UNIT-I

DC MACHINES

DC machine is a rotating machine. It works as either as a dc generator or as a dc motor.

DC machines are mainly two types

a) DC Generator
b) DC Motor

• When Run Variable Conductor Cut the Constant Magnetic Flux, Emf is Induced in Conductor.
• Based on Faraday law of Electromagnetic Induction.

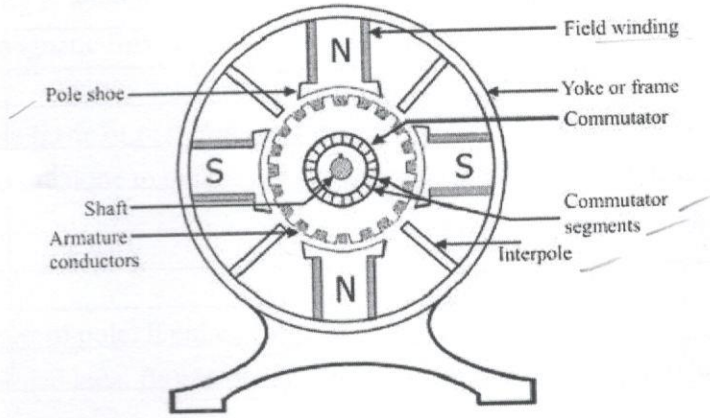
Working Principle of a DC Generator:

DC generator is a machine (rotating device) that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming's right hand rule. Therefore, the essential components of a generator are:

(a) A magnetic field
(b) Conductor or a group of conductors
(c) Motion of conductor w.r.t. magnetic field

Construction of A DC Machine:

There are mainly two parts in a DC machine a) Stator and b) Rotor



Stator contains the following parts:

1. Yoke
2. Pole core and pole shoes
3. Field coil
4. Brushes and bearings

Stator - it is a Set of two magnets which are placed in such a way that opposite polarity faces each other

1. Yoke

Yoke

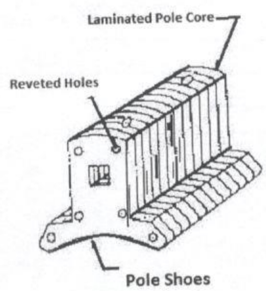
Function

- It provides mechanical Support for poles.
- It also provide protection to whole machine from dust, moisture etc.
- It also carries magnetic flux produced by the poles
- Yoke is also called as frame.

Material used

- For small M/C yoke is made of cast iron.
- For large M/C it is made of cast steel or rolled steel.

2. Pole & Pole core



Pole & Pole core

Function

- Pole of a generator is an electromagnet.
- The field winding is winding over pole.
- Pole provides magnetic flux when field winding is excited.

Material used

- Pole core or pole made of cast iron or cast steel.
- The laminations are done to reduce the power loss due to eddy currents.

3. Pole Shoe

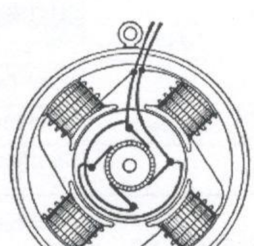
Function

- It is extended part of pole. It enlarge area of pole
- Due to this enlarged area, flux is spread out in the air gap and more flux can pass through the air gap to armature.

Material used

- It is made of cast iron or cast steel.
- The laminations are done to reduce power loss due to eddy currents

4. Pole coil or field windings



Pole coil or field windings

Function

- It is wound around pole core and called as field coil
- When Current is passed through field winding it electro magnetize the poles which produce necessary flux.

Material used

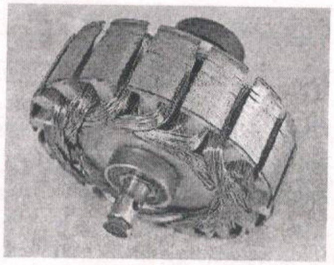
- The material used for field conductor is copper.

Rotor contains the following parts:

1. Armature core
2. Armature winding or Conductor
3. Commutator

Armature : The rotating part of DC Generator is Called Armature.

