BEEF184T10 DC MACHINES

Class Notes

Prepared By

Dr.D.Vanitha

&

Mrs. S. Lavanya

**Assistant Professor,**

EEE Dept.

UNIT- 1

D.C MACHINE CONSTRUCTION

Field System-Armature Core-Commutator and Brushes-Armature winding- E.M.F equation- Methods of Excitation- Armature Reaction-Commutation-Load Characteristics of D.C generators-Series, shunt and compound machines-Parallel operation of D.C Generators

Introduction

DC machines are broadly classified into two types DC motor and DC generator. DC motor is a device which convert electrical energy into mechanical energy. When a current carrying conductor placed in a magnetic field, it experienced a force. DC generator is a device which converts mechanical (rotational) energy into electrical energy. It works based on the principle of faradays law of electromagnetic induction. Whenever the conductor cuts by the magnetic field emf is induced on it.

D.C Motor

Electrical Energy → D.C machine ← Mechanical Energy

D.C Genarator
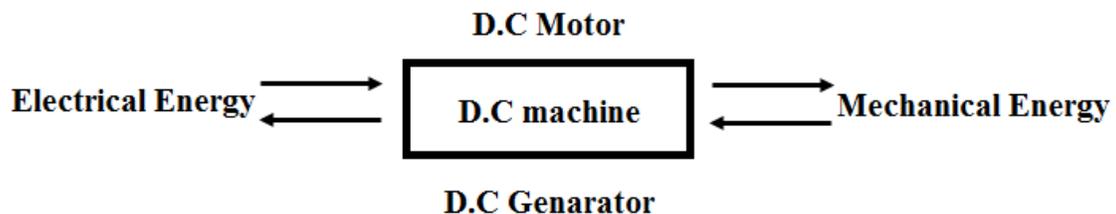
Construction

Based on the working principle DC motor & generator, requirement for the both machines are magnetic fields, conductor & mechanical movement. So construction wise both motor & generator are same. Depends upon the types of input (electrical or mechanical) given to the machines it should be differentiated by either motor or generator.
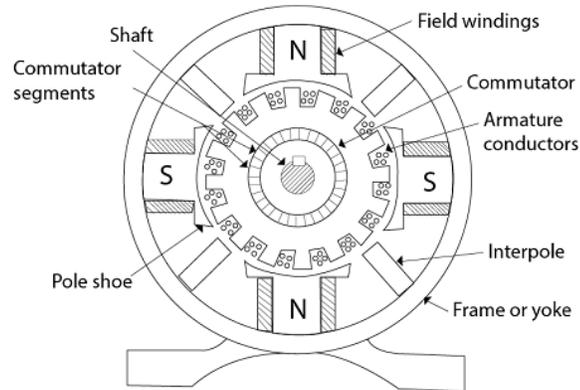
Field Systems:

Field windings to be used to produce uniform magnetic flux. The winding are placed in a poles which is located in the yoke. The yoke is a circular outer part of DC machines which is made upon cast iron and projecting even number of poles. It provides space for the field windings. Field windings are excited by dc supply uniform magnetic field is produced. Windings are made with conducting materials like aluminium or copper. Poles shoe are extended and widen because of flux part distribution over to the armature.

Armature Systems:

It is the rotating part of the machine. It consist of two major parts. One is *armature core* and other is *armature winding*.
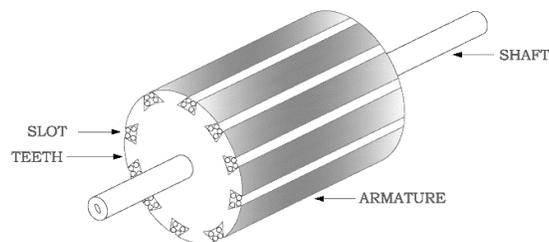
A shaft carries cylindrical shaped with slot which is used place the **rotating (armature) windings**. Usually rotating part of the machines are generally called Rotor. It provides house for the armature conductors and also provides low reluctance to magnetic flux created by the field coils.
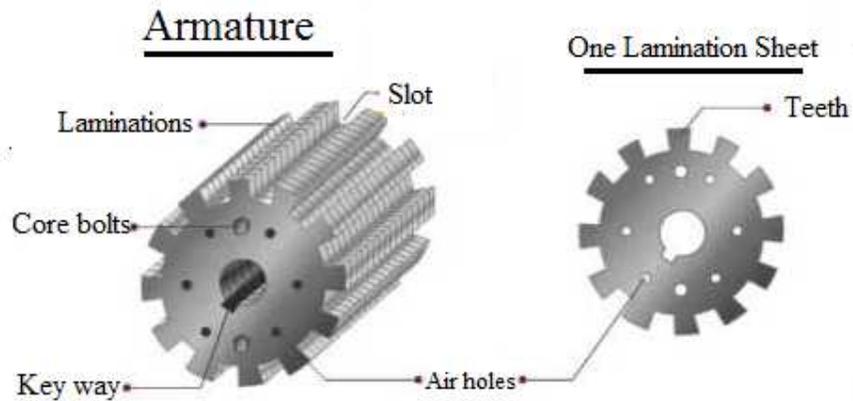
Interconnection of armature conductors/coils is called **Armature Windings**. It is placed over to the periphery of the armature slots.

Main function of the armature coil is to generate e.m.f. also carries current in case of D.C motor. Usually copper are preferred to making materials for this windings.

Commutator:

Induced e.m.f in a D.C generator are alternating nature. Rectification is required so commutator are used for this purpose.
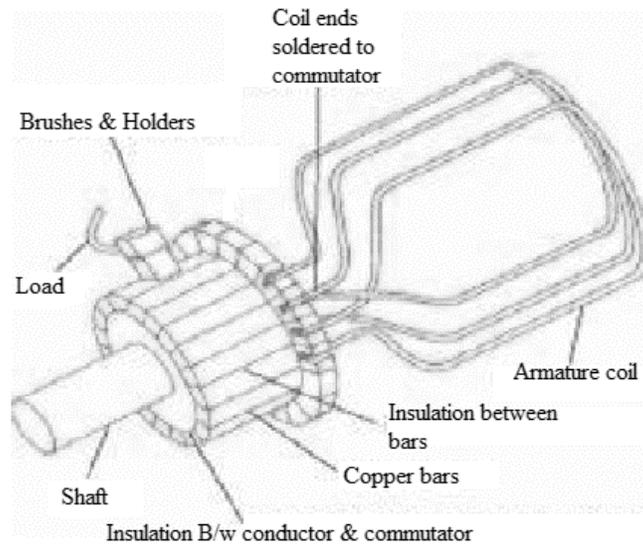
It is cylindrical shaped and each commutator segments are made with copper and connected to armature coil with strips. Connections are shown in figure.

