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శ్లో॥ శరదిందు సమాకారే! పరబ్రహ్మస్వరూపిణీ!!
వాసరా పీఠ నిలయే! సరస్వతీ మాతా నమోస్తుతే!!

Basic Electrical Engineering.

UNIT–VI
DC MACHINES

Learning Objectives:

(1). Basic Definitions
(2) Basic Working Principle of a DC Generator
(3) Constructional Details of a DC Machine
(4) Armature Windings
(5) EMF Equation of a DC Generator
(6) Operation of a DC Machine as a Generator & Types of Generators
(7) Operation of a DC Machine as a Motor & Types of Motors.
(8) Total Losses in a DC Machine
(9) Torque Production in a DC Machine
(10) Speed Control of a DC Motor
(11) DC Generator Characteristics
(12) DC Motor Characteristics
(13) Starter.

(1) Basic Definitions:

(i) Law of Conservation of Energy: " Energy can neither be created nor destroyed. But it can be converted from one form to another form". It means we cannot create energy & we can not destroy energy but energy can be converted from one form (available form) to another form (required form).

(ii) Electro Mechanical Energy Conversion: A device or machine which converts either mechanical energy into electrical energy or electrical energy into mechanical energy is called as Electromechanical Energy Conversion Device.

All the rotating machines are electromechanical energy conversion devices. The best examples of Electromechanical energy conversion devices are DC Generators, DC Motors, Sychronous Generators, Synchronous Motors, Induction Motors etc.

(iii) <u>DC Machine:</u> A dc machine is an electromechanical energy Conversion device. If the dc machine converts mechanical energy into electrical energy then it is known as DC Generator. If the dc machine converts electrical energy into mechanical energy then it is known as DC Motor.

(iv). <u>Generator:</u> A machine which converts mechanical energy into electrical energy is known as Generator.

(V). <u>Motor:</u> A machine which converts electrical energy into mechanical energy is known as Motor.

(Vi) <u>Generator Principle:</u> The Energy conversion is based on the principle of production of dynamically or motionally induced emf.

"Whenever a conductor cuts magnetic flux or magnetic lines of force, dynamically induced emf is produced in it according to Faraday's Laws of Electromagnetic Induction".

This emf causes a current to flow if the conductor circuit is closed.

According to Faraday's laws of Electromagnetic Induction.

"The rate of change of flux linkages is known as Induced emf. in a conductor". It is given by $\frac{d\phi}{dt}$.

(vii) **Motor Principle:** "Whenever a current carrying conductor is placed in a magnetic field it experiences a mechanical force, whose direction is given by Fleming's Left Hand-Rule and whose magnitude is given by $F = BIl \sin\theta$ Newton.

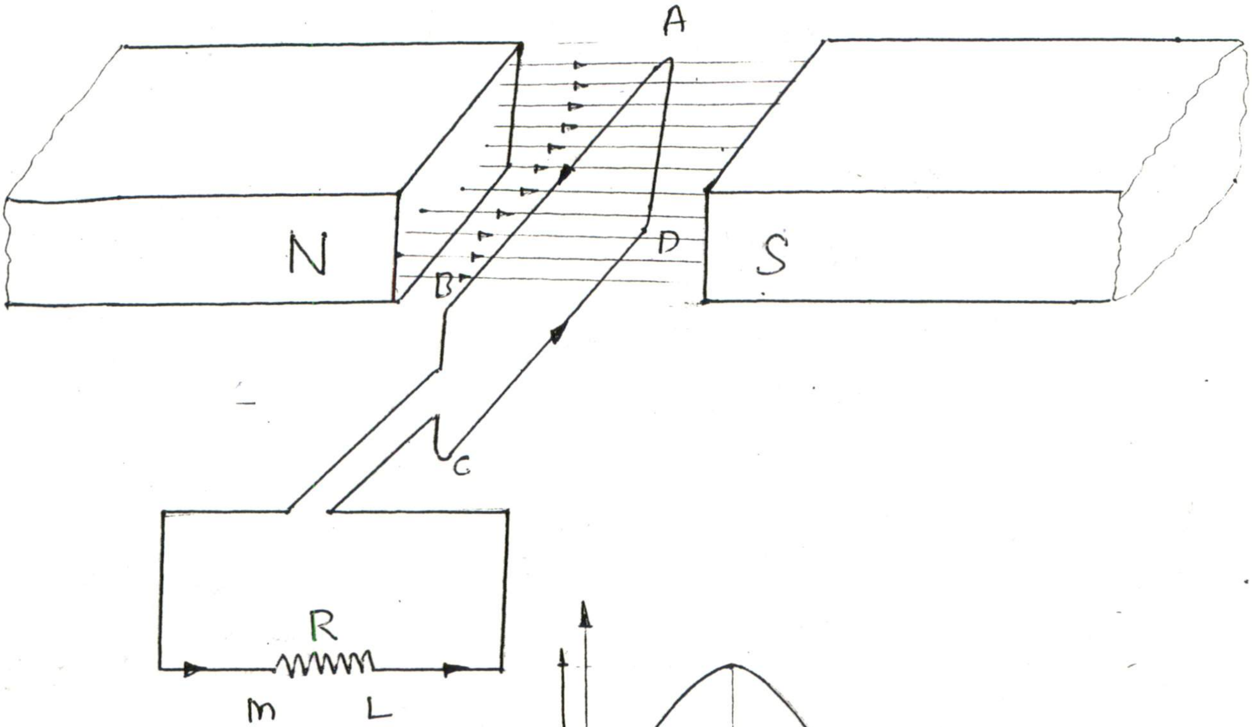
$F \Rightarrow$ Mechanical Force in Newton
$B \Rightarrow$ Magnetic Flux density in Wb/m^2
$l \Rightarrow$ length of the conductor in meters.
$\theta \Rightarrow$ Angle of the conductor in the Magnetic field in degrees

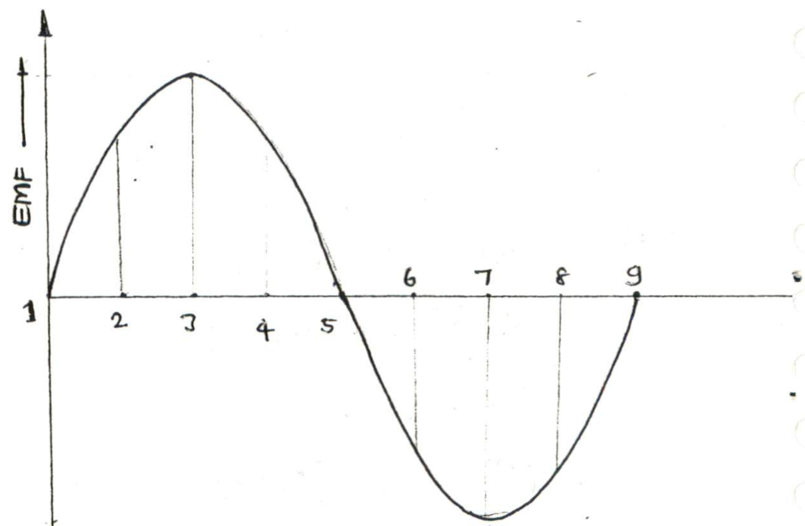
(2) Basic Working Principle of a DC Generator:

According to Faraday's Laws of Electromagnetic Induction " Whenever a conductor cuts magnetic flux or magnetic lines of force, dynamically induced emf is produced in it." If the conductor circuit is closed, the induced emf causes a current to flow in it.

Hence three basic essential elements of an electrical generator are (i) A magnetic field or flux which is produced either by electromagnets or permanent magnets.
(ii) A conductor or group of conductors which has to be rotated in such a way that the magnetic flux can be cut.
(iii) Relative motion between magnetic flux & conductor.

Simple Loop Generator: Consider a simple loop generator. It consists of a magnetic flux, which is produced by either permanent magnets or electromagnets. And a single coil conductor in the form of a rectangular loop, represented by ABCD. This rectangular loop conductor ends are connected to a Resistive load, which is represented by M L





Consider the coil "ABCD" is rotating in the magnetic field in clockwise direction. When the coil is rotating in the magnetic field, the flux linking with the coil varies. According to Faraday's Laws of Electromagnetic Induction, EMF will be induced in it.

(i) When the coil is in vertical position, the flux linking with the coil is maximum. But the rate of change of flux $\left(\frac{d\phi}{dt}\right)$ linking with the coil is minimum. Therefore the induced emf in it is equal to zero.