1. Armature Core



Armature Core

Function

- It has large number of slots in its periphery.
- Armature conductors are placed in these slots.
- It is also provide path of low reluctance to the flux produced by field winding.

Material used

- High permeability low reluctance materials such as cast or iron are used for armature core.
- The lamination is provided so as to reduce the loss due to eddy current.

2. Armature Winding

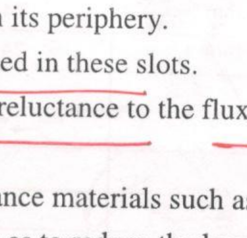
Function

- Armature conductors are inter connected to form armature Winding
- When armature winding is rotated using prime mover. the magnetic flux and voltage gets induced in it.
- Armature winding is connected to external circuit.

Material used

- It is made of conducting material such as coppers.

3. Commutator



Commutator

Function

- It converts alternating current in to unidirectional current.
- It collects the current form armature conductor and pass it load with the help of brushes.
- It also provides unidirectional torque for dc motor.

Material used

- It is made of a large number of edge shaped segments of hard drawn copper.
- The Segments are insulated from each other by thin layer of mica.

4. Brushes

Function

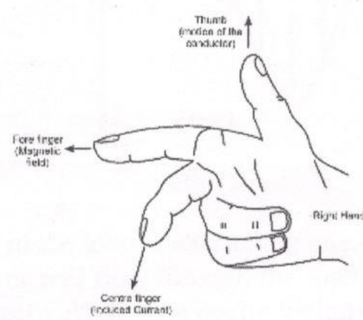
- Brushes collect the current from commutator and apply it to external load.

Material used

- Brushes are made of carbon or graphite it is rectangular in shape.

Working of a simple loop DC Generator:

DC generator is based on the electromagnetic Induction principle. When a rotating conductor placed in a constant magnetic field an emf will be induced across the conductor. This will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming's right hand rule.



Thumb indicates that the direction of Force or motion of the conductor

Fore finger indicates that the direction of magnetic field

Middle finger indicates that the direction of the current

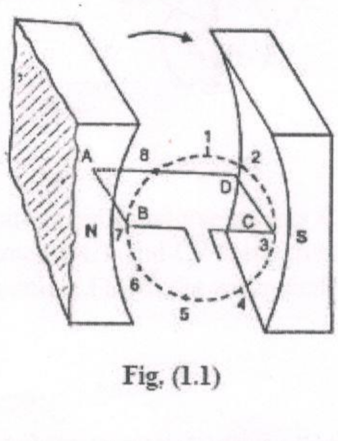


Fig. (1.1)

Consider a single turn loop ABCD rotating clockwise in a uniform magnetic field with a constant speed. As the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f. induced in these coil sides also changes but the e.m.f. induced in one coil side adds to that induced in the other.

(i) When the loop is in position no. 1, the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

(ii) When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated.

(iii) When the loop is in position no. 3, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum.

(iv) At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle.

(v) At position 5, no magnetic lines are cut and hence induced e.m.f. is zero.

(vi) At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The maximum e.m.f. in this direction (i.e., reverse direction) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.

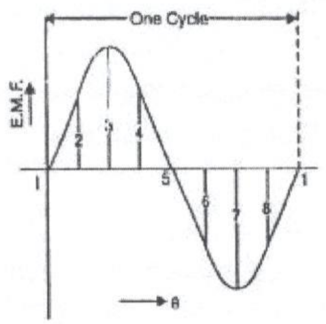


Fig. (1.2)

Note that e.m.f. generated in the loop is alternating one. If a load is connected across the ends of the loop, then alternating current will flow through the load. The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator.

Action of Commutator:

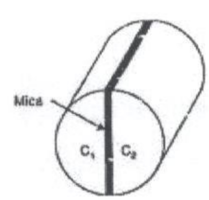


Fig.(1.3)

From the above fig. Commutator having two segments C1 and C2. It consists of a cylindrical metal ring cut into two halves or segments C1 and C2 respectively separated by a thin sheet of mica. The commutator is mounted on but insulated from the rotor shaft.