Brushes:

It is stationary part & seated over to the commutator. It collects current from commutator and given to stationary external circuit. Usually it is made with carbon like soft

materials. It is in rectangular shape and made to press on the surface of the commutator with help of a spring. For D.C machines two carbon brushes are required.

Types of Armature Winding:

More number of conductors arranged in a systematic manner is called windings. Depending upon the conductors connections the armature windings classified as two types,

       1. Lap winding

       2. Wave winding

Lap winding:

First conductor connected to 3rd conductor for return path and continuation is join or overlap into 2nd conductor and move into so on. In this conductor connection are number of poles is number of parallel paths. i,e., P= number of parallel paths. Figure shows the Lap winding diagram.

Lap Winding

(a) Coil sides in (a) single turn winding (b) 3 turn coil

(b)
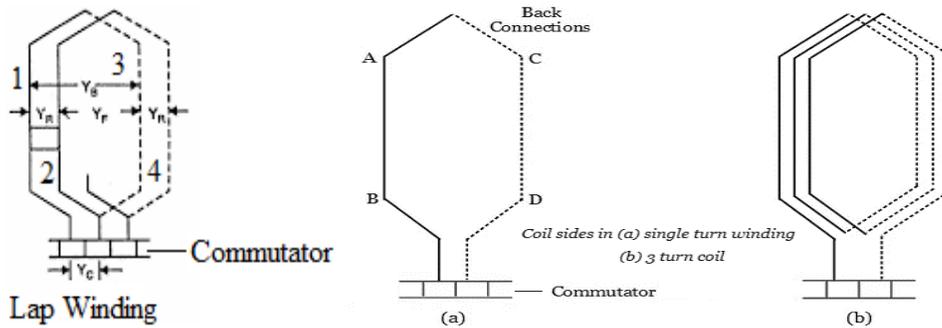
Wave winding

First conductor is move forwarded shown in figure. The conductor moves ahead like wave. For this connection the total conductors are divided into two parallel paths always i.e., A=2

Wave winding
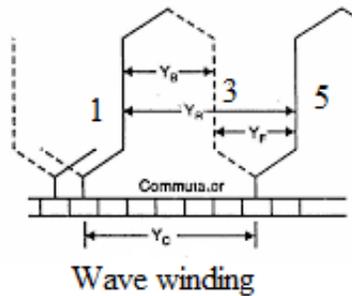
Pole pitch – Peripheral distance between the two adjacent coils. Also defined as number of armature conductors per pole

$$PolePitch = \frac{Number of armature conductors}{Number of pole}$$

Coil Pitch or Coil span – It is the angular distance between two coils. Measured in terms of armature slots. If the coil pitch is equal to the pole pitch than is called as *full pitched coil*. If the coil pitch is less than the pole pitch it is called as *short pitch or fractional pitch coil.*

Back pitch(Y_b) - Distance between top and bottom of an armature conductor. It is denoted by Y_b.

Front Pitch (Y_f)– It is the distance between armature conductors which connected in a same commutator segments

Commutator Pitch(Y_c) - Distance between the commutator segments to which the two ends of a coil are connected.It is denoted by Y_c.

Resultant pitch(Y_r) - Distance between the beginning of one coil and the beginning of the next coil to which it is connected.It is denoted by Y_r.

**Winding Pitch (Y)** – Distance between starting of two consecutive conductors. It is denoted by Y.

$$For Lapwinding Y = Y_b - Y_f$$

$$For Lapwinding Y = Y_b + Y_f$$

Working principle of D.C generator

D.C generator works based on the principle of Faraday's law of electromagnetic induction." Whenever the conductor cuts by the magnetic field e.m.f (electro motive force) induced on the conductor. Direction of the induced e.m.f can be determined using Fleming's right hand rule.
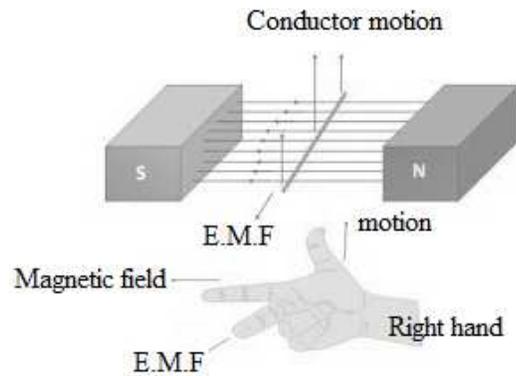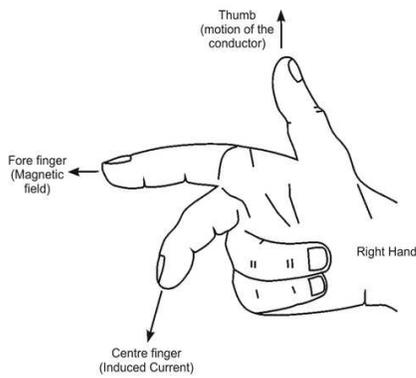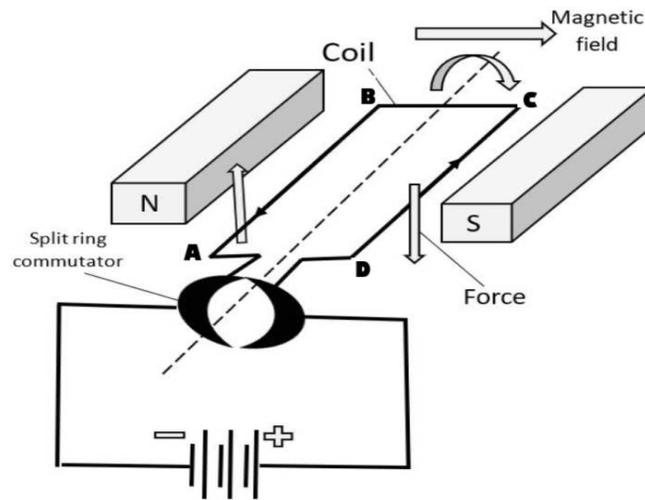
Fleming's Right Hand Rule:

Stretch the thumb, index finger and middle finger of right hand perpendicular to each other. If index finger point out the direction of the magnetic field and thumb represents the direction of the motion conductor means than middle finger gives the direction of the induced e.m.f. In this way we can identify the direction of induced e.m.f using Fleming's right hand rule.