(ii) As the coil moves from its vertical position to horizontal position (i.e. from 0° to 90°). The flux linking with the coil is minimum.

But the rate of change of flux linking with the coil is maximum. Hence max emf is induced in it. It is shown in fig at point "3".

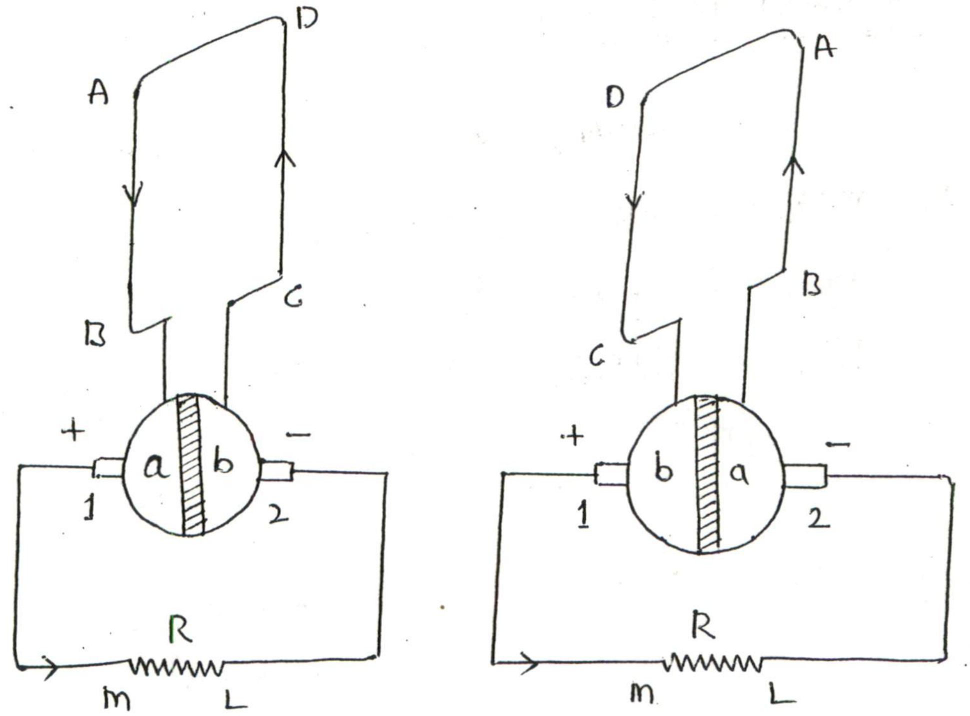
(iii) As the coil moves again from its 90° to 180°; the flux linking with the coil increases. But the rate of change of flux linking with the coil decreases. Hence minimum emf is induced. It is shown in fig at point "5".

(iv) During the first half cycle i.e. from (0° to 180°). the current flows in the coil from A to B and C to D i.e. the current flow path is given by ABMLCD.

(v) During the second half cycle i.e. from (180° to 360°) the induced emf is similar to the first half cycle. But the direction of current is opposite to that of the first half cycle. Therefore the current flow path during second half cycle is given by DCLMBA. It is opposite to the current flow path given by ABMLCD.

(vi) It can be observed that, the induced emf in the armature of a dc generator is alternating only. i.e. ac.

(vi) The ac emf in the armature is converted into dc emf in the external load circuit through a "Commutator". In case of dc generators the Commutator acts as a mechanical rectifier i.e. it converts alternating current in the armature into unidirectional in the external load circuit.


A
B
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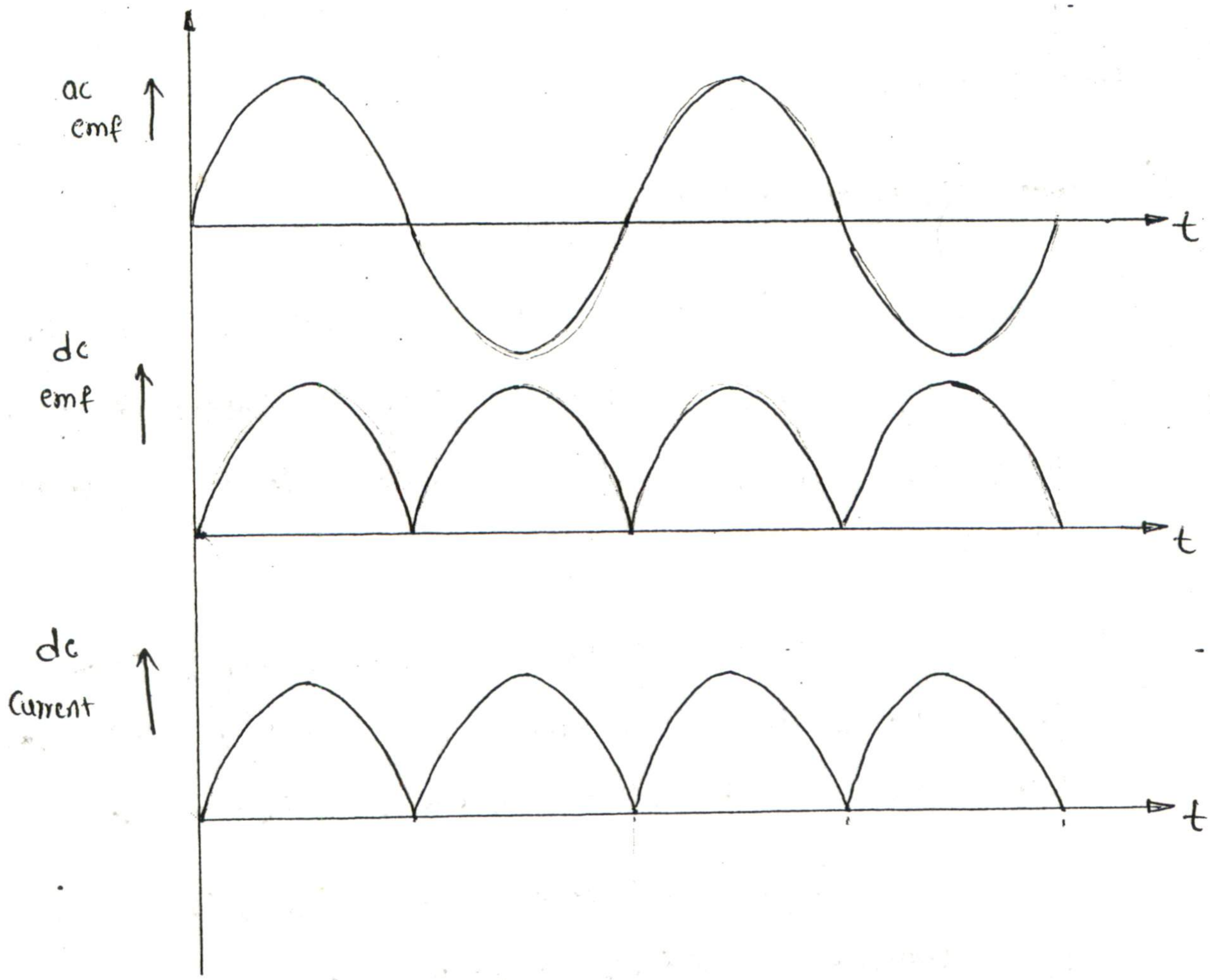

ac emf
t
dc emf
t
dc Current
t

(3) Constructional Details of a DC Machine:

Basically a dc machine consists of two main parts. i.e. Stator and Rotor.

Stator ⟹ Field System
Rotor ⟹ Armature System.

The main parts of a dc machine are:

1. Magnetic Frame or Yoke
2. Pole Cores
3. Pole Shoes
4. Field Windings
5. Interpoles
6. Armature Core
7. Armature Windings
8. Commutator.
9. Brushes
10. Bearings & Shaft.