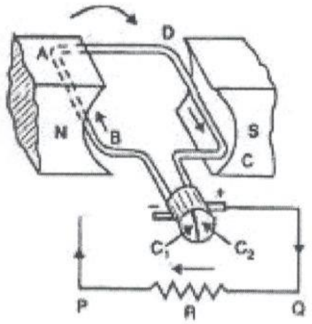


Fig.(1.4)

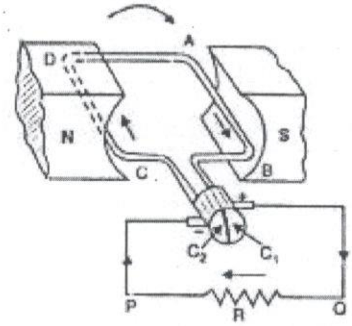


Fig.(1.5)

The ends of coil sides AB and CD are connected to the segments C1 and C2 respectively as shown in the above fig. two stationary carbon brushes rest on the commutator and lead current to the external load. With this arrangement, 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.

(i) In Fig. (1.4), when it is rotating in clock wise direction in the first half revolution the current flowing path is

B-A-D-C-C2-Q-R load-P-C1-B

(ii) After half a revolution of the loop (i.e. , 180 rotation), the current path is

C-D-A-B-C1-Q-R load-P-C2-C

Note that commutator has reversed the coil connections to the load i.e., coil side AB is now connected to point Q of the load and coil side CD to the point P of the load. Also note the direction of current through the load. It is again from Q to P.

The e.m.f. generated in the armature winding of a d.c. generator is alternating one. It is by the use of commutator, it converts the generated alternating e.m.f. into direct voltage. The purpose of brushes is simply to lead current from the rotating loop or winding to the external stationary load.

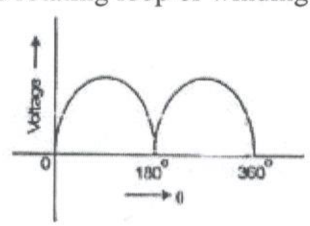


Fig. (1.6)

E.M. F. EQUATION OF A DC GENERATOR:

Let, P = Number of poles of the generator
Φ = Flux produced by each pole in webers (Wb)
N = Speed of armature in r.p.m.
Z = Total Number of Armature Conductors
A = Number of parallel paths in which the 'Z' number of conductors are divided
So A = P for lap type of winding
A = 2 for wave type of winding

Now e.m.f. gets induced in the conductor according to Faraday's law of electromagnetic induction. Hence average value of e.m.f. induced in each armature conductor is,

$$e = \text{Rate of cutting the flux} = d\Phi/dt$$

Now consider one revolution of conductor. In one revolution, conductor will cut total flux produced by all the poles i.e. Φ*P.
While time required completing one revolution is 60/N seconds as speed is N r.p.m.

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

This is the e.m.f. induced in one conductor. Now the conductors in one parallel path are always in series. There are total Z conductors with A parallel paths, hence Z/A number of conductors are always in series and e.m.f. remains same across all the parallel paths.

$\therefore$ Total e.m.f. can be expressed as,

$$E = \phi P \frac{N}{60} \times \frac{Z}{A} \quad \text{volts}$$

This is nothing but the e.m.f. equation of a d.c. generator.