Induced E.M.F equation

Let

P = Number of poles in the filed systems

Φ = flux per pole (webers)

N = Speed of the armature(revolution per minute –rpm)

Z = Total number of conductors

  = Number conductors X slot per conductor

A = parallel paths

For Lap winding, A=P

  Wave winding A=2

According to faraday's law, the rate of change of conductor's cuts by the magnet filed e.m.f induced on the conductor

$$induced\ e.m.f \propto \frac{d\varphi}{dt} ----- 1$$

$$d\varphi = PX\varphi ----- 2$$

$$dt = \frac{60}{N} ----- 3$$

$$induced\ e.m.f\ per\ conductor\ e = 1\ X \frac{d\varphi}{dt} = \frac{PX\varphi}{\frac{60}{N}}$$

For total conductors per parallel path

$$e = \frac{P\varphi N}{60} X \frac{Z}{A} = \frac{\varphi ZNP}{60A} volts ------ 4$$

Equation-4 general equation of a D.C. generator.

For Lap wound machine, A = P, then induced e.m.f

$$E_{induced} = \frac{\varphi ZN}{60} volts ------ 5$$

For wave wound machine, A = 2, then induced e.m.f

$$E_{induced} = \frac{\varphi ZNP}{120} volts ------ 6$$

Problems

 1. A Lap wound D.C machines having 4 poles and flux per is 0.07 webers. Total number of conductors in the armature are 440.The machine rotates at a speed of 900rpm. Calculate the induced e.m.f in the generator.

Given data

For lap wound machines, A = P

P = 4

Φ = 0.07wb

N = 900 rpm

Z = 440

To find

Induced e.m.f = ?

For Lap wound machine, A = P, then induced e.m.f

$$E_{induced} = \frac{\varphi ZN}{60} volts$$

$$= 0.07*440*900/60$$

$$= \textbf{462 volts}$$

2.A wave wound D.C machines having 4 poles and flux per is 0.07 webers. Total number of conductors in the armature are 440.The machine rotates at a speed of 900rpm. Calculate the induced e.m.f in the generator.

Given data

For wave wound machines, A = 2

P = 4

Φ = 0.07wb

N = 900 rpm

Z = 440

To find

Induced e.m.f = ?

For wave wound machine, A = 2, then induced e.m.f

$$E_{induced} = \frac{\varphi ZNP}{120} volts$$

$$= 0.07*440*900*4/120$$

$$= \textbf{924volts}$$

Classification of D.C generator

　　　　The classification of generators are made based on the field how is getting excited by the D.C supply, it may be classified as

　　　　1. Separately excited D.C generator

　　　　2. Self-excited D.C generator

1. Separately excited D.C generator

There is no inter connection between the armature and its field. Field winding is excited by separate D.C supply.so it is called separately excited D.C generator.
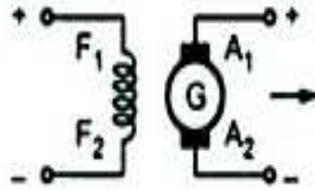

2. Self-excited D.C generator

Part of the generated D.C armature voltage is utilised for the excitation of its field than these types of generators are called self-excited D.C generators. Depends on the way field is connected with the armature it may be classified as

        i. Shunt generator

        ii. Series generator

        iii. Compound generator

            a. Long shunt compound generator

            b. Short shunt compound generator

D.C shunt generator:

The field winding of the generator is connected parallel to its armature than its called as shunt generator. Voltage across the field winding is same as that of terminal voltage.
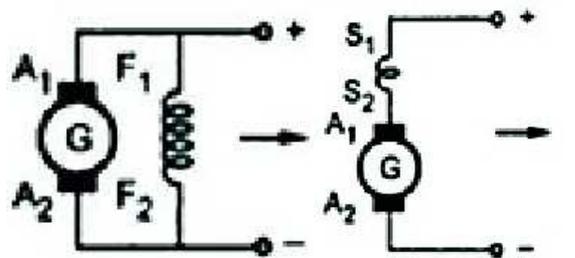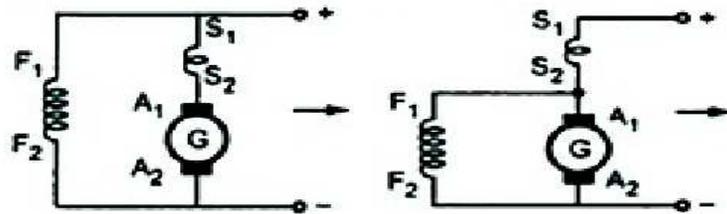

Shunt generator   Series generator

D.C Series generator:

The field connected in series with its armature than it is called as series generator. In series connection all current are same i.e., the armature current, series filed current & load current are equal.

D.C Compound generator:

In this type of generator having more than one field winding are used, than it is called compound generators. Both fields systems are produced more flux. How these two filed coils are connected with its armature than compound generator classified as long shunt compound generator and short shunt compound generator.

Long shunt compound   Short shunt compound

D.C Long Shunt compound generator

There are two field windings named by shunt field and series field winding. The series field is connected in series with armature and this combination are connected in parallel with the shunt filed winding.

D.C. ShortShunt compound generator

The shunt field is connected parallel to armature and this combination are connected in series with series field.