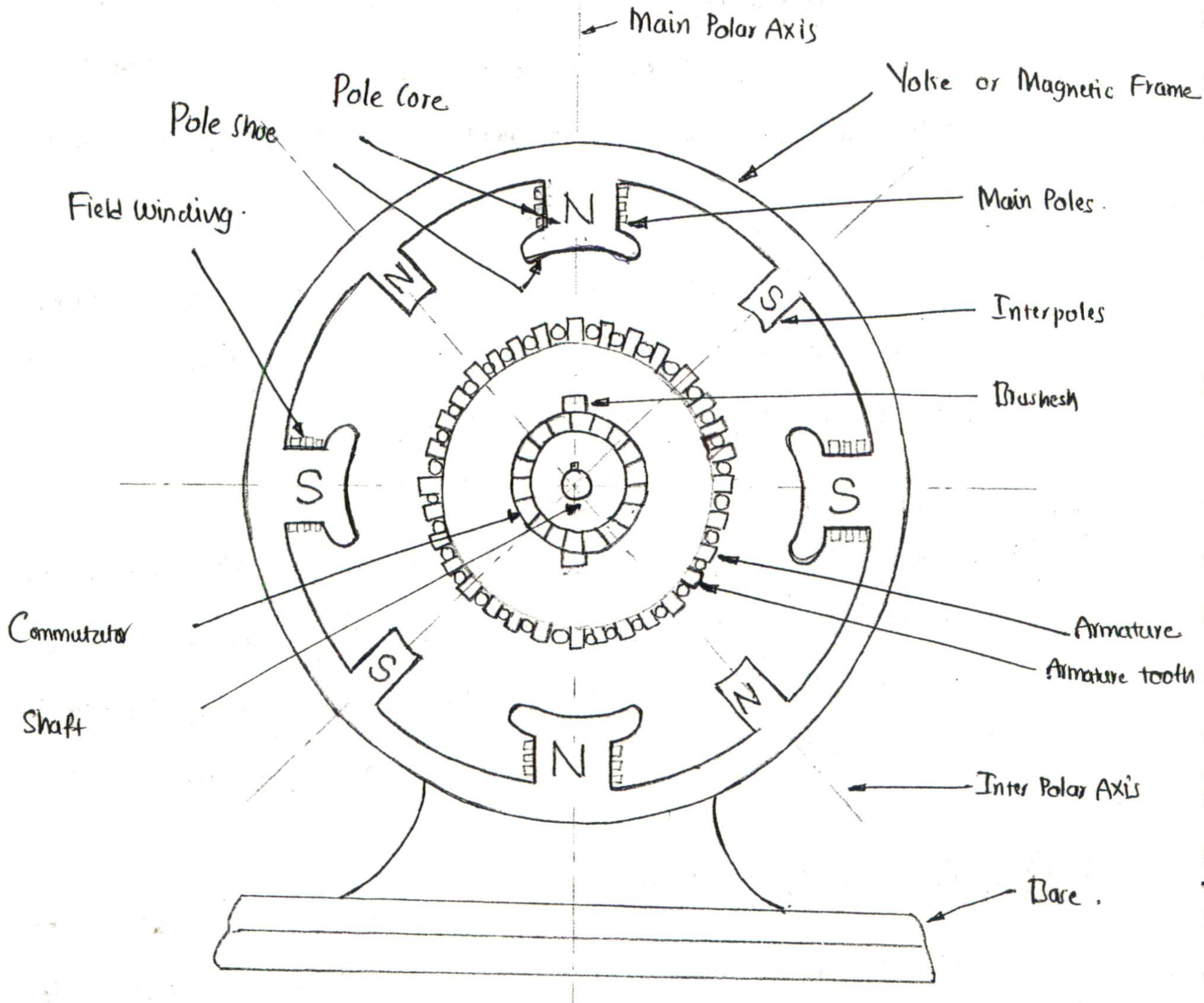
(i) Magnetic Frame or Yoke:

The magnetic frame or yoke is made with some magnetic material. For small rating dc machines the yokes are made with cast iron and for large rating dc machines, the cast steels are used.

The magnetic frame provides mechanical support to the various parts of the machine and it also protects the various parts of the dc machine from moisture, harmful gases etc.

It carries the magnetic flux, which is produced by the electromagnets uniformly in the air gap.

Main Parts and Constructional Details of a DC Machine.



(ii) Pole Cores: The pole cores are made with cast iron or cast steels. The slots are provided on the outer periphery of the pole cores to accomidate the field windings.

The pole core directs the flux produced by the field windings in the air gap uniformly.

(iii) Pole Shoe: The pole shoe is the extension part of the pole core. It is made with cast iron or cast steel. The flux produced by the field magnets is emitted from the surface of the pole shoes only. The main aim of pole shoes is to distribute the flux uniformly in the air gap.

(iv) **Field winding :** The field winding is made with copper material. This field winding is wounded in the slots of the pole core. When the dc current is passed through this field winding the magnetic flux will be produced. and which is emitted from the pole shoes.

∴ The pole cores, pole shoes and the field windings constitutes the Field System of the dc machine. It comes under the category of the "Stator".

(V) **Interpoles :** The interpoles are the small electro magnets, which are provided in between the main poles. The interpoles helps in quick reversal of armature current. The interpoles improves the commutation by reducing the sparks at the brushes.

(Vi) **Armature Core :** The armature core is made with a magnetic material such as cast iron or cast steel. It possesses low reluctance i.e. high permeability.

The armature core is made in cylindrical shape. And the slots are provided on the outer periphery of the cylindrical core, to accomidate the armature windings. The armature core is mounted on the shaft. It is nothing but "rotor" i.e. rotating member.

(Vii) **Armature Windings:** The armature windings are made with good conductors of electricity. Such as copper. The copper winding are wounded in the form of coils, either by lap windings or by wave windings. These windings are placed in the slots provided on the outer periphery of the armature core.

When the armature rotates in the magnetic field, the flux will be cut by the armature conductors. According to Faraday's Laws of Electromagnetic Induction, the emf will be induced in the armature windings.

(viii) Commutator: The emf induced in the armature of a dc generator is alternating nature only. It is converted into dc by using a commutator. It is mounted on the shaft of the armat....

Commutator is made with a good conductor, in the form of segments. Each segment is insulated from each other. The no. of commutator segments is equal to the no. of armature coils.

The commutator acts as a mechanical rectifier in the case of generator. It means it converts ac to dc.

The commutator acts as a mechanical Inverter in the case of motor. It means it converts dc to ac.

(ix) Brushes: The brushes are made with carbon material. These are mounted i.e. pressed on the commutator segments. The main aim of brushes is to collect the currents from the armature, through commutator and conveys these currents to the external load circuit.

(X) Bearings & Shaft:

Bearings: The bearings support the armature shaft. It means the armature shaft rotates in the bearings. The bearing may be ball bearings or roller bearings. The main aim of bearings is to provide smooth rotation of the shaft with perfect alignment.

Shaft: The shaft is the main rotating part on which armature core, armature windings, commutators etc are mounted. The rotation of shaft causes the Electromechanical Energy Conversion in the dc and ac machines.

(4). Armature Windings:

The armature winding is made with copper metal. The armature windings are wounded in the form of dimond shaped coils and are placed in the slots of the armature core. The ends of the armature coils are connected to the commutator segments.

The no. of armature coils is equal to the no. of commutator segments.

The armature windings are classified into two types. These are (i) Lap Wound Winding and
(ii) Wave Wound Winding.

This classification is based upon the manner, in which the coil ends are connected to the commutator segments.

(i) **Lap windings:** In lap winding, the two ends of a coil are designated as "start" and "finish". These two ends are connected to the adjacent commutator segments. In this type of windings, the sides of the successive coils overlap with each other, therefore this type of winding is known as Lap winding.

In Lap Winding, the no. of parallel paths is equal to the no. of poles.

i.e. $\boxed{P=A}$ OR $\boxed{A=P}$

In fig (a) the "finish" of each coil is connected to the commutator segment ahead of the "start" of the coil. Therefore this type of connection of coils to the commutator is known as "Progressive Lap Winding".

In fig (b) the "finish" of each coil is connected to the commutator segment behind the "start" of the coil. Therefore this type of connection of coils to the commutator is known as "Retrogressive Lap winding".

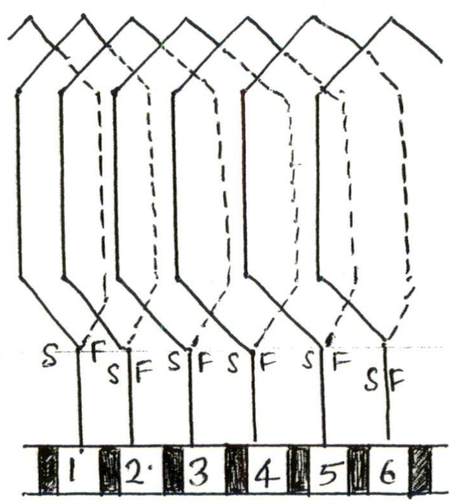


Fig (a).