So $$\boxed{E = \frac{\phi PNZ}{60\,A} \quad \text{e.m.f. equation}}$$

$$E = \frac{\phi NZ}{60} \quad \text{for lap type as } A = P$$

$$E = \frac{\phi PNZ}{120} \quad \text{for wave type as } A = 2$$

TYPES OF DC GENERATORS

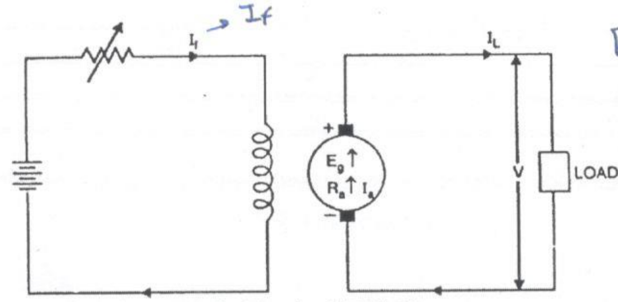
Based on the excitation, dc generators are divided into the following two classes:

1. Separately excited dc generators
2. Self-excited dc generators

Separately Excited D.C. Generators

A dc generator whose field winding is supplied from an independent external d.c. source (e.g., a battery etc.) is called a separately excited generator.

The output voltage depends upon the speed of rotation of armature and the field current (Eg =φZNP/60 A). The speed and field current is greater, then the generated e.m.f is also greater.



Eg → Generated E.m.f.
Ra → Armature resistance
Ia → Armature current
I_L → Load current.
I_f → field current.

Separately Excited DC Generator

- Armature current, Ia = IL
- Terminal voltage, V = Eg - IaRa
- Electric power developed = EgIa
- Power delivered to load = EgIa - I R = I E - I R = VIa

This document is available free of charge on studocu

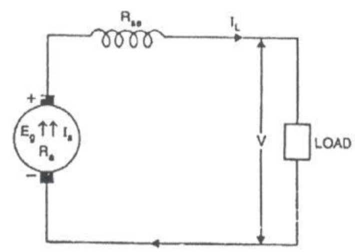
Self-Excited D.C. Generators

A d.c. generator whose field winding is supplied current from the output of the generator itself is called a self-excited generator. There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely;

- Series generator
- Shunt generator
- Compound generator

Series generator (Low Resistance).

In a series wound generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as the load. Since the field winding carries the whole of load current, it has a few turns of thick wire having low resistance. Series generators are rarely used except for special purposes e.g., as boosters.



Series Generator

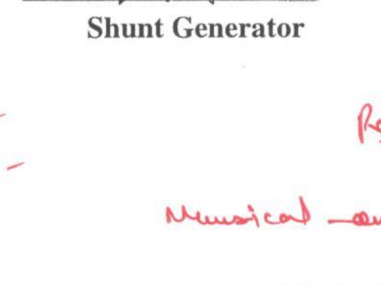
Rse → Resistance of field wire in series.

Armature current, Ia = Ise = IL = I(say)
Terminal voltage, V = EG - I(Ra + Rse)
Power developed in armature = EgIa

Shunt generator (high Resistance).

In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it.

The shunt field winding has many turns of fine wire having high resistance. Therefore, only a part of armature current flows through shunt field winding and the rest flows through the load.



Shunt Generator

V.imp.

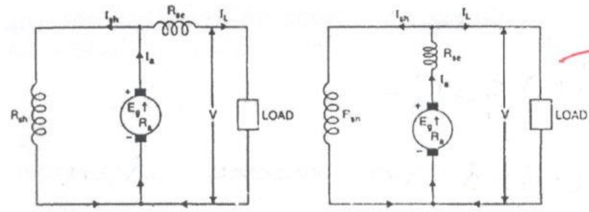
Shunt field current, Ish = V/Rsh
Armature current, Ia = IL + Ish
Terminal voltage, V = Eg - IaRa
Power developed in armature = EgIa
Power delivered to load = VI_L

Rsh → Resistance of Shunt.

Numerical on Shunt.

Compound generator

In a compound-wound generator, there are two sets of field windings on each pole - one is in series and the other in parallel with the armature. A compound wound generator may be:



(i) (ii)

→ Long Shun

1. **Short Shunt Compound generator:** In which only shunt field winding is in parallel with the armature winding.
2. **Long Shunt Compound generator:** In which shunt field winding is in parallel with both series field and armature winding.