Voltage and Current Relations

E – induced e.m.f in volts

Vt – terminal voltage in volts

I_L – load current in amps

I_a - armature current in amps

I_{se} -current in the series filed

I_{sh} - current in the shunt filed

R_a - armature resistance in ohms

I_f - filed current in amps

R_{se} - series field resistance in ohms
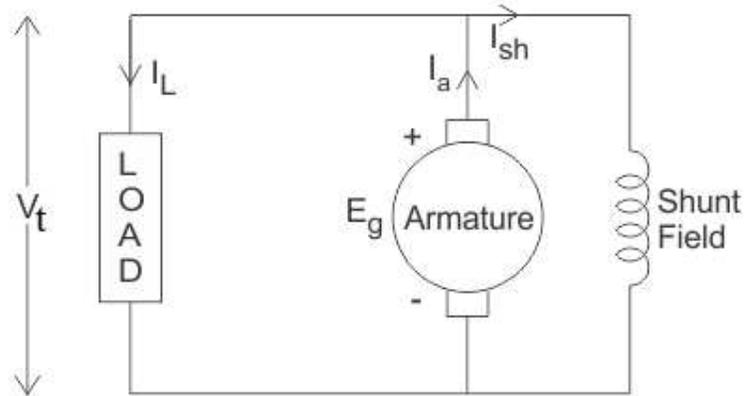
R_{sh} – shunt field resistance in ohms

V_{brush} – Brush drop

Voltage equation for separately excited generator can be written as

$$E = V_t + I_a R_a + V_{brush} \text{ Volts}$$

$$Also E = \frac{\varphi ZNP}{60A}$$

Shunt generator

Form this diagram

$$I_a = I_L + I_{sh}$$

$$I_{sh} = V_t / R_{sh}$$

Than voltage equation

$$E = V_t + I_a R_a + V_{brush}$$

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

In practical case, drop in the brush are neglected.

Series generator

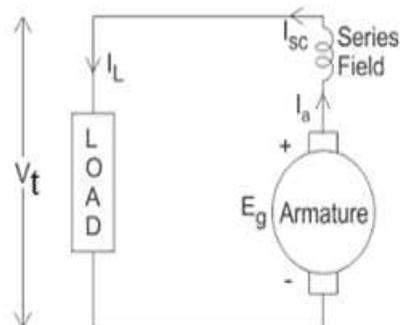Form the diagram, armature, field & load are connected in series. So

$$I_a = I_L = I_{se}$$
$$E = V_t + I_a R_a + I_{se} R_{se} + V_{brush}$$
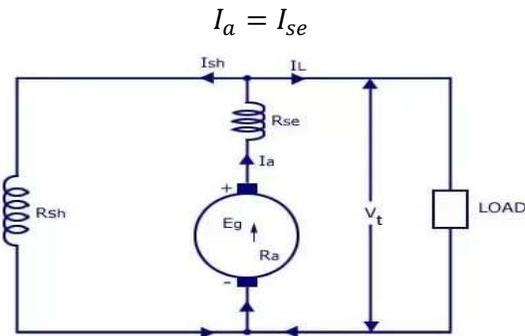$$E = V_t + I_a (R_a + R_{se}) + V_{brush} (\because I_a = I_{se})$$

Also

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

Long Shunt Compound generator

From the diagram, armature & series field are connected in series. So current in both are equal.

$$I_a = I_{se}$$

And $\quad I_a = I_L + I_{sh}$

Current in the filed winding is

$$I_{sh} = \frac{V_t}{R_{sh}}$$

Voltage equation for this type of generator is

$$E = V_t + I_a R_a + I_{se} R_{se} + V_{brush}$$
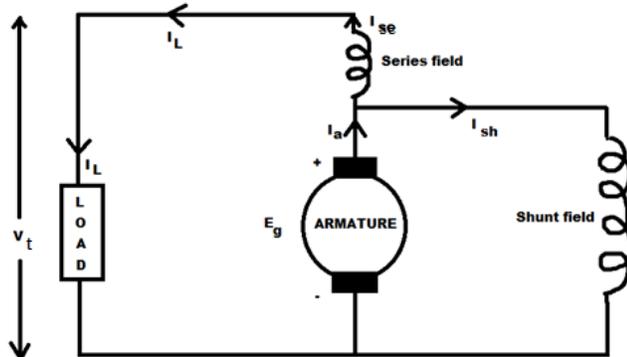$$E = V_t + I_a (R_a + R_{se}) + V_{brush} (\because I_a = I_{se})$$

Also

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

Short Shunt Compound generator

From the diagram,

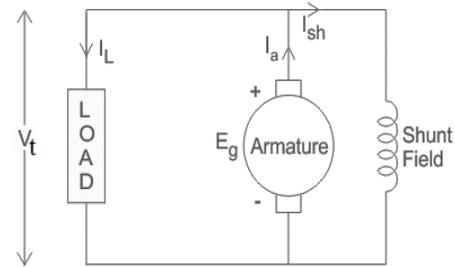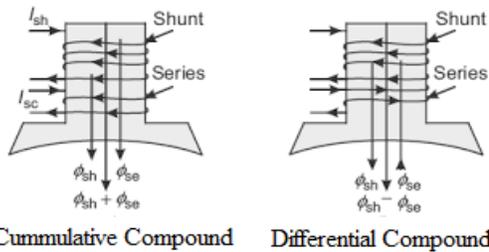$$I_a = I_{se} + I_{sh}$$

And $\quad I_{se} = I_L$

$$\therefore I_a = I_L + I_{sh}$$
$$E = V_t + I_a R_a + I_L R_{se} + V_{brush}$$

Cumulative compound and Differential Compound generator

Compound generator have two filed winding, shunt filed and series field winding. Both field produced magnetic flux. Both flux($\emptyset_{sh}$&se)helps each other than it is called "*cummulative compound generator*".

$$\emptyset_T = \emptyset_{sh} + \emptyset_{se}$$

Cummulative Compound   Differential Compound

Both field produced magnetic flux. Both flux ($\emptyset_{sh}$&se) opposes each other than it is called "*differential compound generator*".

$$\emptyset_T = \emptyset_{sh} - \emptyset_{se}$$

Where

$\emptyset_T$ - Total flux produced

$\emptyset_{sh}$ - Flux produced by the shunt field winding

$\emptyset_{se}$ - Flux produced by the series field winding

Problems

1. A lap connected 4 pole shunt generator has supplying load of 55KW at 420V. The armature and field resistance are 0.06Ω and 110Ω respectively. Calculate the field and current and induced e.m.f. Take brush drop as 2V for the both brushes.