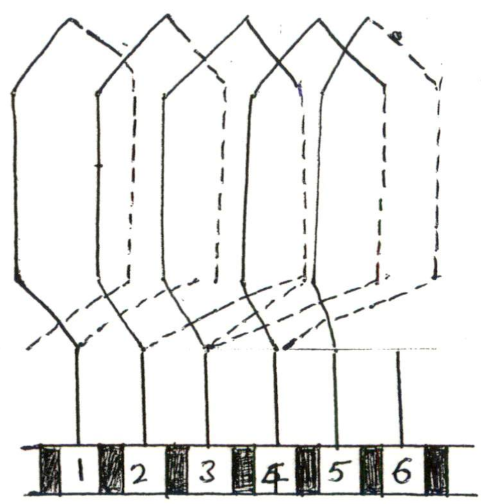


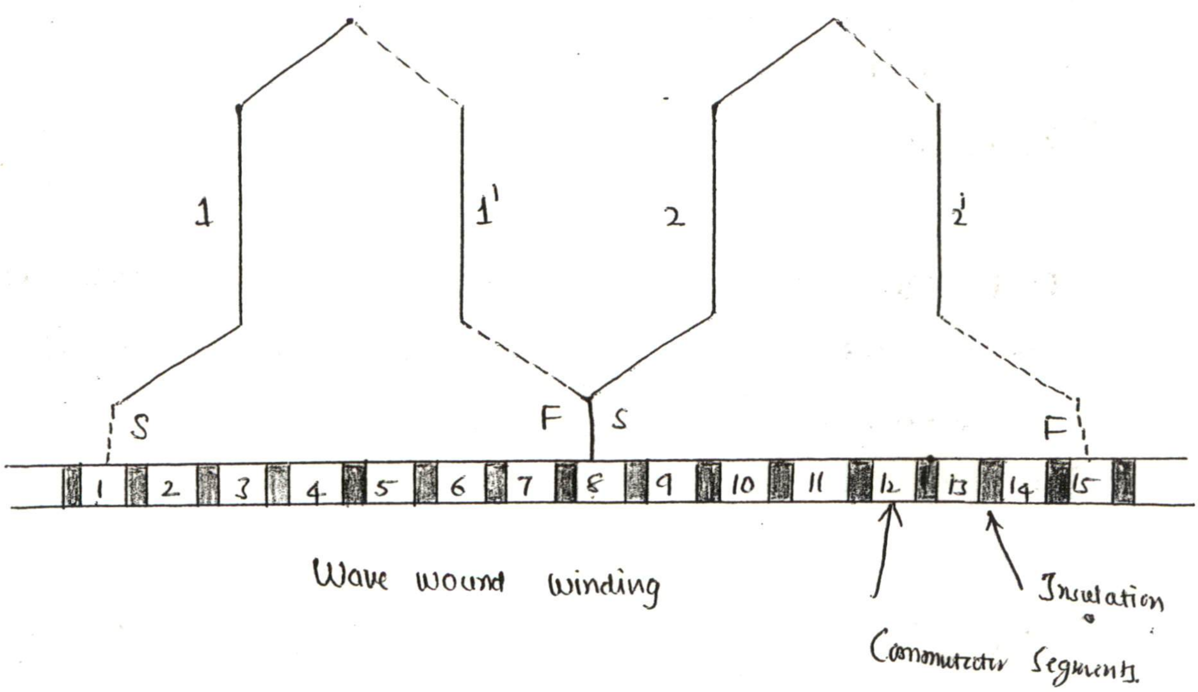
Fig (b).

(ii) **Wave Winding:** In wave wound winding, the "finish" of one coil is connected to the "start" of another coil. And these two ends are connected to the same commutator segment.

It means the "finish" of one coil and the "start" of another coil are connected to the same commutator segment.

In wave wound winding, the no. of parallel paths is equal to ~~(two)~~ two.

$$\boxed{A=2}$$



Wave wound winding

Comparison of Lap wound and Wave wound windings.

Sl. No.	Lap Wound Winding	Wave Wound Winding.
(1).	In lap wound winding the no. of parallel paths is equal to the no. of poles. i.e $A=P$	(1). In wave wound winding the no. of parallel paths is always equal to two. i.e. $A=2$.
(2)	In lap wound winding the no. of brushes is equal to the no. of poles.	(2) In wave wound winding the no of brushes is equal to two.
(3).	Current in each coil is equal to $\frac{I_a}{A}$. Where I_a = Armature Current, A = No. of Parallel Paths	(3) Current in each coil is equal to $\frac{I_a}{2}$ Where I_a = Armature Current, A = No. of Parallel Paths.
(4).	The lap wound winding is used for higher current ratings and lower Voltage rating machines	(4). The wave wound winding is used for lower current rating and higher voltage rating machines.

(5) EMF Equation of a DC Machine:

Let $P =$ No. of Poles

$\phi =$ Flux per poles in wb.

$Z =$ Total No. of armature conductors

$\Rightarrow Z =$ No. of Slots X No. of Conductors/slot.

$N =$ Armature rotation in revolutions per minute i.e. in rpm.

$A =$ No. of parallel paths.

$E =$ EMF induced in any parallel path in the armature

$E_g =$ Generated EMF in the armature.

According to Faraday's Laws of Electromagnetic Induction
"The rate of change of flux linkages with the conductor is known as Induced EMF."

$\therefore$ The average value of Induced EMF/conductor $= \frac{d\phi}{dt}$

The flux cut by one conductor in one revolution $d\phi = \phi P$.

No. of revolutions/second $= \frac{N}{60}$.

$\therefore$ The time required for one revolution $dt = \frac{60}{N}$.

$\therefore$ The average emf generated/conductor $\Rightarrow \frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{\phi N P}{60}$

$\therefore$ The average emf induced in Z no. of Conductors is given by

$$\boxed{E_g = \frac{\phi Z N}{60} \times \frac{P}{A}}$$

Where $A =$ No. of Parallel Paths.

$\therefore$ The average generated EMF $\boxed{E_g = \frac{\phi Z N}{60} \times \frac{P}{A}}$

(a) For a wave-wound generator $A=2$.

$$\therefore E_g = \frac{\phi Z N}{60} \times \frac{P}{2}$$

(b) For a Lap-wound generator $A=P$

$$\therefore E_g = \frac{\phi Z N}{60} \times \frac{P}{P} \Rightarrow E_g = \frac{\phi Z N}{60}.$$

(6). Operation of a DC Machine as a Generator:

It is nothing but Basic Working Principle of a DC Generator See the Topic (2).

Types of DC Generators: The dc generators are classified according to the way in which the field systems are excited.

These are classified into two types.

(i) **Separately Excited DC Generators:** The generators in which their field systems are excited by a separate dc voltage source. are called as Separately Excited DC Generators.

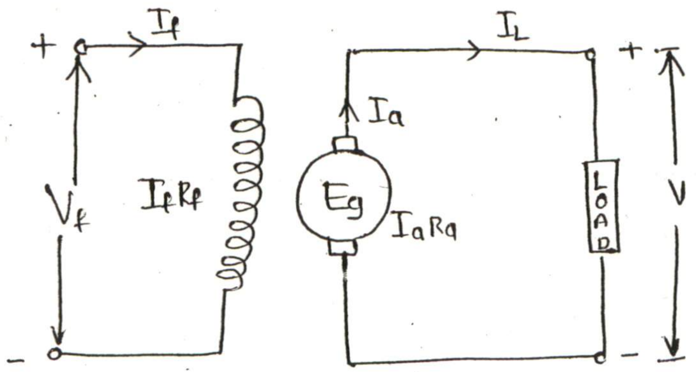
(ii) **Self Excited DC Generators:** The generators in which their field systems are excited by the current which is produced in the armature itself only. It means a small amount of current is transfered to the field system.

The Self Excited generators are classified according to the manner in which their field winding is connected to the armature. There are of four types.

* DC Shunt Generator. * DC Series Generator.
* DC Long Shunt Compound Generator * DC Short Shunt Compound Generator.

(i) **Separately Excited DC Generator:** The generators in which their field windings is excited by a separate dc Voltage source is known as a "Separately Excited DC Generator".

There is no electrical connection between armature system and field system. Only magnetic coupling will exists.



$$V_f = I_f R_f$$

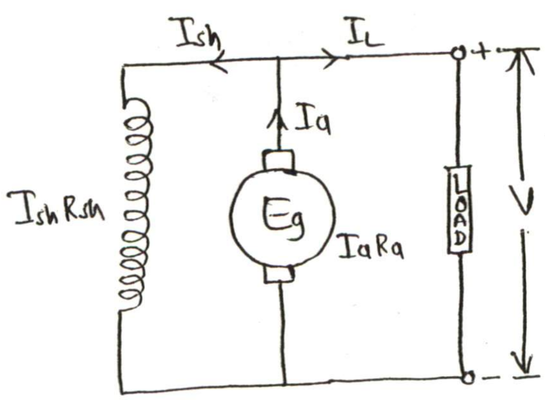
$$\Rightarrow I_f = \frac{V_f}{R_f}$$

$$E_g = V + I_a R_a$$

$$\Rightarrow I_a = \frac{E_g - V}{R_a}$$

Here $I_a = I_L$

(ii) **DC Shunt Generator:** The generator in which the field system is connected in parallel with the armature system is known as "DC Shunt Generator".



