⇒ generator & Motor action ⇐

A motor and generator perform opposite functions, but their fundamental structure is the same. Their structure is a coil mounted on an axel within a magnetic field. An electric motor is used to product rotational motion from an electric supply. In a motor an electric current is passed through the coil. The oil then creates a magnetic field that intracts with the already existing magnetic field. This interaction forces the coil to rotate.

⇒ For a motor the input energy is electrical energy and the useful output energy is methanical energy

The generator is used to product an electric current from rotational motion (on large scale power stations a turbine is used to provide this rotation). In a generator the rotation causes the coil to rotate inside the megnetic field. This induces an alternating current in the coil.

⇒ For a generator the input energy is machanical energy and the usefull output energy is electrical energy.

in power station it is usually the magnet which is attached to the axel and rotated, with the coil surrounding the magnet, However the end result is the same.

For Motor

BASIS Function

The motor converts electrical energy into Mechanical Energy.

Electricity

uses electricity

Driven element

The shaft of the motor is driven by the magnetic force developed between armature and field.

Current

In a motor the current is to be supplied to the armature windings.

Rule Followed

Motor follows Fleming's Left hand rule.

Example

An electric car or bike is an example of electric motor.

For generator

Function

Generator converts Mechanical energy to electrical energy

electricity

generates electricity

Driven element

The shaft is attached to the rotor and is driven by mechanical force.

current

In the generator current is produced in ~~a~~ the armature windings.

Rull followed

generator follows ~~Fell~~ fleming's Right hand rule.

Example

Energy in the from of eletricity is generated at the power stations.

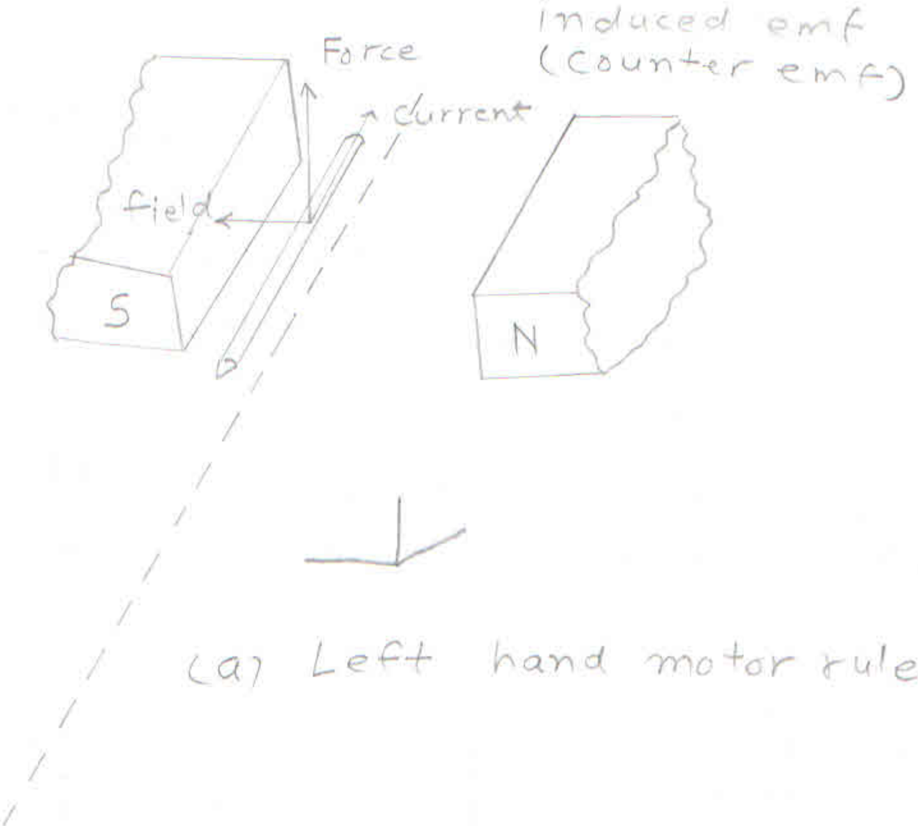
The motor and the generator are almost similar from the construction point of view, as both have stator and rotor. the main different between the two is that the motor is an electric device which convert electrical energy into mechanical energy. The generator is vice versa of the motor.

Difference between Motor and Generator are follows:-

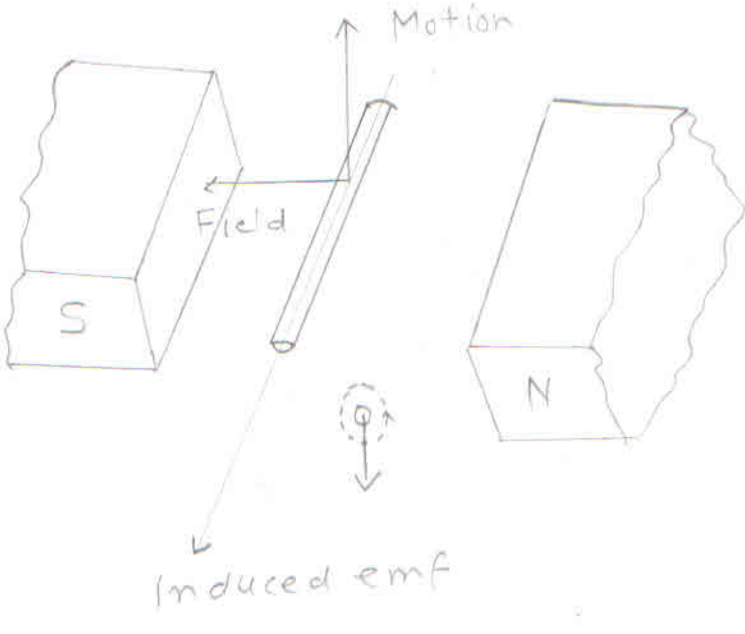
- The motor convert electrical energy into mechanical energy, wheres generator does the opposite.

- Electricity is used in the motor, but the generator produce the electricity

- The shaft of the motor is driven by the magnetic force developed between armature and field windings Wheres, in the case of the generator the shaft is attached to the rotor and is driven by mechanical force.



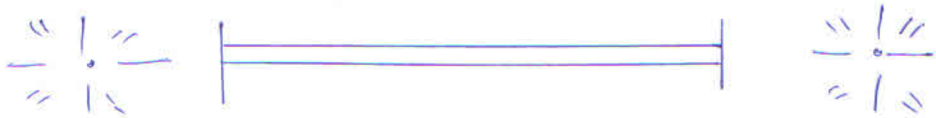
(a) Left hand motor rule



(b) Right hand generator rule

- The current is to be supplied to the armature windings in case of a Motor, and in generator, current is produced in the armature windings.

- Motor follows Fleming's Left hand rule while Generator follows fleming's Right hand rule.