Long shunt

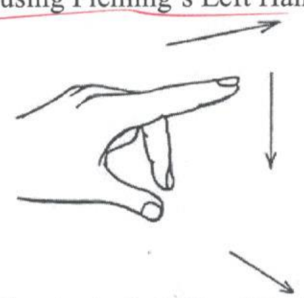
Series field current, Ise = Ia = IL + Ish
Shunt field current, Ish = V/Rsh
Terminal voltage, V = Eg - Ia(Ra + Rse)
Power developed in armature = EgIa
Power delivered to load = VI_L

Short shunt

Series field current, Ise = I_L
Shunt field current,
Terminal voltage, V = Eg - IaRa - IseRse
Power developed in armature = EgIa
Power delivered to load = VI_L

DC MOTOR WORKING PRINCIPLE:

When a current carrying conductor placed in a magnetic field then it will experiences a force i.e. Mechanical force. The direction of the conductor is can be found from Fleming's left hand rule. The direction of motion can be found using Fleming's Left Hand Rule.



Fleming's ***Left Hand Rule***

Thumb indicates that the direction of the motion
Fore Finger indicates that the direction of magnetic field
Middle finger indicates that the direction of current

Mechanical Force

The force exerted upon the conductor can be expressed as follows.

$$F = B\,i\,l \text{ Newton}$$

Where, B is the density of the magnetic field,
l is the length of conductor,
i the value of current flowing in the conductor.

TORQUE EQUATION OF A DC MOTOR:

When a DC machine is loaded either as a motor or as a generator, the rotor conductors carry current. These conductors lie in the magnetic field of the air gap. Thus, each conductor experiences a force. The conductors lie near the surface of the rotor at a common radius from its centre. Hence, a torque is produced around the circumference of the rotor, and the rotor starts rotating.

When the current carrying conductor is placed in the magnetic field, a force is exerted or it which exerts turning moment or torque F x r. This torque is produced due to the electromagnetic effect, hence is called **Electromagnetic torque.** The torque which is produced in the armature is not fully used at the shaft for doing the useful work. Some part of it where lost due to mechanical losses. The torque which is used for doing useful work in known as the shaft torque.

Since, Voltage equation of a dc motor is

$$V = E_b + I_a R_a \quad \dots\dots(1)$$

Multiplying the equation (1) by I_a we get

$$VI_a = E_b I_a + I_a^2 R_a \quad \dots\dots(2)$$

Where,

VI_a is the electrical power input to the armature.

$I^2_a R_a$ is the copper loss in the armature.

We know that,

Total electrical power supplied to the armature = Mechanical power developed by the armature + losses due to armature resistance

Now, the mechanical power developed by the armature is Pm.

$$P_m = F_b I_a \dots\dots(3)$$

Also, the mechanical power rotating armature can be given regarding torque T and speed n.

$$P_m = \omega T = 2\pi\, nT \quad \dots\dots(4)$$

Where n is in revolution per seconds (rps) and T is in Newton-Meter.

Hence, by equating the equations (3) and (4)

$$2\pi\, nT = E_b I_a$$

$$T = \frac{E_b I_a}{2\pi n}$$

But, Back emf Eb is

$$E_b = \frac{\varphi ZNP}{60\ A}$$

Where N is the speed in revolution per minute (rpm) and

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

Where, n is the speed in (rps).

Therefore,

$$E_b = \frac{\varphi ZnP}{A}$$

So, the torque equation is given as

$$\boxed{T = \frac{\varphi ZP}{2\pi A} . I_a}$$

$T_e \propto I_a$

For a particular DC Motor, the number of poles (P) and the number of conductors per parallel path (Z/A) are constant.

$$T = K\varphi I_a$$

Where,

$$K = \frac{ZP}{2\pi A} \quad \text{or}$$

$$\boxed{T \propto \varphi I_a \dots \dots (5)}$$

Thus, from the above equation (5) it is clear that the torque produced in the armature is directly proportional to the flux per pole and the armature current.