Given data:

For Lap connected machine

Poles – 4

Power P – 55KW = 50×10^3 watts

Terminal Voltage V_t – 420Volts

R_a - 0.06Ω

R_{sh} - 110Ω

Brush Drop for 2 brushes – 2Volts

To find :

Induced e.m.f = ?

$I_L = P/V_t$ $= 50 \times 10^3/420$

         $= \mathbf{130.95A}$

I_{sh} $= V_t/ Rsh$

         $= 420/110$

         $= 3.82A$

I_{sh} $= I_L + I_{sh}$

         $= 130.95 + 3.82$

         $= \mathbf{134.77A}$

Induced e.m.f

E_g $= V_t + I_a R_a +$ brush drop

         $= 420 + 134.77*0.06 + 2$

         $= \mathbf{430.09 \ Volts}$

2. A 20 KW, 200 Volt shunt generator has an armature resistance of 0.5Ω & shunt field resistance of 200Ω.Calculate the power developed by the shunt generator.

Given data:

Generator capacity (load capacity) = 20KW = 20×10^3

Terminal Voltage V_t = 200 Volts

Armature resistance R_a = 0.5Ω

Shunt field resistance R_{sh} = 200Ω

To find:

Power developed by the generator?

Power delivered to the load = VI_L

Power delivered in an armature = $E_g I_a$

$I_L = P/V = 20 \times 10^3 / 200 = 100A$

$I_{sh} = V/R_{sh} = 200/200 = 1A$

For the shunt generator $I_a = I_{sh} + I_L$

                    $= 100 + 1 = 101A$

$E_g = V_t + I_a R_a = 200 + 101*0.05$

                    $= 205.05$ volts

Power developed by the armature $= E_g*I_a = 205.05*101$

$$= 20.71KW$$

Building of E.M.F in a self-excited generator

Self-excited D.C generator produced voltage based on its own filed. Even though generator is in standstill condition, there some amount flux is there in the poles. This is called as "residual flux". Due to this small amount of flux, conductors cuts the residual flux, induced proportional voltage. This voltage produce some more filed current, the will increase the flux. Due to increase in flux induced e.m.f developed more. In this way e.m.f or voltage is built in an generator.

Voltage build up in shunt generator.
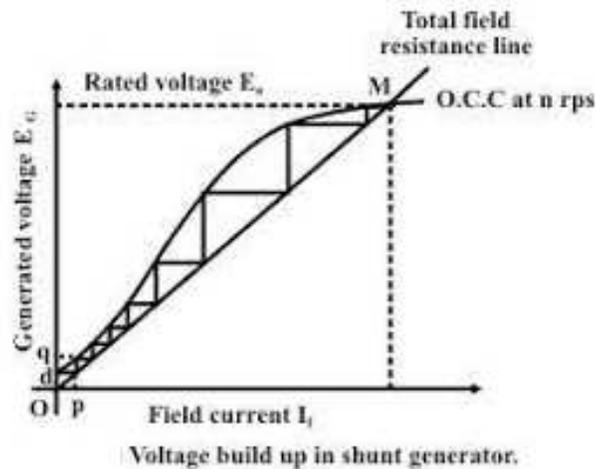
Characteristics of D.C generator

D.C Generator having the following characteristics

➢ Open circuit characteristics (O.C.C) / Magnetisation characteristics curve/ No load characteristics curve

➢ Load characteristics curve

Open circuit characteristics (O.C.C) / Magnetisation characteristics / No load characteristics curve

Form the name itself, no-load is connected, only generated e.m.f alone there with their flux. This curve is drawn between generated e.m.f(E_o) and field current(I_f) at no load condition and speed of generator is maintained at constant.
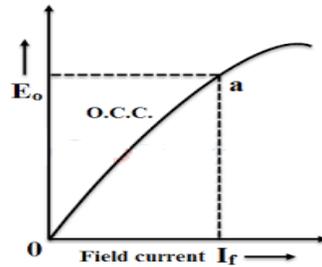
$$E = \frac{\varphi ZNP}{60A}$$

Except φ rest of parameters are constantans$E = \frac{ZNP}{60A}$

$E_0 \propto \varphi$

Flux is produced based the filed current so, $\varphi \propto I_f$

Field current increases flux in the poles also increases linearly up to saturation. While reaching the saturation even though further increase in field current magnetic field is saturated in the core.
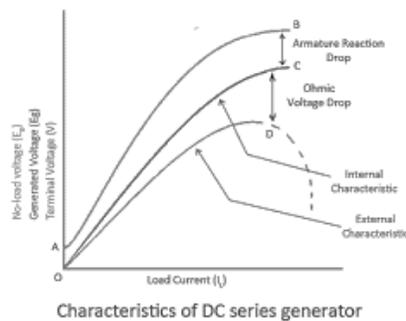

Load characteristics curve

Load is connected to the generator. The curve will plotted against terminal voltage or E_g Vs current (I_L or I_a) than called as Load characteristics curve. There are two types of load characteristics curve are there.
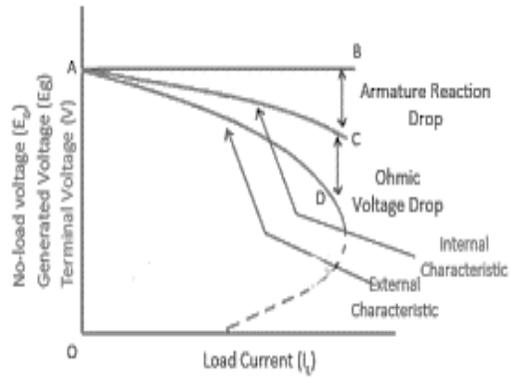
　　i. Internal characteristics curve (E_g Vs I_a)