DC - Machines

DC Machines are the Electro-Mechanical Energy converter's which work from D.C Source & generate mechanical power or Convert Mechanical power in a D.C Power.

→ Basic Structure of Electric Machine -

A rotating electric Machine has two main part's, stator & rotor, seperated by the air gap's -

STATOR ÷ The stator of the machine does not move & normally is the outer Part of the Machine -

ROTOR ÷ The rotor is free to move & normally is the inner part of the machine -

The stator has two pole's i,e North & South - The field winding's are fastened around these poles -

The rotor consist's of an iron core that has slot's which house the armature Conductor's & a Commutator & the brushe's-

→ There are 2 type's of D.C Machine's-

1) D.C Generator ÷ Convert's Mechanical energy into Electrical energy.

2) D.C Motor ÷ Convert's Electrical energy into Mechanical energy.

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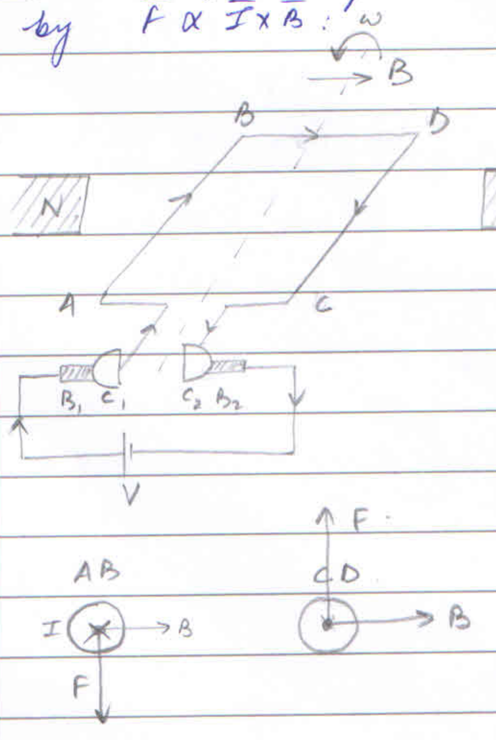
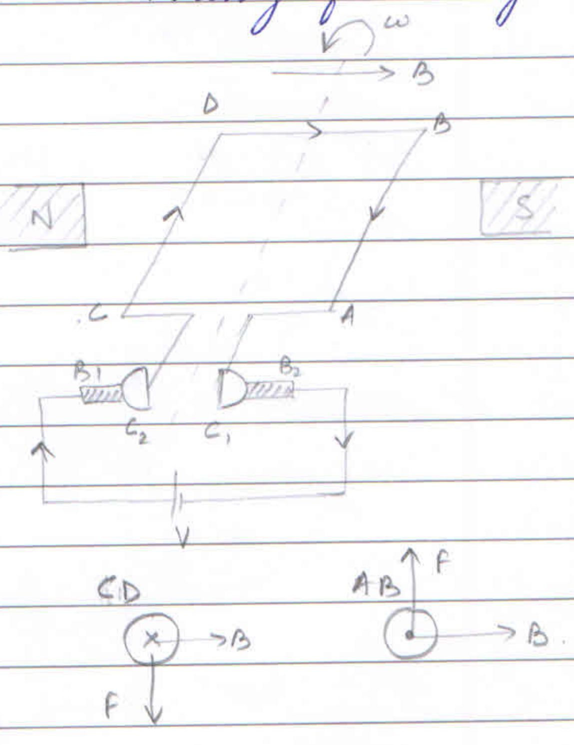
Operating Principle of DC Machines:

The basic principle of all machines is electromagnetic induction.
DC Machines are of two types: DC generators, which convert mechanical energy into electrical energy & DC motors which convert electrical energy into mechanical energy.
The operation of DC machines can be explained as:

DC Motor:

When a current carrying conductor is placed in a magnetic field, it experiences torque. The DC motor works on this principle.
Voltage is supplied to the rotor through ~~sb~~ brushes.
When current flows through the armature, in presence of magnetic field, the armature rotates due to the torque produced.
Consider a simple loop of wire; the Lorentz force is given by $\bar{F} \propto \bar{I} \times \bar{B}$:



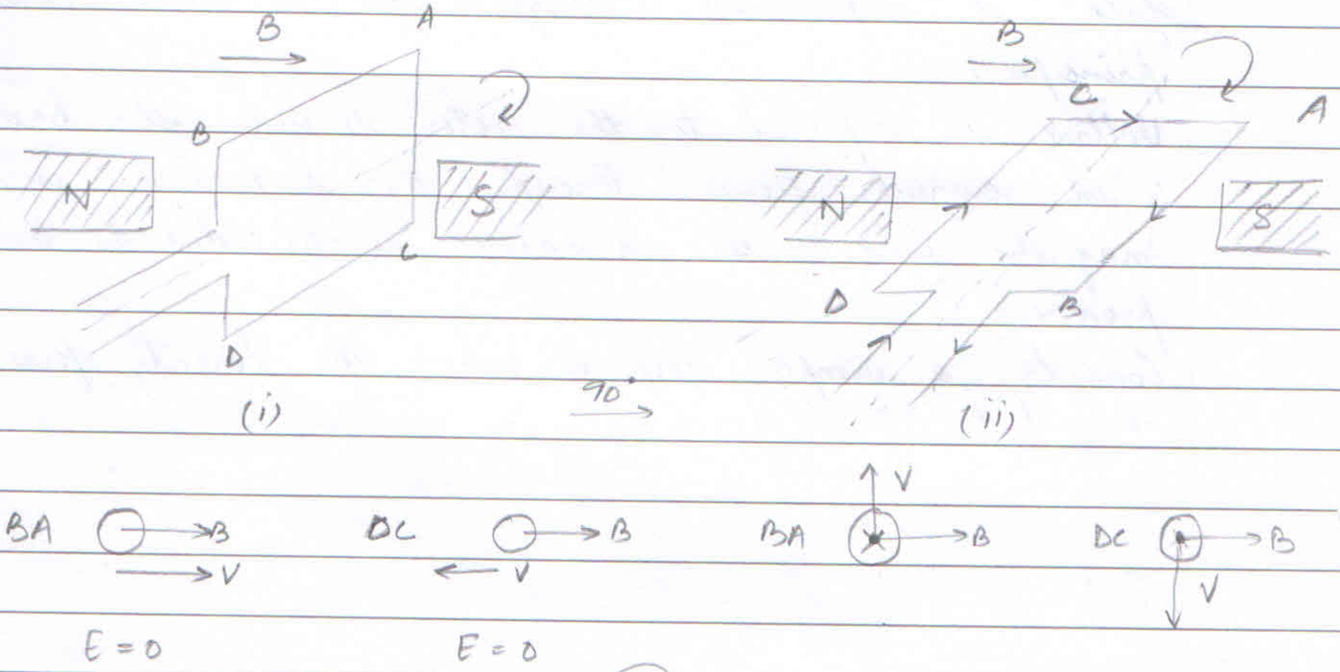


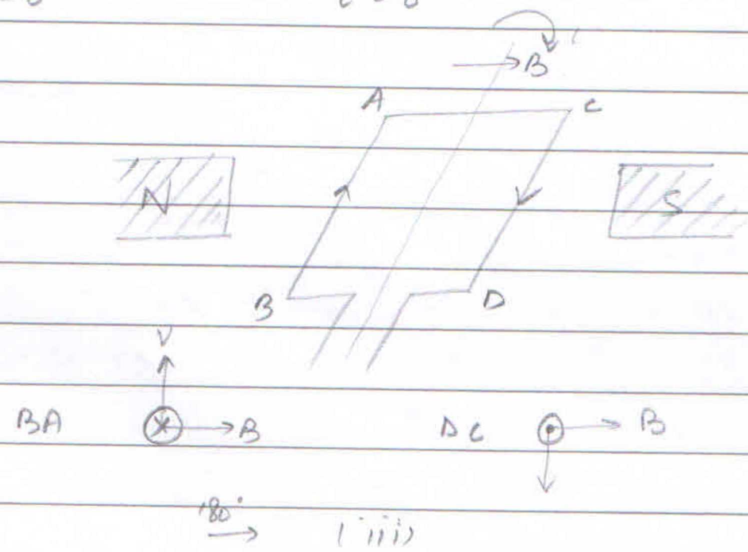
DC Generator :

According to Faraday's Law of EMI, when a conductor links with a changing flux, it will have an induced emf across it. The magnitude of this emf depends on the rate of change of flux linkage with the conductor & its direction can be determined by Fleming's right hand rule.

Consider a basic conceptual model of DC generator represented by a single loop as shown:

We know, $E = lv \times B$





The alternating current produced in the loop goes through load as it is if a slip ring is used. A commutator brush arrangement is used to get a rectified DC o/p through the load.

Thus, structurally and construction wise, DC motors and generators are exactly similar but electrically they are opposites.

EMF Equation Of an AC Machine

An alternator is an AC generator. It consists of an armature and a rotor. The rotor runs by a dc generator or stator. When the rotor rotates inside the armature section it induces a emf in the armature windings. Generally, we use armatures with 120 degree phase angle.

The output end of the armature windings are generally star connected. So, when the rotor rotates what we get is a 3-ϕ alternating voltage. It is capable of generating AC power at a specified frequency. It is also called a "synchronous generator".

Electricity is generated by electromagnetic induction. In alternator field windings are on rotor & armature windings happen to be on stator. A DC current is passed through field windings, which induces magnetic field, and as rotor rotates it is termed as rotating magnetic field whose flux intersects with armature coil and an alternating EMF is generated.

An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. The flow of electrical charge periodically reverses direction.

Let,

Z = no of conductors or coil sides in series per phase

ϕ = flux per ~~phase~~ pole in webers

P = No of rotor poles

N = Rotor speed in rpm

In one revolution (i.e 60/N seconds), each stator conductor is cut by $P\phi$ webers i.e

$$d\phi = P\phi \quad ; \quad dt = 60/N$$

∴ Average Emf induced in one, stator conductor

$$= \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ volts}$$

Since there are Z conductors in series per phase

∴ Average Emf per phase $= \frac{P\phi N}{60} \times Z$

$$= \frac{P\phi N}{60} \times \frac{120f}{P}$$

$$= 2f\phi Z \text{ volts}$$

Rms value of EMF/phase E

$$= \text{Avg value/phase} \times \text{form factor}$$

$$= 2f\phi Z \times 1.11$$

$$= 2.22 f\phi Z$$

$$E_{rms}/\text{phase} = 2.22 f\phi Z \text{ volts}$$

Torque of a DC machine

When a DC machine is loaded either as a motor or generator, the conductor carries current. These conductors lie in the magnetic field of air gap. Thus each conductor experiences a force. Hence a torque is produced around the circumference of the rotor and the rotor starts rotating.

The expression of torque is same for the motor and the generator and is deduced as :-

The voltage eq^n of a dc motor

$$V = E + I_a R_a .$$

Multiplying both sides with I_a :-

$$V I_a = E I_a + I_a^2 R .$$

- $V I_a$ — electrical power I/P to the armature.
- $E I_a$ — electrical equivalent of gross mechanical power.
- $I_a^2 R$ — copper loss in armature

We know;

I/p = losses + O/p .

τ_{av} = average electromagnetic torque developed by the armature in Nm.

$$P_m = \omega \tau_{av} = 2\pi n \tau_v.$$

$$\therefore \quad P_m = E I_a = \omega \tau_{av} = 2\pi n \tau_{av}.$$

$$E = \frac{nP\phi Z}{A}$$

$$\therefore \quad \frac{nP\phi Z}{A} \cdot I_a = 2\pi n \tau_{av}.$$

$$\boxed{\tau_{av} = \frac{PZ}{2\pi A} \cdot \phi I_a.}$$

Torque equation of DC motor.

$P, Z, A \rightarrow$ constant.

$\left.\frac{PZ}{2\pi A}\right\} \rightarrow$ constant.

Let $\frac{PZ}{2\pi A} = k.$

$$\tau_{av} = k\phi I_a.$$

$$\tau_{av} \propto \phi I_a.$$

EXCITATION OF DC MACHINE :

The magnetic flux in a d.c machine is produced by field coils carrying current. The production of magnetic flux in the machine by circulating current in the field winding is called excitation.

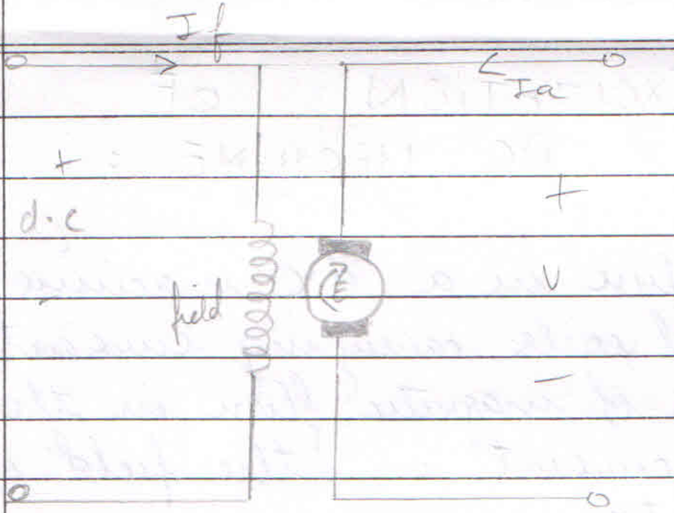
TYPES OF EXCITATION :

There are 2 methods of excitation, namely
i Seperate excitation
ii Self excitation
DC Machines are named according to the connection of the field winding with the armature. The principle types of D.C machine are:

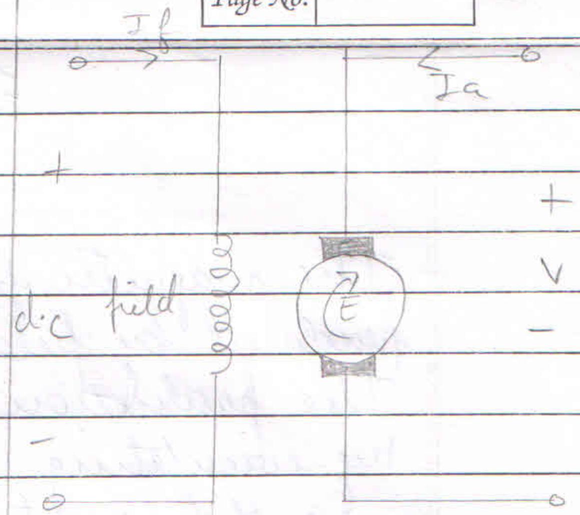
a) Seperately excited D.C Machine :

As the name implies, the field coils are energised by a ~~s~~ seperate D.C source. The connection showing the seperately excited D.C machine are shown in the figure

D.C generator

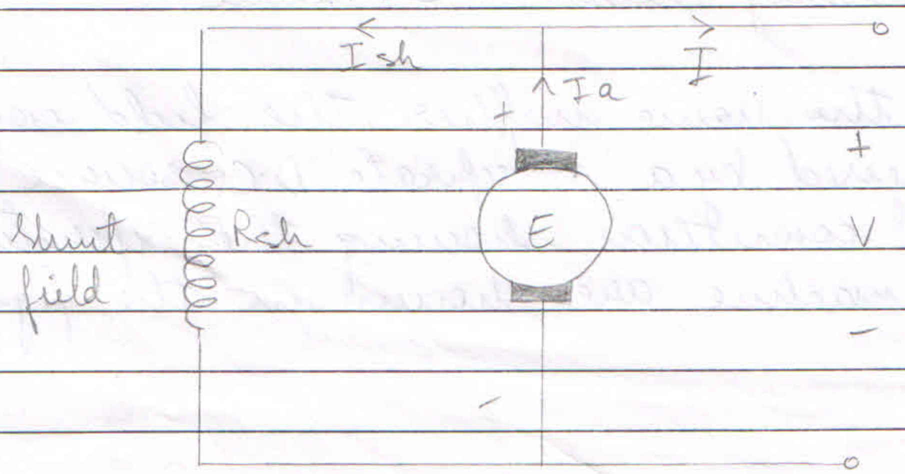


D.C Motor



b) Shunt wound D.C Machine :

A machine in which the field coils are connected in parallel with the armature is called a shunt machine. Since the shunt field recieves the full output voltage of a generator or the supply voltage of a motor, it is generally made of large number of turns of the fine wire carrying a small field current. The diagram of d.c shunt motor are as given



Shunt wound D.C generator

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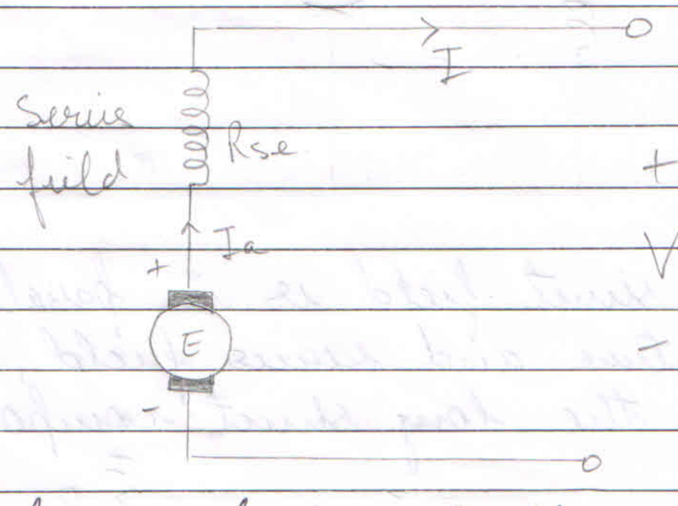
c) Series wound D.C Machine :

A d.c machine in which the field coils are connected in series with the armature is called a series machine. The series field winding carries the armature current and since the armature current is large, the series field winding consists of a few turns of wire of large cross section area. The diagram shows the connection of D.C series generator.

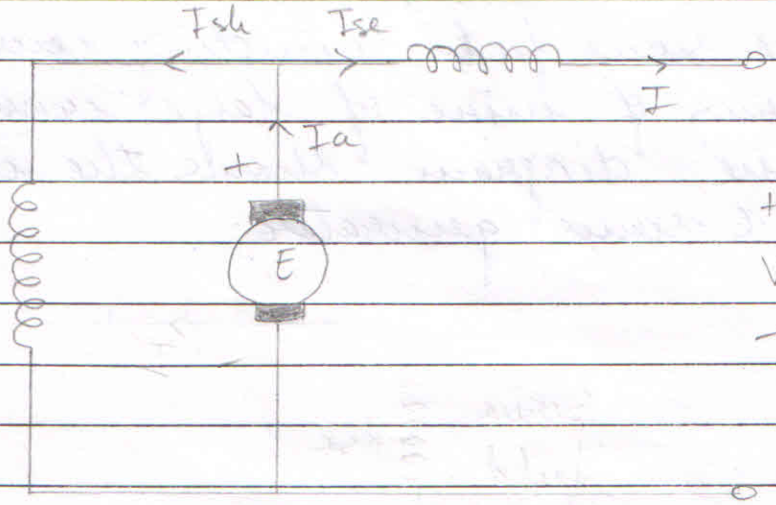


D.C series generator

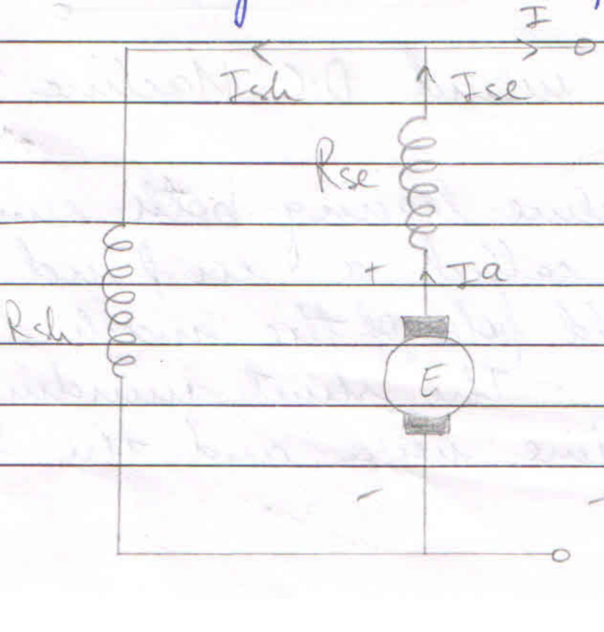
d) Compound wound D.C Machine :

A d.c machine having both shunt and series fields is called a compound machine. Each field pole of the machine carries two windings. The shunt winding has many turns of fine wire and the series winding has few turns of large cross sectional area. The compound machine may be connected in two ways. If the shunt field is connected in parallel with the armature alone, the machine is called the short shunt compound machine. Such a machine is shown in the diagram

Short shunt compound D.C generator



If the shunt field is in parallel with both armature and series field, the machine is called the long shunt compound machine



Long shunt D.C generator

ARMATURE WINDINGS :-

The winding through which a current is passed to produce the main flux is called the field winding. The winding in which voltage is induced is called armature winding.