TYPES OF DC MOTORS:

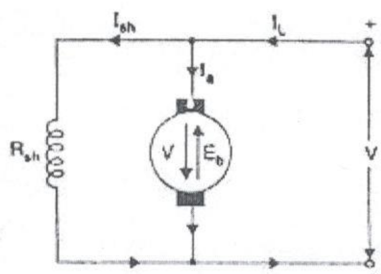
Like generators, there are three types of d.c. motors characterized by the connections of field winding in relation to the armature. They are

1. Shunt DC Motor
2. Series DC Motor
3. Compound Wound DC Motor
    1. Short Shunt DC Motor
    2. Long Shunt DC Motor

~~Rsh~~ $E_b = \frac{\phi Z N P}{60A}$.

- $I_L = I_a + I_{sh}$.
- $I_{sh} = \frac{V}{R_{sh}}$

Shunt DC Motor



- $I_a = \frac{V}{R_a}$.
- $V = E_g + I_a R_a$.

Including Brush drop.

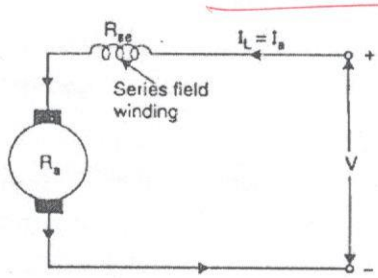
$V = E_b + I_a R_a + 2V_b$

Power Supplied $= V I_L$

In Shunt DC motor the field winding is connected in parallel with the armature. The current through the shunt field winding is not the same as the armature current. Shunt field current is relatively small compared with the armature current.

Series DC Motor

In Series DC motor the field winding is connected in series with the armature.



- $E_b = \frac{\phi Z N P}{60A}$.

wave $= P = 2$.

Lap $= A = P$

- $I_L = I_{se} = I_a$.
- $V = E_b + I_a(R_a + R_{se})$

Therefore, series field winding carries the armature current. Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with much fewer turns than shunt field windings for the same m.m.f.

- Including Brush.

$V = E_b + I_a(R_a + R_{se}) + 2V_b$

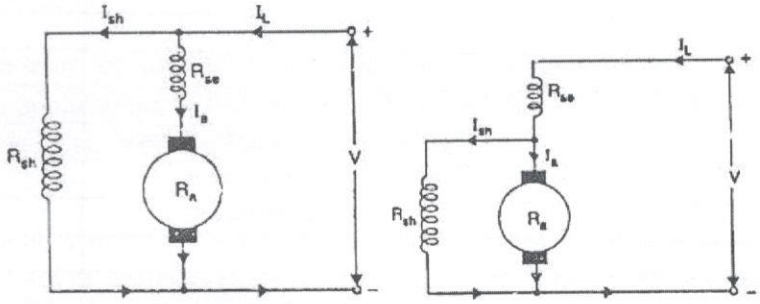
- Power Supplied $= V . I_L$

Therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

Compound DC Motor

Compound DC motor which has two field windings:

- One connected in parallel with the armature.
- Other in series with it.



Long-shunt connection Short-shunt connection

There are two types of compound motor connections (like generators).

- When the shunt field winding is directly connected across the armature terminals, it is called short-shunt connection.
- When the shunt winding is so connected that it shunts the series combination of armature and series field, it is called long-shunt connection.

The compound machines (generators or motors) are always designed so that the flux produced by shunt field winding is considerably larger than the flux produced by the series field winding.

APPLICATIONS OF A DC GENERATOR:

The applications of the various types of DC Generators are as follows:-

Separately Excited DC Generators

- Separately excited DC Generators are used in laboratories for testing as they have a wide range of voltage output.
- Used as a supply source of DC motors.

Shunt wound Generators

- DC shunt wound generators are used for lighting purposes.
- Used to charge the battery.
- Providing excitation to the alternators.

Series Wound Generators

- DC series wound generators are used in DC locomotives for regenerative braking for providing field excitation current.
- Used as a booster in distribution networks.

Over compounded cumulative generators are used in lighting and heavy power supply.
Flat compounded generators are used in offices, hotels, homes, schools, etc.
Differentially compounded generators are mainly used for arc welding purpose.