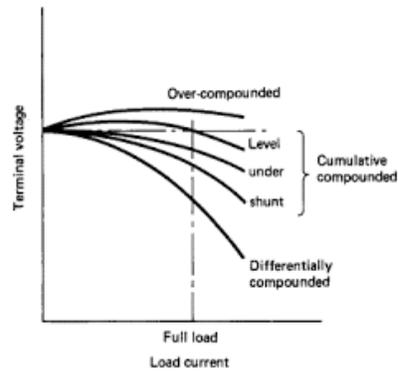　　ii. External characteristics curve(V_t Vs I_L)
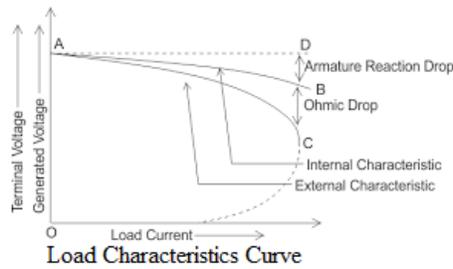
Load characteristics curve of series generator

Characteristics of DC series generator

Load characteristics curve of shunt generator

Load characteristics curve of Compound generator

Applications of D.C Generators

1. Separately Excited D.C generator

- Accurate supplies for testing labs
- Ward-Leonard speed control systems

2. Series generator

There are very few applications in these types

- Series arc lighting
- Arc welding supplies
- Series incandescent lighting
- Series booster for increasing the voltage

3. Shunt generator

- Power supply

- Lighting
- Battery charging

4. Compound generator

- Heavy service railways
- Line voltage booster for D.C systems
- Arc welding
- Lighting

<h1 align="center">UNIT- II</h1>
<h1 align="center">DC MOTOR</h1>

Principle of Operation of a D.C Motor

The principle of operation of 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 dc 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.

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

(a) Interaction of two fluxes   (b) Force experienced by the conductor
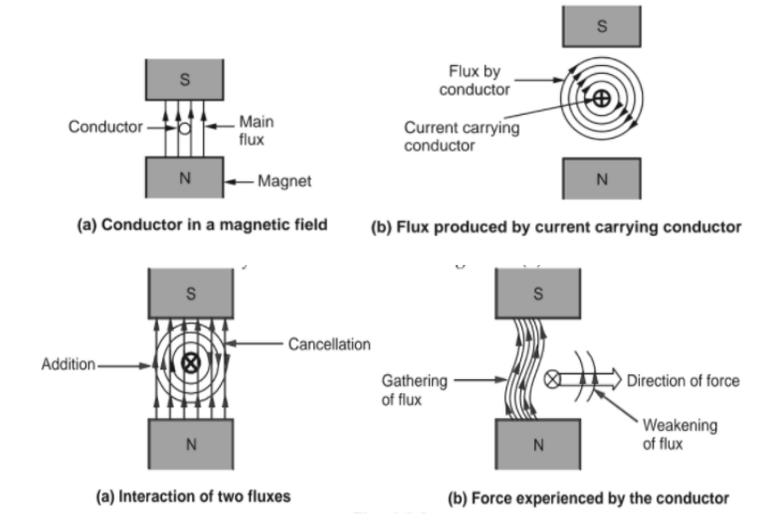
Torque Equation:

Turning or twisting force about an axis is called torque. Consider a wheel of radius R meter acted upon by a circumferential force F newton as shown in fig
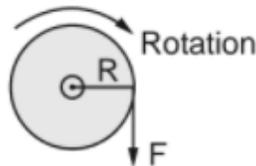
$$\omega = \frac{2\pi N}{60} rad/sec$$

work done in one revolution is,

W = F * Distance travelled in one revolution

$= F*2\pi R$ joules

$P = Powerdevelop = \dfrac{workdone}{Time}$

$= \dfrac{F \times 2\pi R}{Time for\ 1\ rev} = \dfrac{F \times 2\pi R}{\frac{60}{N}}$

$= (F \times R) \times \dfrac{2\pi N}{60}$

$P = T * \omega$ Watts

T = Torque in N.m

Let T_a be the gross torque developed by the armature of the motor and it is called as armature torque. The gross mechanical power developed in the armature is $E_B I_a$

Power in armature = Armature torque * ω

$E_B I_a = T_a * \dfrac{2\pi N}{60}$

Then., E_B in a motor is given by,

$E_B = \dfrac{\emptyset ZNP}{60A}$

$\dfrac{\emptyset ZNP}{60A} * I_a = Ta * \dfrac{2\pi N}{60}$

$T_a = 0.159 \emptyset I_a \dfrac{PZ}{A}$ Nm

This is the torque equation of a d.c motor.

Significance of back EMF:

This induced emf 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 emf is always so as to oppose the cause producing it. So as this emf always oppose the supply voltage, it is called back emf. And denoted as $E_b.$

$Eb = \dfrac{\emptyset ZNP}{60A}$

Back emf in a dc motor   Equivalent circuit
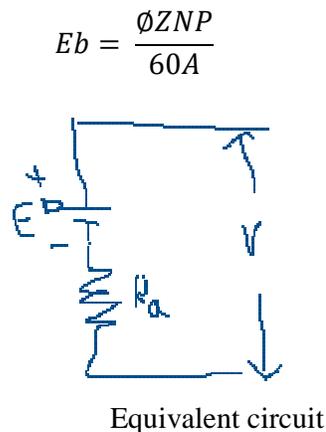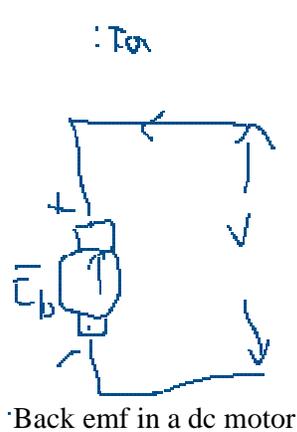
Voltage Equation of a DC motor:

$V = E_b + I_a R_a +$ Brush drop

Neglecting brush drop, then

$V = E_b + I_a R_a$

DC Motor Characteristics:

The characteristics of DC motor under various condition are

➢ Torque- armature current characteristics (T Vs I_a)

➢ Speed -armature current characteristics (N Vs I_a)

➢ Speed – Torque characteristics (N Vs T)

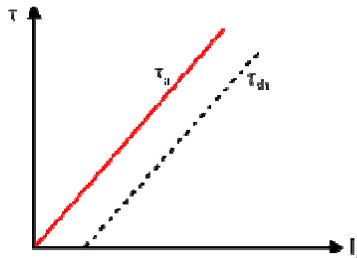**Torque - armature current characteristics (T Vs I_a)**

For Shunt Motor:

$T = \emptyset I_a$

For constant value of R_{sh}& voltage supply V, shunt field current constant, hence flux is also constant.