Some basic terms related to the armature winding are defined as follows:

A turn consists of two conductors connected to one end by an end connector.

A coil is formed by connecting several turns in series.

A winding is formed by connecting several coils in series.

The turn, coil and winding are shown schematically in figure.

The begning of the turn, or coil, is defined by symbol S (start) and the end of the turn or coil by the symbol F (Finish).

The concept of electrical degrees is very useful in the study of machine.

If

~~θ_{md} = Mechanical degrees is very useful in the study of machine.~~

θ_{md} = Mechanical degrees or angular measure in space.

θ_{ed} = Electrical degrees or angular measure in cycle.

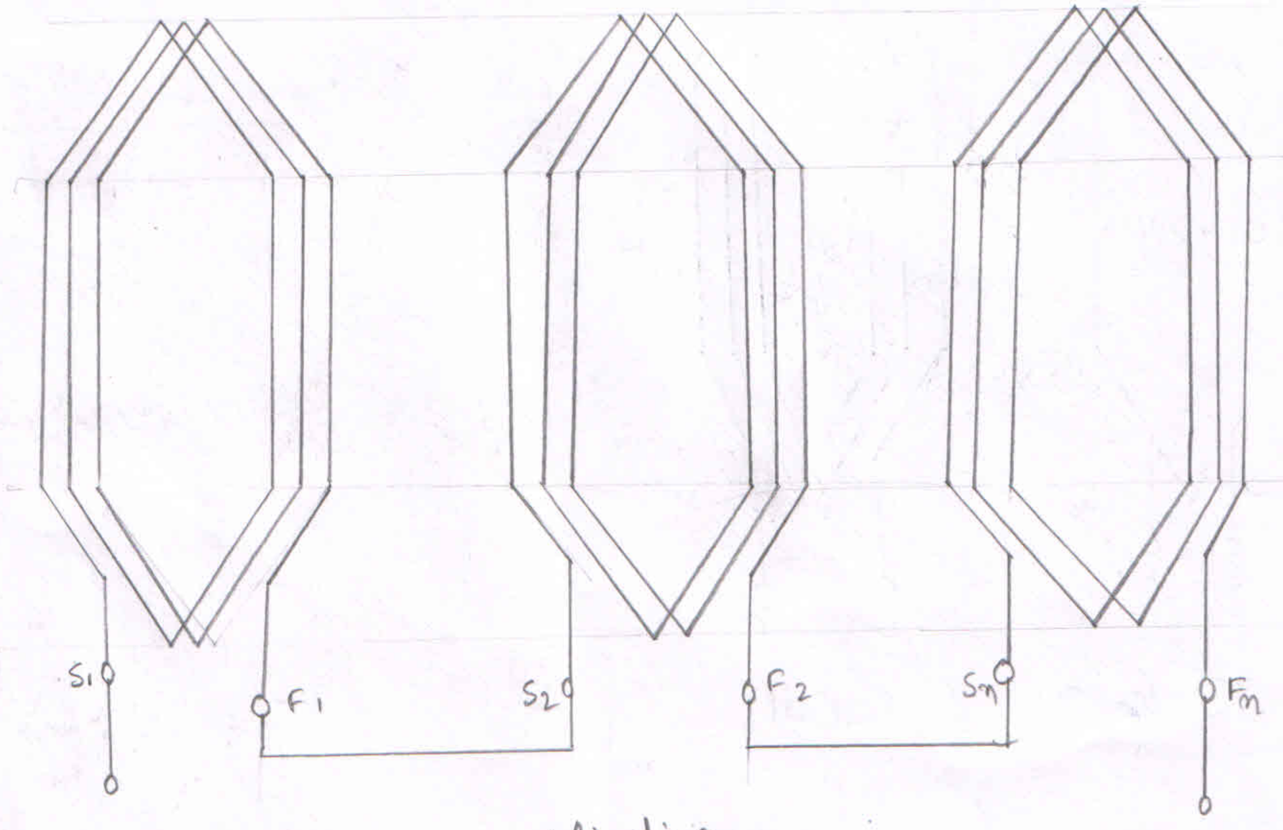
For a P-pole machine, electrical degree is defined as follows

$$\theta_{ed} \triangleq \frac{P}{2} \theta_{md}$$

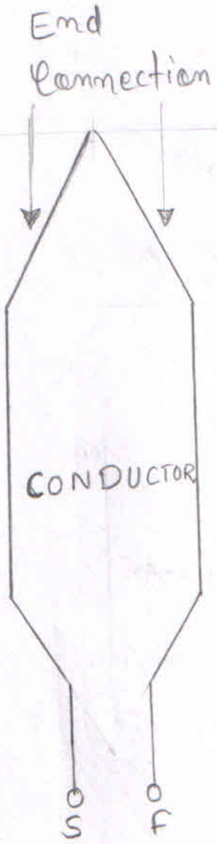
The advantage of this notation is that expressions written in terms of electrical angles apply to machines having any number of poles.

The angular distance between the centres of two adjacent poles on a machine is known as pole pitch or pole span.

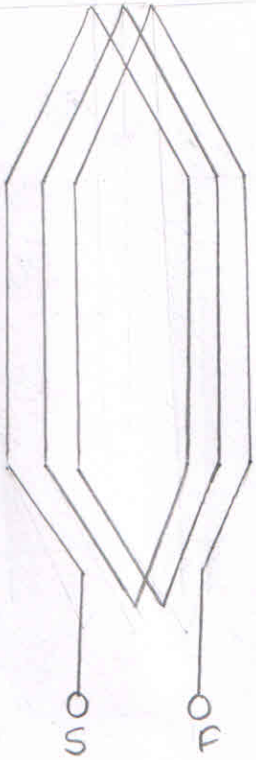
$$\text{One pole pitch} = 180^\circ_{ed} = \frac{360^\circ_{md}}{P}$$