APPLICATIONS OF DC MOTORS:

The main applications of the three types of direct current motors are given below.

Series Motors

The series DC motors are used where high starting torque is required, and variations in speed are possible. For example – the series motors are used in Traction system, Cranes, air compressors, Vaccum Cleaner, Sewing machine, etc.

Shunt Motors

The shunt motors are used where constant speed is required and starting conditions are not severe. The various applications of DC shunt motor are in Lathe Machines, Centrifugal Pumps, Fans, Blowers, Conveyors, Lifts, Weaving Machine, Spinning machines, etc.

Compound Motors

The compound motors are used where higher starting torque and fairly constant speed is required. The examples of usage of compound motors are in Presses, Shears, Conveyors, Elevators, Rolling Mills, Heavy Planners, etc.

Three point Starter:

Necessity of a 3 point starter:

1. A three-point starter is a device that helps in starting and running the shunt wound motor or compound wound DC motor.
2. The back EMF (Eb) plays a crucial role in governing the operation of motors.
3. The back EMF (Eb) is developed as motor armature starts to rotate in presence of magnetic field, so initially; back EMF (Eb) is zero.
4. For motors, $V = Eb + IaRa$. Since Initially $Eb = 0$. so $Ia = V/Ra$
5. By the above equation, it says that starting current is dangerously high as Ra (armature resistance) is small.
6. To limit high starting current.
7. To prevent motor from under voltage, no voltage and over voltage.

A 3-Point Starter is a device whose main function is starting and maintaining the speed of the DC shunt motor. The 3-point starter connects the resistance in series with the circuit which reduces the high starting current and hence protects the machines from damage. Mainly there are three main points or terminals in 3-point starter of DC motor. They are as follows

L is known as Line terminal, which is connected to the positive supply.

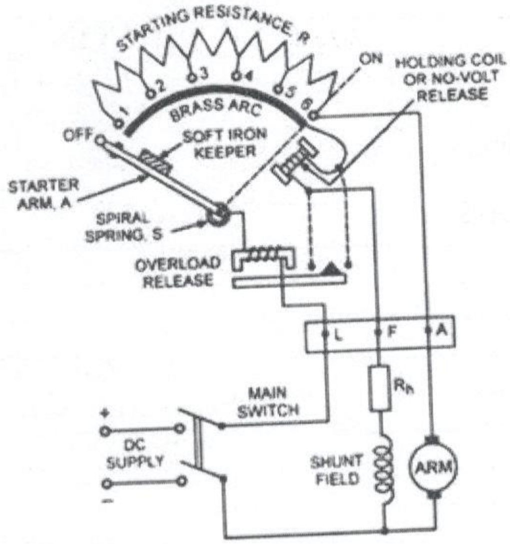
A is known as the armature terminal and is connected to the armature windings.

F is known as the field terminal and is connected to the field terminal windings

Operation of three-point starter:

The handle is in OFF position:

- When power is switched on to the motor. The handle is slowly moved to stud '1' against the spring force.
- Field winding will get supply via parallel path provided through stud 1 and NVC.
- Entire starting resistance is in series with the armature and limits the starting current.
- As the handle moves further to stud 2,3,4,5 and finally RUN position. It bypasses the starting resistance and the motor rotates at normal speed.
- NVC coil holds the starter in RUN position so it is also called as holding coil.



Three-Point Starter

Functions of No Volt Coil (NVC):

- The field winding is supplied through NVC and field current makes it an electromagnet.
- When the handle is at the RUN position, the soft iron piece on handle gets attracted by the magnetic force produced by NVC.
- Whenever there is supply failure or field supply is broken then NVC loses its magnetism and unable to hold the handle. The spring action brings back the handle to OFF position.
- NCV perform the similar action during low voltage condition and save the device.