$T \alpha I_a$

When armature current increases, the torque increase linearly and the armature current depends on load. So, L ↑, I_a↑ , T ↑
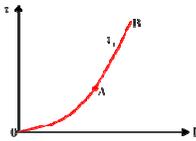

For Series Motor:

$T = \emptyset I_a$

In series motor, the series field winding is carrying the entire armature current.

$\emptyset \alpha I_a$

Hence

$T \alpha \emptyset I_a = Ia^2$

As load increase, armature current increase and torque increase proportional to the square of the armature current Upto certain limit. the entire current passes to the field winding, the winding get saturated, hence flux remains constant.
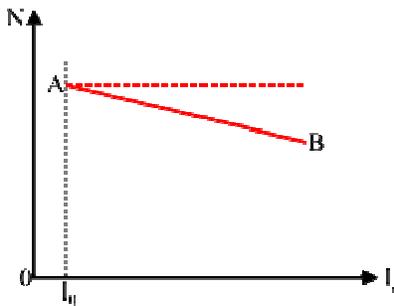
Speed - armature current characteristics (N Vs I_a)

For shunt Motor:

From speed equation

$$N = \frac{V - IaRa}{\emptyset} \propto V - IaRa$$

$\emptyset$ is constant

As load increase, the armature current increase and hence IaRa drop increase. For constant voltage supply V-IaRa decrease and speed get reduced.

For Series Motor:

From speed equation

$$N = \frac{V - IaRa - IaRse}{\emptyset}$$
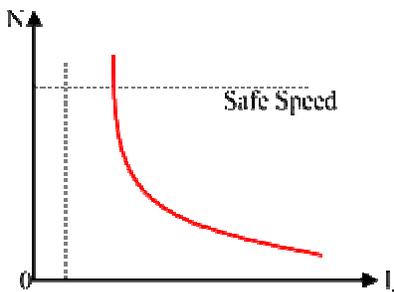
$E_b = V - IaRa - IaRse$

$\emptyset \propto I_a$ in series motor

The value of Ra and Rsh are so small, E_b = V and assume constant

Then $N \propto \frac{1}{Ia}$

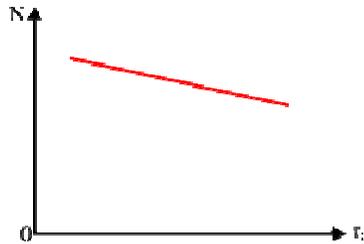As load increases, the armature current increases and speed decrease

Speed – Torque characteristics (N Vs T)

For shunt Motor:

Ta $\propto$ Ia

$N = \dfrac{I}{Ia}$ hence $N = \dfrac{I}{Ta}$

As load increase, the armature current increase, the torque increases hence speed decrease which is similar to speed armature current characteristics.

For Series Motor:

Ta $\propto$ Ia^2

$N = \dfrac{I}{Ia}$ hence $N = \dfrac{I}{\sqrt{Ta}}$

As load increases, the armature current increases, torque increase and speed decrease
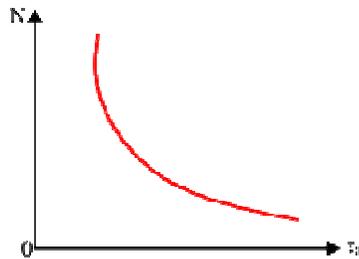
Factors affecting the speed of a dc motor:

Speed equation $N = \dfrac{V - IaRa}{\emptyset}$

E$_b = V - IaRa$

$N = \dfrac{Eb}{\emptyset}$

Thus, the factors affecting the speed of a motor are

  ➢ E$_b = V - IaRa - IaRse$

➤ The flux Ø

➤ The voltage across the armature

➤ The applied voltage V

Speed control of DC Motor:

For Shunt Motor:

Flux Control:

$$N = \frac{1}{\emptyset}$$ V is assumed constant

The speed is inversely proportional to the flux

Ø ∝I_f, at start supply voltage is rated value, the rated current flow through shunt field winding is rated and R is minimum, hence the speed is also rated value called normal speed.

Then R is increased due to that shunt field current is decrease, flux decrease and speed beyond the rated speed value. Thus, by this method, the above rated speed control is possible.

Armature voltage control method:

N ∝ EbØ is assume constant

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

Applied 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.

Necessity of starter:

When motor is switched on with normal voltage and as armature resistance is very small, the armature current at start is very high.

Now at the starting instant the speed of the motor is zero N = 0. As speed is zero, back emf is also zero, since Eb α N

Eb at start is Zero

V = Eb + IaRa

V = IaRa

$$Ia = \frac{V}{Ra}$$

So, at start, motor is showing a tendency to draw an armature current which is 15 to 20 times more than the full load current.

In a constant voltage system, such high inrush of current may cause tremendous line voltage fluctuations. This may affect the performance of the other Equipments connected to the same line. Such excessively high armature current, blows out the fuses.

To restrict this high starting armature current, the variable resistance is connected in series with the armature at start. This resistance is called starter or starting resistance.

So, starter is basically current limiting device. In the beginning the entire resistance is in series with armature and then gradually cur off as motor gathers speed, producing the back emf.

In addition to the starting resistance, there are some protective devices provided in a starter.