Wlinding



(a) Turn



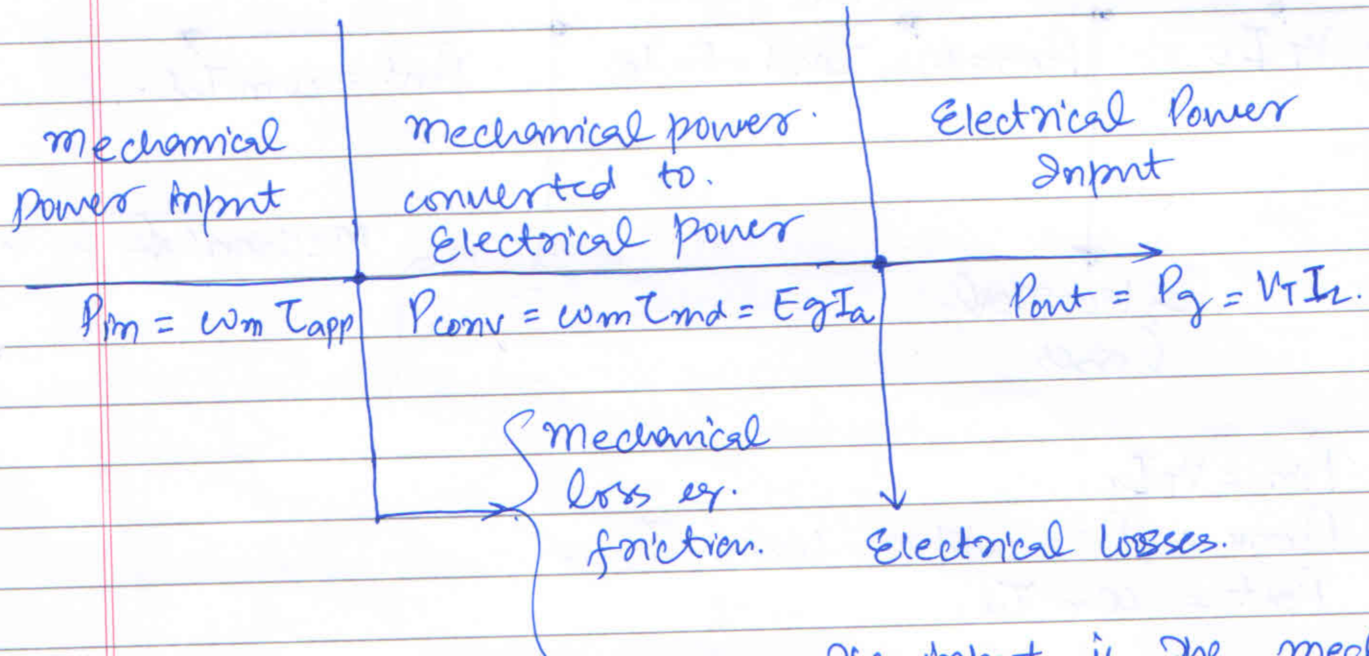
(b) Coil

Regardless of number of poles in the machine, a pole - pitch is always 180 electrical degrees.

The two sides of a coil are placed in two slots on the stator surface. The distance between the two sides of a coil is called the coil pitch. If the coil pitch is one pitch is one pole pitch, it is called the full-pitch coil. If the coil pitch is less than one pole pitch, the coil is called the short-pitch coil or fractional-pitch coil.

Power - Flow - Diagram. - for DC Generator:

is used for determining the generator and motor efficiencies. A power flow diagram for a d.c generator is shown below.



In a d.c generator, the input is the mechanical power:

$$P_{in} = \omega_m \tau_{app}.$$

ω_m = angular speed of armature rad/s.

τ_{app} = applied torque in Nm.

$P_{con} = P_i$ - stray loss - mechanical loss - core loss

$= \omega_m \tau_{ind} = \omega_m \tau_e$.

τ_e = electromagnetic torque.

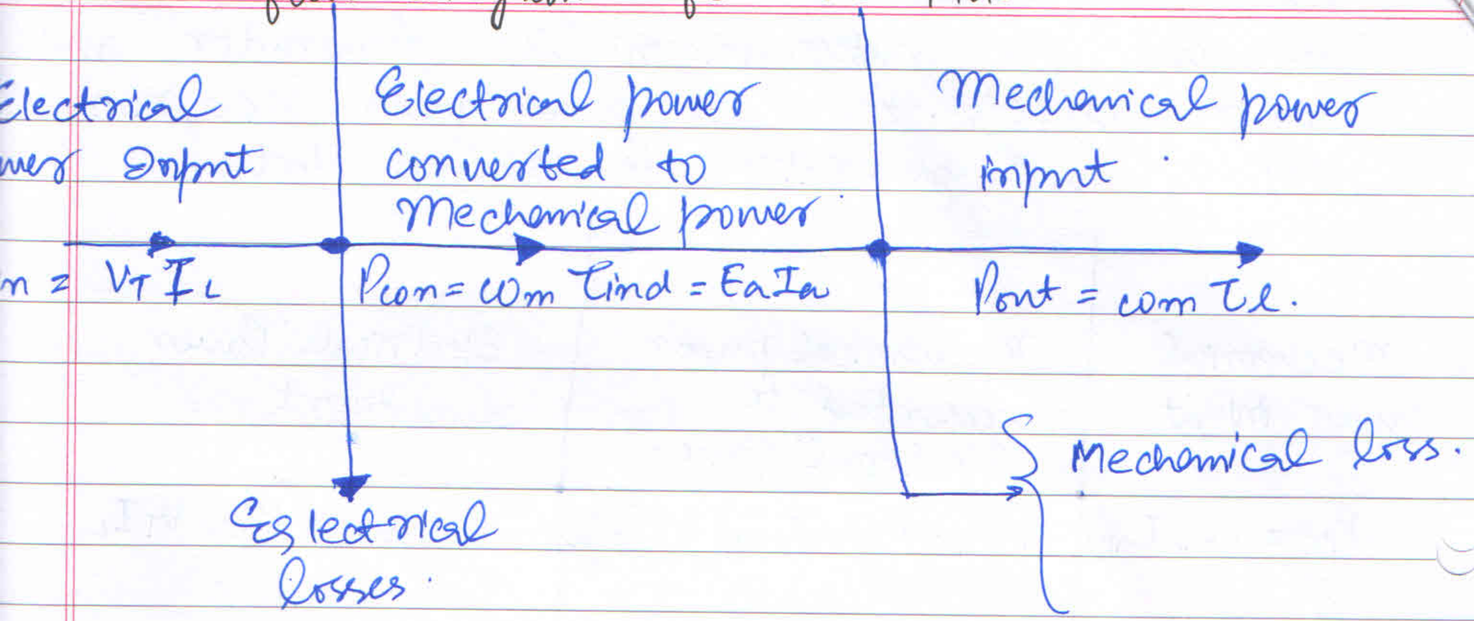
$$P_{conv} = E_g I_a.$$

$P_{out} = P_{conv}$ - electrical i^2R loss - brush losses.

$$P_{out} = V_T I_L.$$

V_T = Terminal voltage.