Functions of Overload release (OLR):

- The motor current is supplied through OLR coil, which makes it an electromagnet.
- Below the OLR coil, there is an arm which is fixed at its lying horizontally.
- At the end of the arm, a small triangular iron piece is fitted which is in the proximity of two ends of the shorting cable of NVC.
- It is so designed that, till the full load current OLR coil magnetism and gravitational force are balanced and OLR is unable to lift the lever.
- Whenever motor draws high current the magnetism of the OLR coil pull the arm and triangular piece of the arm shorts both point of NVC coil.
- NVC coil loses its magnetism and leaves the handle. The handle than retracts back to OFF position because of spring action. The motor will stop.

Speed control of a DC shunt Motor:

Back emf E_b of a DC motor is the induced emf in the armature conductors due to the rotation of armature in magnetic field. Thus, magnitude of the E_b can be given by the EMF equation of a DC generator.

$$E_b = {}^{P\text{Ø}NZ}/_{60A}$$

Where, P = no. of poles,

Ø = flux/pole,

N = speed in rpm,

Z = no. of armature conductors,

A = no. of parallel paths

Thus, from the above equations

$$N = E_b \, 60A / P \phi Z$$

But, for a DC motor A, P and Z are constants

Therefore, $N \propto K\, E_b/\phi$ (where, K=constant)

This shows the speed of a dc motor is directly proportional to the back emf and inversely proportional to the flux per pole.

E_b can also be given as,

$$E_b = V - I_a R_a$$

$N \propto \frac{E_b}{\phi}$

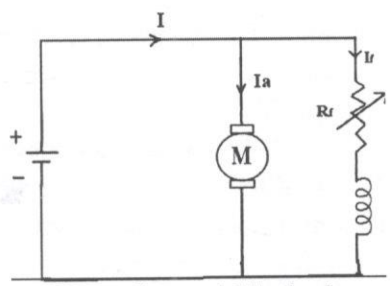
Speed control methods of a DC shunt motor:

Speed of a DC motor can be varied by varying flux, armature resistance or applied voltage. Speed control methods are:

1. Flux control method
2. Armature and Rheostat control method

Flux Control Method:

In this flux control method, speed of the motor is inversely proportional to the flux. Thus, by decreasing flux and speed can be increased vice versa. To control the flux, the rheostat is added in series with the field winding then flux will decrease. So, the field current is relatively small and hence I^2R loss is decreased. This method is quite efficient.

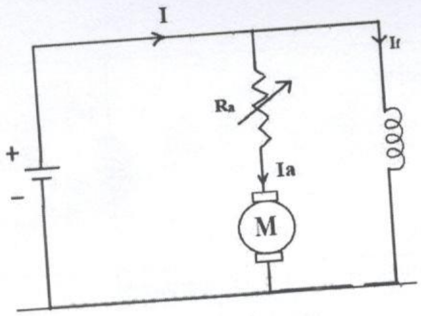


Flux Control Method

So in this method, the speed can be increased by reducing the field flux. This method is only applicable to increase above rated speed.

Armature Control Method:

In the armature control method, the speed of the DC motor is directly proportional to the back emf (Eb) and Eb = V- IaRa. When supply voltage (V) and armature resistance Ra are kept constant, the Speed is directly proportional to armature current (Ia). If we add resistance in series with the armature, the armature current (Ia) decreases and hence speed decreases. This method is used for below rated speed.



Armature Control Method

Assignment Questions

S.No.	Question	CO Mapping	Taxonomy Level
1	(a) Deduce the EMF equation for a dc machine. (b) The wave connected armature of a two pole 200V generator has 400 conductors and runs at 300rpm. Calculate the useful flux per pole.	CO1	Understanding
2	Explain the various types of dc motors with diagrams and necessary equations.	CO1	Remembering
3	(a) Derive the torque equation for a dc motor. (b) A dc machine induces an EMF of 240V at 1500rpm. Find the developed torque for an armature current of 25A.	CO1	Applying
4	Draw a neat sketch of a dc machine and name the component parts. Also explain the function of each part.	CO1	Understanding
5	Explain why dc motors should require starters. And Draw the connection diagram of a dc motor starter.	CO1	Understanding