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

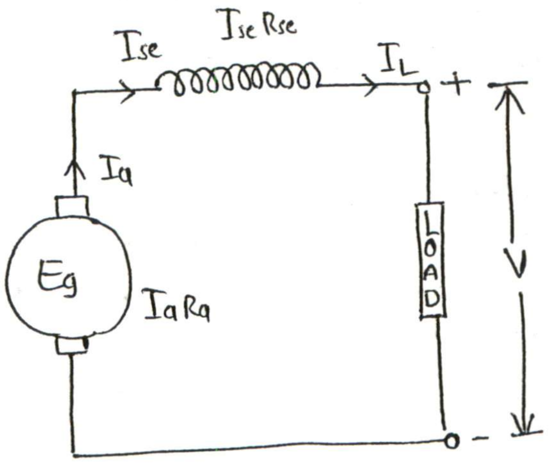
$$E_g = V + I_a R_a$$

$$\Rightarrow I_a = \frac{E_g - V}{R_a}$$

$$V = I_{sh} R_{sh} \Rightarrow I_{sh} = \frac{V}{R_{sh}}$$

Output Power $P = V I_L$

(iii) **DC Series Generator:** The generator in which the field system is connected in ~~parallel~~ series with the armature system is known as "DC Series Generator."



Here $I_a = I_{se} = I_L$

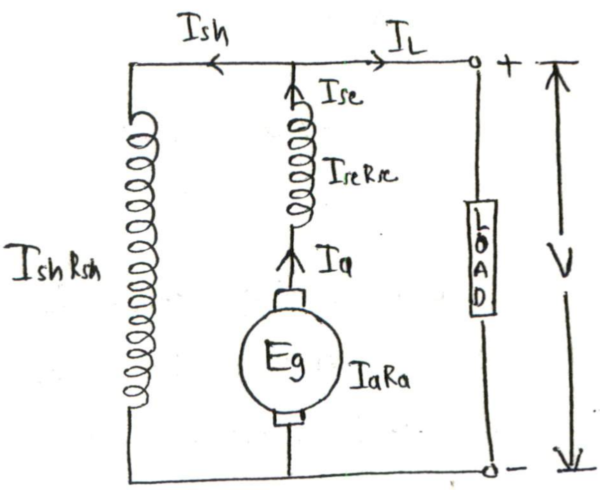
$$E_g = V + I_aR_a + I_{se}R_{se}$$

$$\Rightarrow E_g = V + I_a(R_a + R_{se})$$

$$\Rightarrow I_a = \frac{E_g - V}{(R_a + R_{se})}$$

Out Put Power. $P = VI_L = VI_a$

(iv) **DC Long Shunt Compound Generator:** In this type of generators a part of field winding is connected in series with the armature and a major part of the field winding is connected in parallel with the "armature and series field winding".



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

$$E_g = V + I_aR_a + I_{se}R_{se}$$

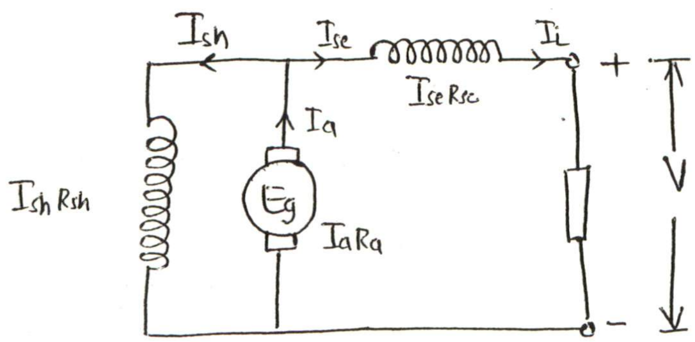
$$E_g = V + I_a(R_a + R_{se})$$

$$\Rightarrow I_a = \frac{E_g - V}{(R_a + R_{se})}$$

$$V = I_{sh}R_{sh} \Rightarrow I_{sh} = \frac{V}{R_{sh}}$$

Out Put Power $P = VI_L$

(V) <u>DC Short Shunt Compound Generator:</u> In this type of generators, a part of field winding is connected in parallel to the armature and a part of the field winding is connected in series with the load and armature.



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

$I_a = I_{sh} + I_L$

$\because I_{se} = I_L$

$$E_g = V + I_aR_a + I_{se}R_{se}$$

$$I_{sh}R_{sh} = V_{sh} \implies V_{sh} = I_{sh}R_{sh}$$

$$V_{sh} = V + I_{se}R_{se}.$$

$$\therefore I_{sh} = \frac{V + I_{se}R_{se}}{R_{sh}}.$$

(7) <u>Operation of a DC Machine as a Motor:</u>

An electric motor is a machine which converts electrical energy into mechanical energy.

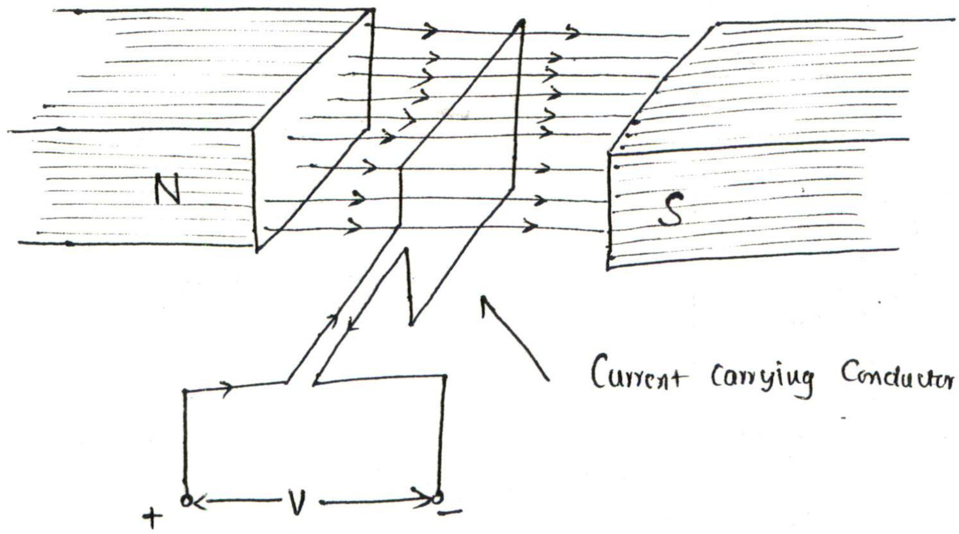
<u>Motor Principle:</u> "Whenever a current carrying conductor is placed in a magnetic field it experiences a mechanical force, whose direction is given by Fleming's Left Hand Rule and whose magnitude is given by $F = BIl \sin\theta$. Newton.

Where $F \implies$ Mechanical Force in Newton

$B \implies$ Magnetic flux density in Wb/m^2

$l \implies$ Length of the conductor in meters.

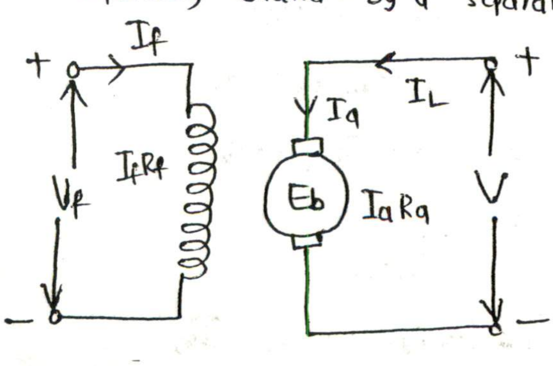
$\theta \implies$ Angle of the conductor in the magnetic field.



Whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force i.e. it starts rotating in the magnetic field. Due to rotation, the flux linking with the conductor or coil varies. According to the Faraday's Laws of Electromagnetic Induction, emf will be induced in the conductor. The emf induced in this manner is known as "back emf". It is denoted by "E_b". The back emf "E_b" always opposes the applied Voltage "V"

Types of DC Motors:

(i) Separately Excited DC Motor: In this type of motors, the field systems are separately Excited by a separate DC Voltage Source.