Types of staters:

➢ Three-point starter

➢ Four-point starter

➢ Two-point starter

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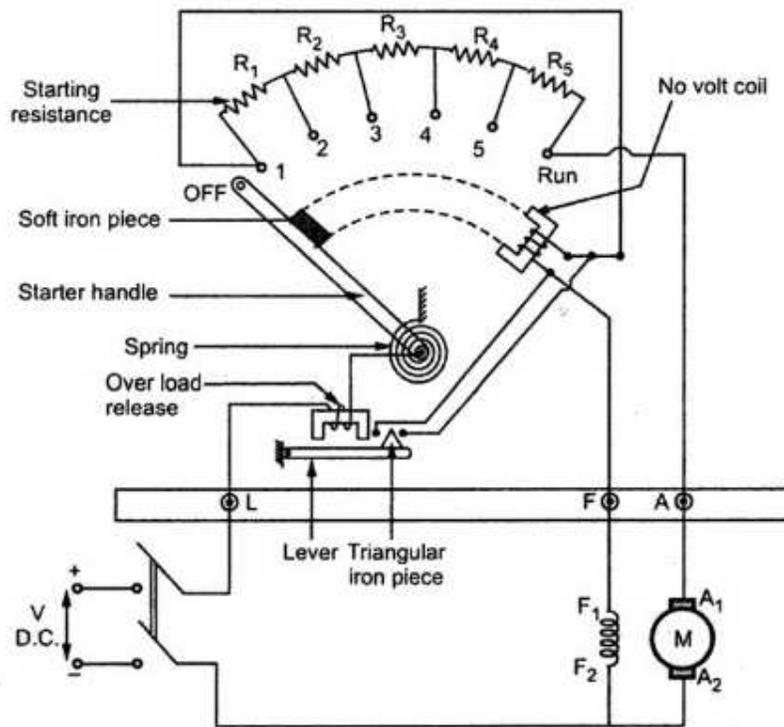
The starter is basically a variable resistance, divided into number of sections. The contact points of these sections are called studs and brought out separately as OFF, 1,2…. upto RUN. There are three main points of this starter

L – line terminal to be connected to positive of supply

A – to be connected to the armature winding

F – to be connected to the field winding

Initially the handle is in the OFF position. The dc 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. 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.

Losses in a dc machine:

Thevarious losses in a dc machine are

- ➢ Copper losses
- ➢ Iron losses
- ➢ Mechanical losses

Copper losses:

The copper losses are the losses taking place due to the current flowing in a winding. The copper losses are proportional to the square of the current flowing through armature and field winding. This loss is also called variable loss

Armature copper loss = $I_a^2 R_a$

Shunt field winding = $I_{sh}^2 R_{sh}$

Series field copper loss = $I_{se}^2 R_{se}$

Iron Losses:

These losses are called magnetic losses or constant loss or no-load power loss. This loss includes hysteresis loss and eddy current loss.

$P_0 = V_0 I_0 Cos\emptyset_0$

Mechanical losses:

These losses consist of friction and windage losses. Some power is required to overcome mechanical friction and wind resistance at the shaft. The magnetic and mechanical losses together are called stray losses.

Thus, for a dc machine

Total losses = Constant losses + Variable losses

Efficiency of a dc Machine

Overall efficiency is given by $\eta = \frac{Total\,output}{total\,input}$

$$\%\eta = \frac{Pout}{Pin + Pcu + Pi} \times 100$$

P_{out} = Total output power

P_{in} = Total input power

P_{cu} = Variable losses
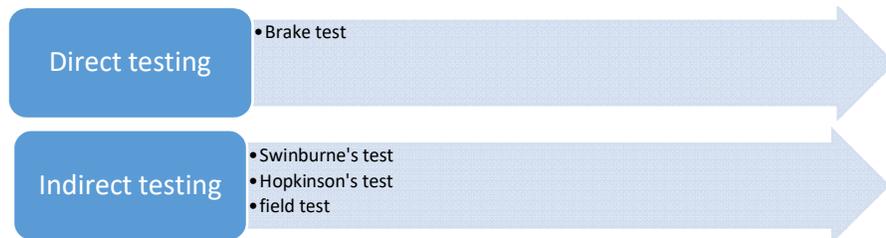
P_i = Constant losses

Condition for maximum efficiency:

Variable losses = Constant losses

$P_i = P_{cu}$

Testing of dc Motors:

The various losses taking place in a dc motor and efficiency can be calculated by carrying out testing of dc motors. The two methods are

Direct testing
• Brake test

Indirect testing
• Swinburne's test
• Hopkinson's test
• field test

Swinburne's Test or No-load test:

In this method of testing, the flux remains practically constant ie in case of shunt motor and compound motor. Without loading the motor, the losses and efficiency at different loads can be calculated.
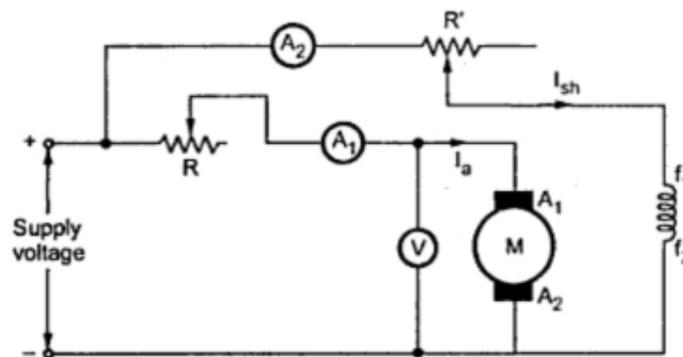
When motor runs at its rated voltage at no load, high starting current is decrease by some of resistance connected in series with armature is cut off to attain sufficient speed. Now the speed of the motor is adjusted to the rated speed with the help of shunt field rheostat. The no load armature current is measured by ammeter A_1 where as the shunt current is measured by ammeter A_2.

The motor input at no load will be,

Power input at no load = $V (I_a + I_{sh}) = W_0$

There will be some cu loss in the field is given by

> ➤ Field copper loss = $V \times I_{sh}$
> ➤ Armature copper loss = $I_a^2 R_a$

Thus, the stray losses which includes iron, friction and windage losses can be obtained as,

Stary losses = input at no load – Field copper loss – no load armature copper loss

Stary losses = $V (I_a + I_{sh}) - V \times I_{sh} - I_a^2 R_a = W_a$

To find efficiency at Full load current

Now the full load current is I_{FL}

$I_{FL} = I_{sh} + I_a$

$I_a = I_{fL} + I_{sh}$

Full load armature copper loss = $Ia^2 R_a$ in watts

Total losses = Full load armature Cu loss + Constant losses

$P_T = Ia^2 R_a + W_0$ in watts

Full load motor input = V.I

Full load motor output = input – total losses

$$\%\eta \, at \, full \, load = \frac{full \, load \, output}{full \, load \, input} \times 100$$