Power Flow Diagram for DC Motor.



- $P_{in} = V_T I_L$.
- $P_{conv} = P_i$ = copper losses.
- $P_{out} = \omega_m \tau_L$.
- $P_{out} = P_{con}$ − core losses − mechanical losses − stray losses.

Efficiency of a D.C Machine.

R_{at} = total resistance of the armature circuit.

I = output current.

I_{sh} = current through the shunt field.

I_a = armature current = $I + I_{sh}$.

V = Terminal voltage.

Total copper loss in armature circuit = $I_a^2 R_{at}$.

Power loss in the shunt circuit = $V I_{sh}$.

Mechanical losses = friction loss at bearings + friction loss at commutator + windage loss.

Core losses = hysteresis loss + eddy current loss

Stray loss = mechanical loss + core loss.

~~Total losses = mechanical loss + core loss.~~

Total losses = $I_a^2 R_{at} + P_K + V_{BD} I_a$.

Generator efficiency.

$$\eta_G = \frac{\text{Generator output}}{\text{Generator output + losses}} = \frac{VI}{VI + I_a^2 R_{at} + P_K + V_{BD} I_a}$$

$I_a = I + I_{sh}$.

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$$\eta_G = \frac{1}{1 + \frac{IR_{at}}{V} + \frac{V_{BD}}{V} + \frac{P_k}{VI}}$$

η_G is max. when denominator is minimum.

$$\therefore \quad D_r = 1 + \frac{IR_{at}}{V} + \frac{V_{BD}}{V} + \frac{P_k}{VI}$$

$$\frac{dD_r}{dI} = 0 \qquad \frac{d^2 D_r}{dI^2} > 0$$

$$0 = 0 + \frac{R_{at}}{V} + \frac{P_k}{V} - \left(\frac{1}{I^2}\right)$$

$$P_k = I^2 R_{at}$$

$$\frac{d^2 D_r}{dI^2} = \frac{2P_k}{VI^3} > 0.$$ condition for minima is full filled.

Load Corresponding to Maximum Efficiency.

I_{fl} = full load current

I_M = current at max. efficiency

for max. eff.

$$I_M^2 R_{at} = P_k.$$

$$\Rightarrow I_M^2 = \frac{P_k}{R_{at}} = \frac{I_{fl}^2 P_k}{I_{fl}^2 R_{at}} \Rightarrow I_{fl}^2 \sqrt{}$$

$$I_M = I_{fl} \sqrt{\frac{P_k}{I_{fl}^2 R_{at}}} \Rightarrow$$

$I_{fl}^2 R_{at}$ = f.l copper loss

I_{fl} = full load current

P_k = constant loss.

* Characteristics and Applications of DC Motors.

There were 4 types of Motors

1. Seperated excited DC Motors.
2. Shunt motors.
3. Series Motors
4. Compound motors.

Characteristics of Seperated excited DC Motors

1st type → * Possible to obtain very accurate speeds
* Most suitable for applications requiring speed variation from very low value to high value

e.g Paper Machine
Steel rolling units
Diesel electric propulsion of ships.

2nd type. Shunt motors are of two types

1. Constant Speed
2. Adjustable Speed.

Characteristics of Shunt motor (Constant Speed)

* Starting torque - medium usually limited to 250% by a starting resistor but may be increased
* Maximum operating torque usually limited to about 200% by commutation.
* Speed Control :→ increase upto 200% speed by field control
  decrease by armature voltage control.

Characteristics of Shunt Motor (Adjustable speed)

* Starting torque - medium, usually limited to 250% by a starting resistor but may be increased
* Maximum operating torque usually limited to 200% by Commutation
* Speed regulation 10 to 15%
* Speed Control ⇒ 6 : 1 range by field control.

Characteristics of Series Motors :-

* Adjustable varying Speed.
* Starting torque very high upto 500%
* Maximum momentary operating torque upto 400%
* Speed regulation widely variable, very high at no-load
* Speed Control : by series resistance
* Suitable for drives requiring high starting torque and where adjustable, varying Speed is satisfactory.

Characteristics of Compound motors :-

* Variable Speed
* Adjustable varying speed
* Starting torque high upto 450% depending upon the degree of Compounding
* Maximum momentary operating torque higher than shunt upto 350%
* Speed regulation : Varying depending upon degree of Compounding upto 25 - 30%.

Speed Controll usually not used but may be upto 125% by field Control.

* Torque and Speed almost Constant
* Tendency towards Speed instability with a possibility of motor running away and strong possibility of motor starting in wrong direction.

Applications of DC Motors :-

→ Employed for Constant Speed applications, may be used for adjustable speed not greater than 2 : 1 range

→ field of application includes Lathes, Centrifugal pumps, fans and blowers, Wood working, Spinning, printing presses etc

→ for application required adjustable speeds control, either Constant torque or Constant output e.g Cranes, Hoists, Trolley Cars, electric locomotives etc

→ Load must be positively connected, not belted.

→ To prevent overspeed lightest load should not be much less than 15 to 20% of full-load torque

→ Field of applications also includes.
Shears, Punches, elevators, Conveyors, Rolling mills, Heavy planes etc.

• Starting D.C. motors:

A device used to start and accelerate a motor is known as a starter.
While the device used to start, control speed, reverse, stop and protect the motor is known as a controller.

• NEED FOR STARTERS:

Armature current of a motor is given by

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

Thus, if V is kept constant, I_a depends upon E and R_a.
When the motor is first switched on, the armature is stationary so the back emf. E is zero.
The initial starting armature current I_{as}, is given by

$$I_{as} = \frac{V-0}{R_a} = \frac{V}{R_a}$$

Since the armature resistance of a motor is very small, generally less than one ohm, therefore the starting armature current I_{as} would be very large.

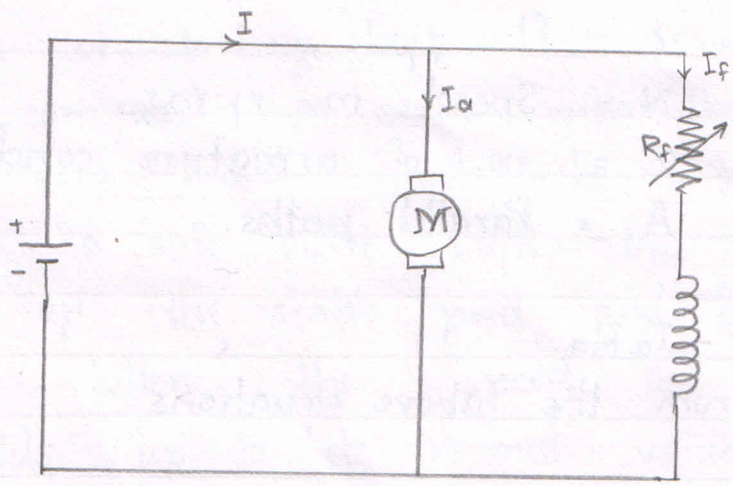
As the ~~starting~~ motor speed increases, or $N \propto \frac{V - I_a R_a}{\phi}$

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

- **speed control methods of DC motor:**

1) **Shunt motors:**

➤ FLUX CONTROL METHOD:



It is already explained above that the speed of a DC motor is inversely proportional to the flux per pole. Thus by decreasing the flux, speed can be increased and vice versa.