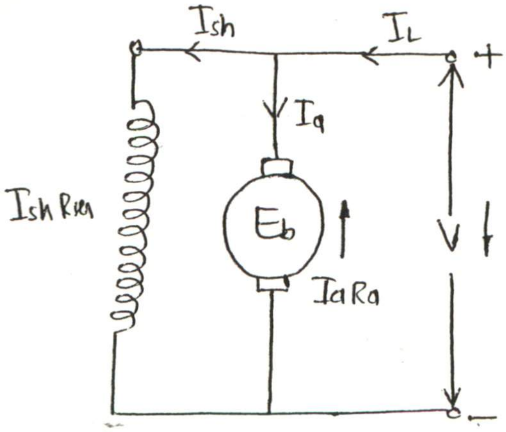
$$V_f = I_f R_f \Rightarrow I_f = \frac{V_f}{R_f}$$

$$V = E_b + I_a R_a \Rightarrow I_a = \frac{V - E_b}{R_a}$$

Here $I_L = I_a$

$E_b \uparrow \quad V \downarrow$

(ii) **DC Shunt Motor:** If the field system is connected in parallel with the armature system, then it is known as DC Shunt Motor.



Here $I_L = I_a + I_{sh}$

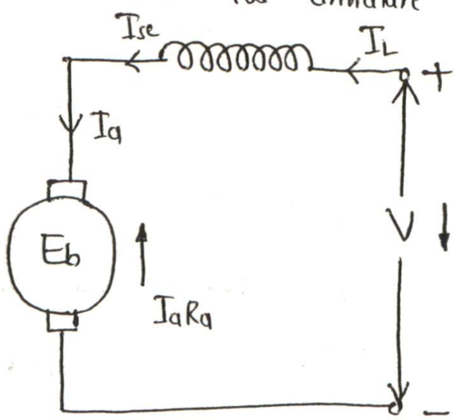
$$V = E_b + I_aR_a$$

$$I_a = \frac{V - E_b}{R_a}$$

$$V = I_{sh}R_{sh} \Rightarrow I_{sh} = \frac{V}{R_{sh}}$$

Input Power $P = VI_L$

(iii) **DC Series Motor:** In this type of motor, the field winding is connected in series the armature winding.



Here $I_L = I_{se} = I_a$

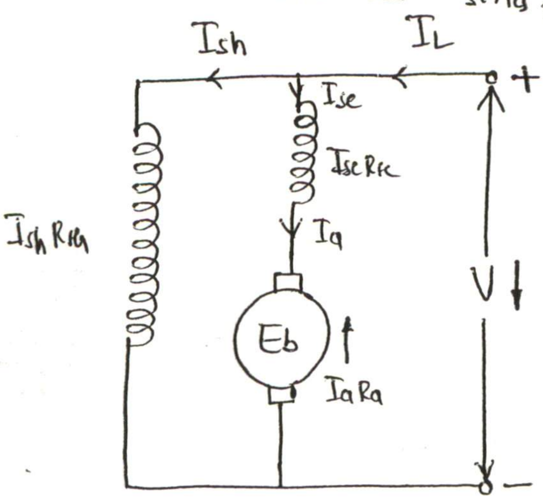
$$V = E_b + I_aR_a + I_{se}R_{se}$$

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

$$I_a = \frac{V - E_b}{(R_a + R_{se})}$$

Input Power $P = VI_L$

(iv) **DC Long Shunt Compound Motor:** A part of field winding is connected in series with the armature and a major part of the field winding is connected in parallel with the "series field and armature".



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

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

$$V = E_b + I_aR_a + I_{se}R_{se}$$

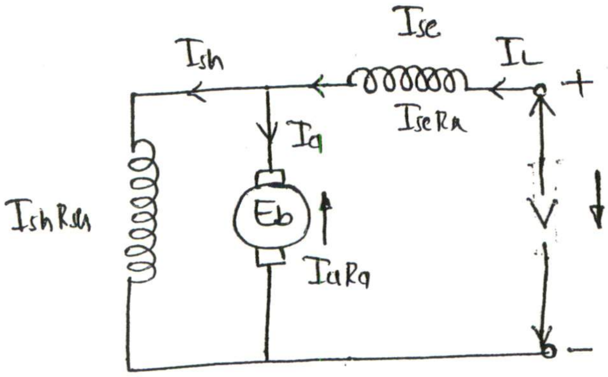
$$V = E_b + I_a(R_a + R_{se})$$

$$I_a = \frac{V - E_b}{R_a + R_{se}}$$

Input Power $P = VI_L$

$$V = I_{sh}R_{sh} \Rightarrow I_{sh} = \frac{V}{R_{sh}}$$

(V) DC Short Shunt Compound Motor: In this type of motor, a part of field winding is connected in parallel with the armature and remaining part of the field winding is connected in series with the armature and load.



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

$$V = E_b + I_aR_a + I_{se}R_{se}.$$

$$I_{sh}R_{sh} = V_{sh}$$

$$V_{sh} = -I_{se}R_{se} + V$$

$$\Rightarrow V_{sh} = V - I_{se}R_{se}$$

$$V_{sh} = E_b + I_aR_a.$$

$$\therefore I_{sh}R_{sh} = E_b + I_aR_a$$

(8) Total Losses in a DC Machine:

The total losses in a dc machine can be subdivided into three categories. There are

(a) Copper Losses:

(i) Armature Cu losses $= I_a^2 R_a$

(ii) Shunt Field Losses $= I_{sh}^2 R_{sh}$

(iii) Series Field Losses $= I_{se}^2 R_{se}$

(b) Iron Losses or Core Losses or Magnetic Losses:

(i) Hysteresis Losses $W_h \propto B_m^{1.6} f$

(ii) Eddy Current Losses $W_e \propto B_m^2 f^2$

(c) Mechanical Losses:

(i) Friction losses at bearings and Commutator

(ii) Windage losses due to rotation of the armature.

Stray Losses = Iron Losses + Mechanical Losses.

Constant Losses = Iron Losses + Mechanical Losses + Shunt field Cu losses

Variable Losses = Armature Cu losses $I_a^2 R_a$

Total Losses = Constant Losses + Variable losses.

Electrical Efficiency $\eta = \frac{Output}{Input} = \frac{VI}{E_g I_a}$

Condition for maximum Efficiency:

Generator output $= VI$

Generator Input $=$ OutPut + Losses

$= VI + I_a^2 R_a + W_c$

$= VI + I^2 R_a + W_c$

$$\eta = \frac{Output}{Input} = \frac{VI}{VI + I^2 R_a + W_c}$$

$$\frac{d\eta}{dI} = \frac{(VI + I^2 R_a + W_c)V - VI(V + 2IR_a)}{(VI + I^2 R_a + W_c)^2}$$

for max efficiency $\frac{d\eta}{dI} = 0$

$$\Rightarrow VI + I^2 R_a + W_c - VI + 2I^2 R_a = 0$$

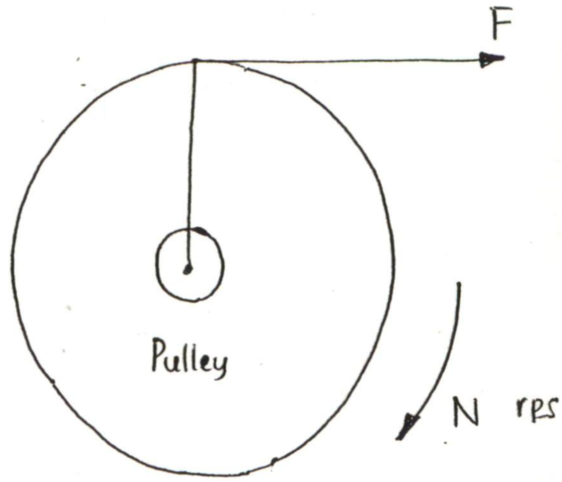
$$\Rightarrow W_c - I^2 R_a = 0 \Rightarrow \boxed{W_c = I^2 R_a}$$

$\therefore$ The Condition for maximum efficiency is

$$\boxed{\text{Constant Losses} = \text{Variable Losses}}$$

(9). Torque Production in a DC Machine:.

Torque is the turning or twisting moment of a Force about an axis. It is measured by the product of the "Force" and the radius "r" at which this force acts.



* Consider a pulley of radius "r" meters.
* A force "F" Newton acts upon the circumference of the pulley and causes it to rotates at "N" rps.

