is necessary. 2. Overall efficiency is low.

* General steps to solve problems on speed control

1. Identify the method of speed control i.e. in which winding of the motor, the external resistance is to be inserted.
2. Use the torque equation, $T \propto \phi I_a$ to determine the new armature current according to the condition of the torque given. Load condition indicates the condition of the torque.
3. Use the speed equation $N \propto \frac{E_b}{\phi}$ to find the unknown back e.m.f. or field current.
4. From the term calculated above and using voltage current relationship of the motor, the value of extra resistance to be added, can be determined. The above steps may vary little bit according to the nature of the problem but are always the base of any speed control problem.

Example 3.19.1 *A 220 V D.C. shunt motor with constant field drives a load whose torque is proportional to the speed. When running at 1000 r.p.m. it takes 30 A. Find the speed at which it will run if a 10 Ω resistance is connected in series with its armature. The resistance of armature may be neglected.* **JNTU : Dec.-03, Marks 8**

Solution :

$$E_{b1} = V - I_{a1}R_a = 220 - 0 = 220 \text{ V} \ldots R_a \text{ neglected}$$