According to the defination of the "Torque"

$$\text{Torque} = F \times r \quad \text{Newton-meter}$$

$$\Rightarrow \quad T = Fr \quad \text{N-m.}$$

Work done by this force in one revolution

$$W = \text{Force} \times \text{distance}$$

$$\Rightarrow W = F \times 2\pi r$$

Power developed $P = F \times 2\pi r \times N$ Joules/sec or Watts

$$\Rightarrow P = Fr \times 2\pi N.$$

$$\Rightarrow P = T\omega$$

$\because T = Fr \Rightarrow$ Torque

$\omega = 2\pi N \Rightarrow$ Angular Velocity.

$\therefore$ Power developed $P = T\omega$

$$P = Fr \cdot 2\pi N.$$

Armature torque of a Motor:

Let T_a = torque developed by the motor
E_b = back emf
I_a = Armature Current.

$\therefore$ Power developed $P = T_a \omega$

$P = T_a \, 2\pi N$. Watts. $\longrightarrow$ (i)

In a dc motor the electrical power is converted into mechanical power

$\therefore$ Mechanical Power developed $= E_b I_a$ watts $\longrightarrow$ (ii)

$$\therefore T_a \, 2\pi N = E_b I_a$$

$$\Rightarrow T_a = \frac{E_b I_a}{2\pi N} \text{ (N-m).} \qquad \because E_b = \frac{\phi Z N}{60} \times \frac{P}{A}$$

$$\therefore T_a = \frac{E_b I_a}{2\pi N} \quad \text{N-m.}$$

$$T_a = \frac{\phi Z N}{60} \times \frac{P}{A} \times \frac{I_a}{2\pi N}$$

$$\Rightarrow T_a = \phi I_a \left[\frac{ZP}{2\pi A \times 60}\right]$$

$$\Rightarrow \boxed{T_a \propto \phi I_a} \qquad \because Z, P, 2\pi, A, 60 \text{ are constants.}$$

$$\therefore \boxed{T_a = \frac{E_b I_a}{2\pi N}}$$

(10). Speed Control of a DC Motor:

The Voltage Equation of a dc motor is $V = E_b + I_a R_a$

$$\Rightarrow E_b = V - I_a R_a$$

$$\Rightarrow \frac{\phi Z N}{60} \times \frac{P}{A} = V - I_a R_a$$

$$\Rightarrow N = \frac{V - I_a R_a}{\phi} \left(\frac{60A}{ZP}\right)$$

$$N = k\left(\frac{V - I_a R_a}{\phi}\right) \qquad \because K = \frac{60A}{ZP} = \text{constant}$$

$$\Rightarrow N = k \frac{E_b}{\phi}$$

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

By observing the above equation the speed "N" of a dc motor is directly proportional to the back emf "E_b" i.e. armature Voltage and inversly proportional to the flux "ϕ"

It means the speed of a dc motor is controlled by
(i) armature Voltage control method
(ii) field flux control method "ϕ"

(i) By armature voltage control method, we can obtain the speeds below rated speed

(ii) By field flux control method, we can obtain the speeds above the rated speed.

(11). DC Generator Characteristics:

The generator characteristics are classified into three types.

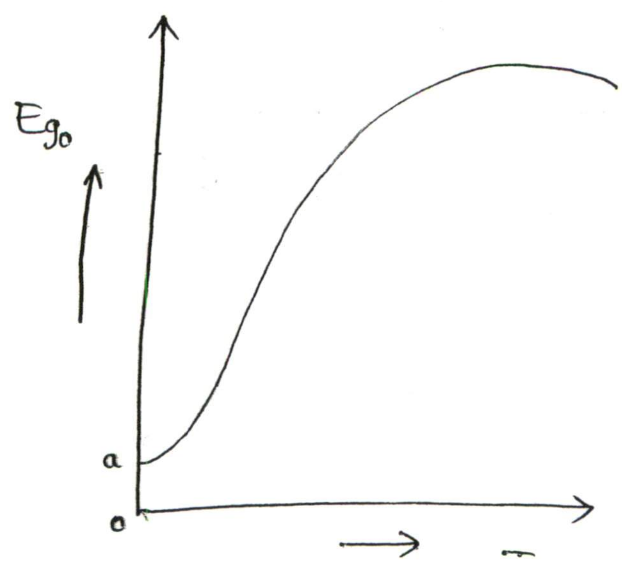
(a). Magnetisation Characteristics or Open Circuit Characteristics or No load Saturation Characteristics.

The Magnetisation Characteristics shows the relation between "No load generated emf E_{g0}" and "field current or exciting current. I_f". It is the graph plotted for "E_{g0} Vs I_f".

The magnetisation curve is the same for Separately Excited DC Generator and DC Shunt Generator.

Initially without giving any field excitation to the electromagnets, there is always present some magnetism in the field poles. This field system produces small amount of flux. When the armature rotates in this flux emf will be induced. As we increase the field current from minimum value to max. value, the emf induced in the armature also gradually increases.

The curve shows, linear relationship upto saturation point. beyond that point the curve shows non linear relation ship.

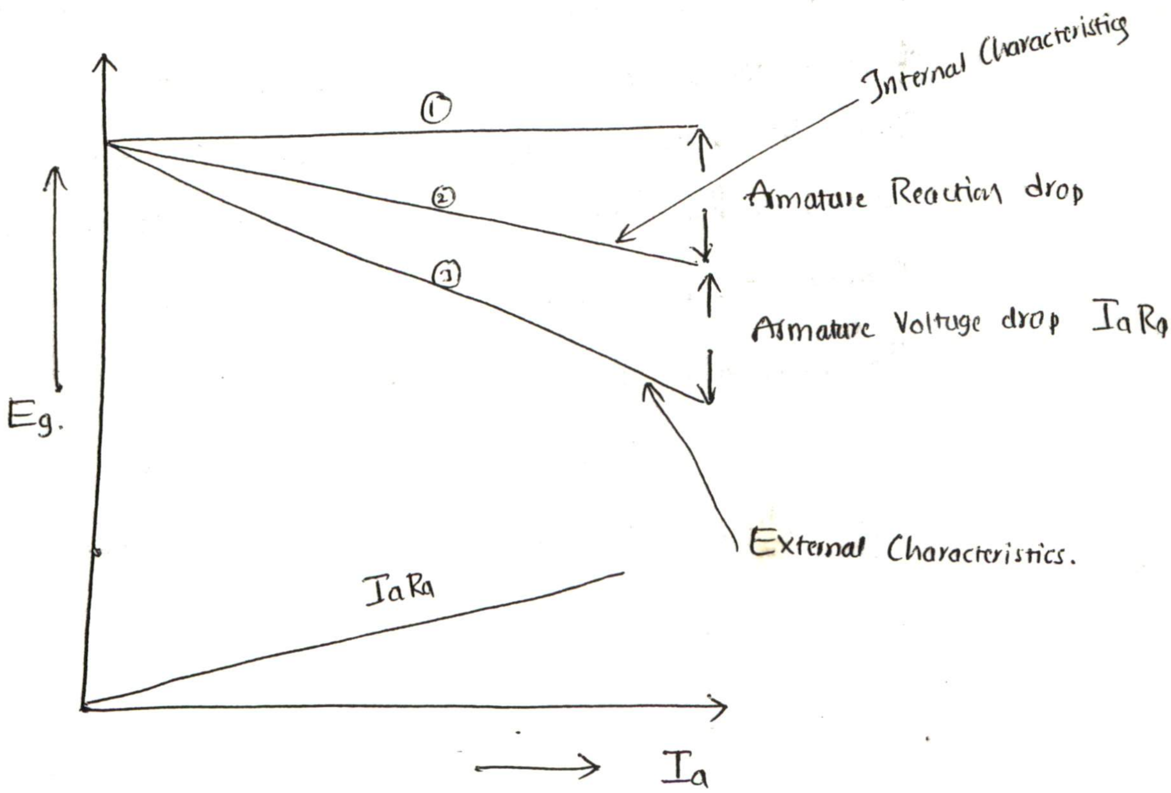


(b) Internal or Total Characteristics:

It is the graph plotted between the generated emf E_g and the armature current I_a. after allowing the demagnetisation effect of armature reaction.

(c) External Characteristics:

It is the graph plotted between the terminal voltage V and the load current I. The terminal voltage is obtained after substracting the armature voltage drop from the generated emf.



(12) DC Motor Characteristics:

The characteristic curves for a dc motor are classified into types.

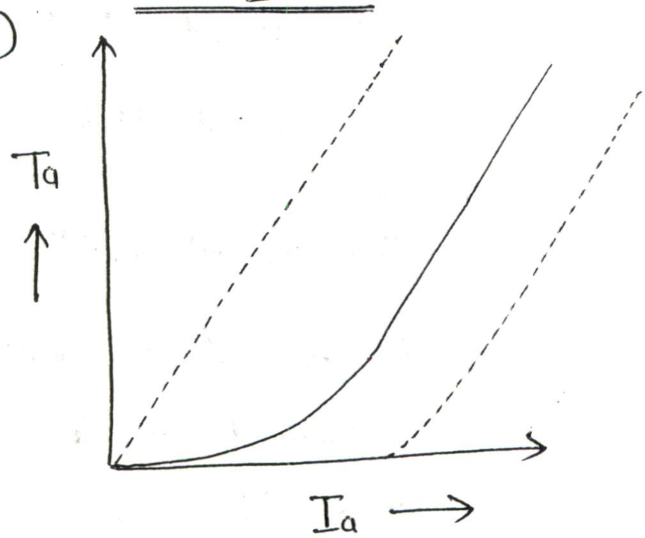
(i) Torque Vs Armature Current T_a / I_a

(ii) Speed Vs Armature Current N / I_a.

(iii) Speed Vs Torque. N / T_a.

(a). DC Series Motor Characteristics:

(i) T_a Vs I_a



Since $T_a \propto \phi I_a$.

But in a series motor

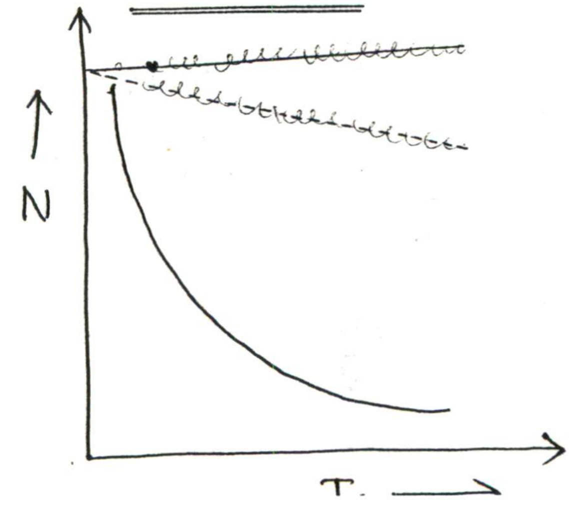
$\phi \propto I_a \Rightarrow T_a \propto I_a^2$.

It means "T_a" is proportional to the square of the armature current up to magnetic saturation.

After magnetic saturation the "ϕ" is independent of I_a.

$\therefore$ After magnetic saturation $T_a \propto I_a$

(ii) N Vs I_a



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

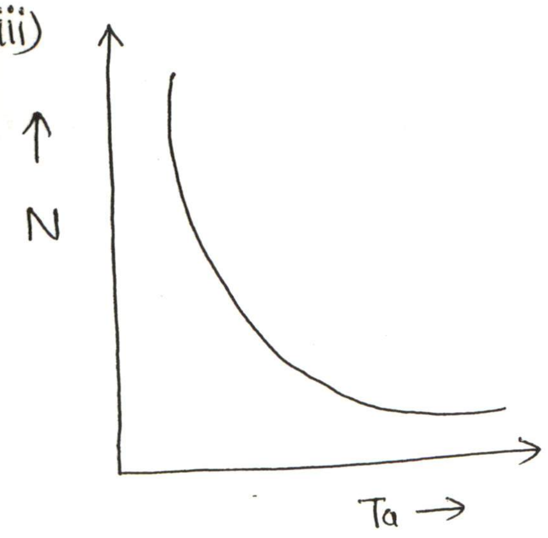
As the load on the dc series motor increases, the armature current increases

Since $I_a \propto \phi$; ϕ increases,

Since ϕ is inversely proportional to "N"

$\therefore$ "N" decreases.

(iii) N Vs Ta



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

As the load on the dc series motor increases, the I_a increases.

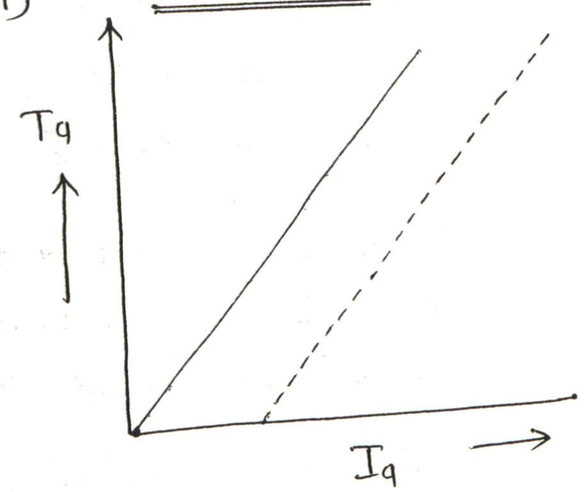
as I_a increases T_a increases.

$\because I_a \propto \phi$

As ϕ increases the "N" reduces.

(b) DC Shunt Motor Characteristics:

(i) Ta Vs Ia



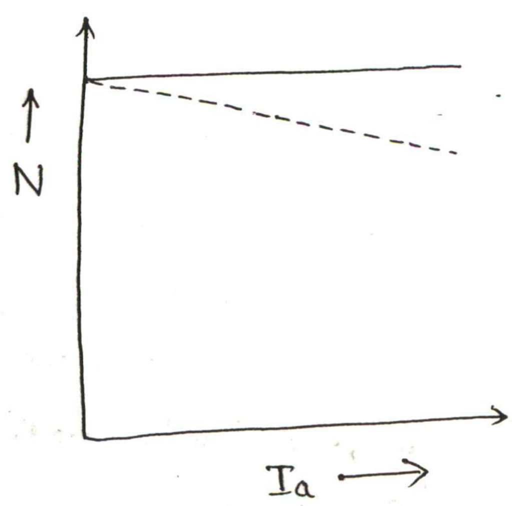
$\because N \propto \frac{E_b}{\phi}$ & $T_a \propto \phi I_a$

In a shunt motor, the flux "ϕ" almost remains constant.

$\therefore T_a \propto \phi I_a \Rightarrow T_a \propto I_a$

$\therefore$ As the load on the motor increases, the armature current I_a increases. Therefore as I_a increases T_a increases.

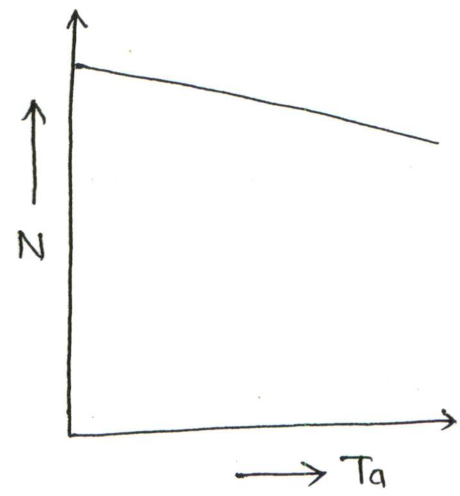
(ii) N Vs Ia



Since a DC Shunt Motor is a constant Speed motor as "ϕ" almost remains constant. But when load on the motor increases, the speed slightly drops.

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

(iii) N Vs Ta



Since the shunt motor is a constant speed motor, as "ϕ" almost remains constant.

But, when the load on the motor increases the armature current I_a increases.

As the I_a increases T_a increases

$$\because T_a \propto \phi I_a \Rightarrow T_a \propto I_a.$$

As the Torque "T_a" increases the speed slightly reduces.

(13). **STARTER:** Starter is a variable resistor which is connected in series with the armature circuit, to limit the starting current.

At stand still conditions, the dc motor armature is at rest.

The back emf "E_b" at stand still condition is zero. Due to small value of armature resistance, the armature draws more current. This high in rush current may damage the armature. To avoid such high starting currents "Starter". is used. $\Rightarrow V = E_b + I_a R_a$

$\Rightarrow$ At stand still $E_b = 0 \Rightarrow V = 0 + I_a R_a \Rightarrow I_a = \dfrac{V}{R_a}$.

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* GIVE PRIMARY PRIORITY TO HUMANITY & NATIONALITY. *
* GIVE SECONDARY PRIORITY TO COMMUNITY. *
* DON'T GIVE ANY PRIORITY TO PARTIALITY. *

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❀ BHARATH MATHA KI JAI ❀

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