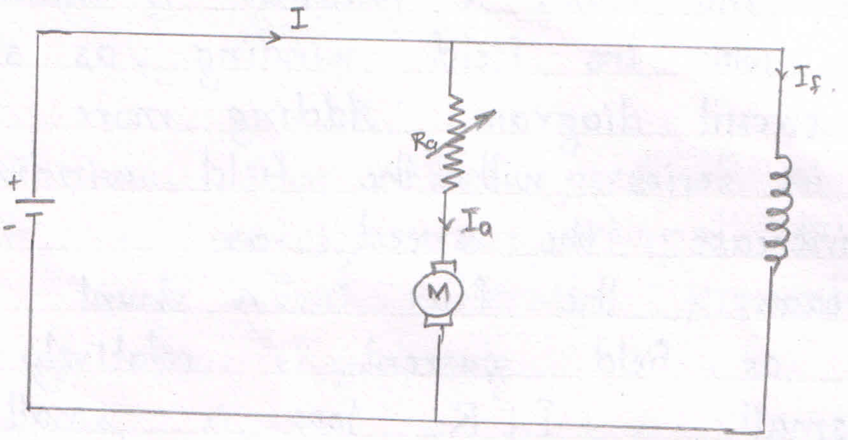
To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram. Adding more resistance in series with the field winding will increase the speed as it decreases the flux. In shunt motors, as field current is relatively very small, $I_{sh}^2 R$ loss is small. Therefore, this method is quite efficient. Though the speed can be increased above the rated value by reducing flux with this method, it puts a limit to maximum speed as weakening of field flux beyond a limil will adversely affect the commutation.

- **ARMATURE CONTROL METHOD :**

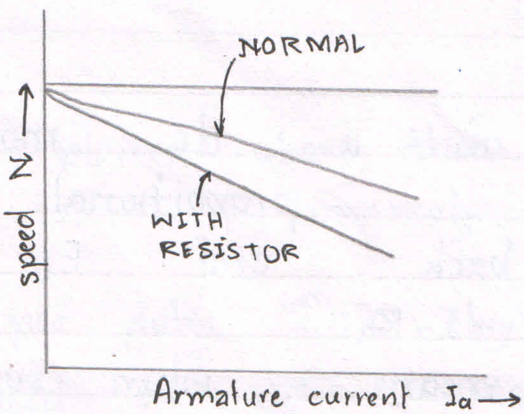
Speed of a dc motor is directly proportional to the back emf E_b &

$E_b = V - I_a R_a$.

That means, when supply voltage V.



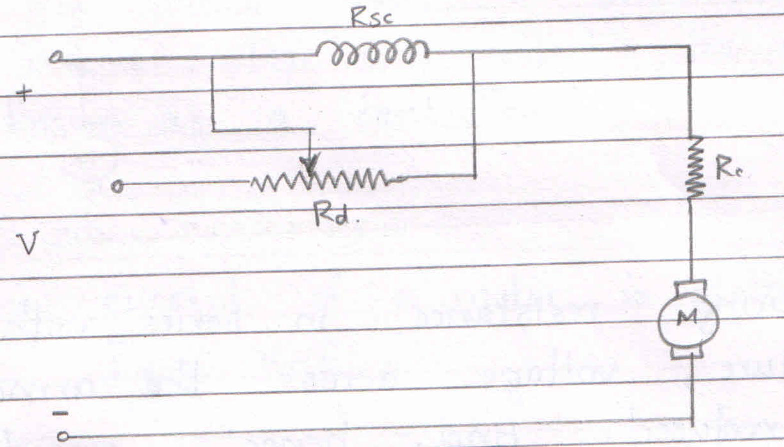
and the armature resistance R_a. are kept constant, then the speed is directly proportional to armature current I_a. Thus, if we add resistance in series with the armature, I_a decreases and, hence the speed also decreases. Greater the resistance in series with the armature, greater the decrease of speed.



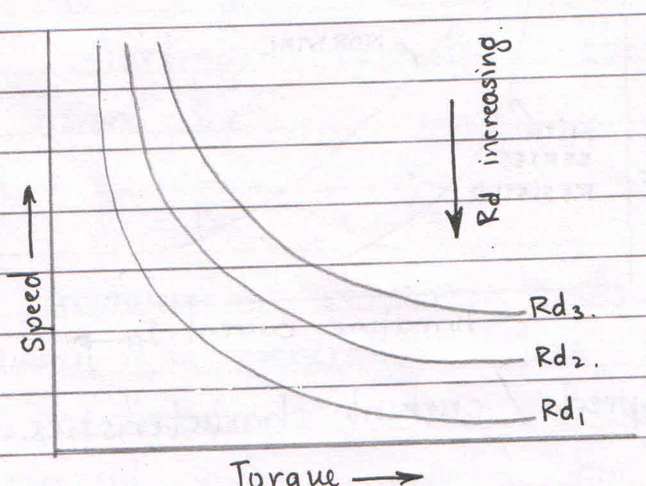
Speed /current characteristics.

2) Series motors:

- FLUX CONTROL METHOD:

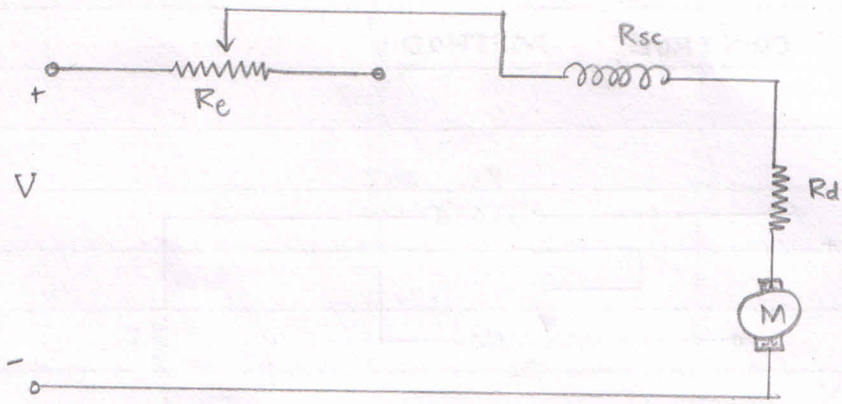


Diverter in parallel ~~to~~ ~~with~~ the series of DC motor. Hence current through field coil can be decreased. Thus, flux can be decreased to desired amount & speed can be increased.

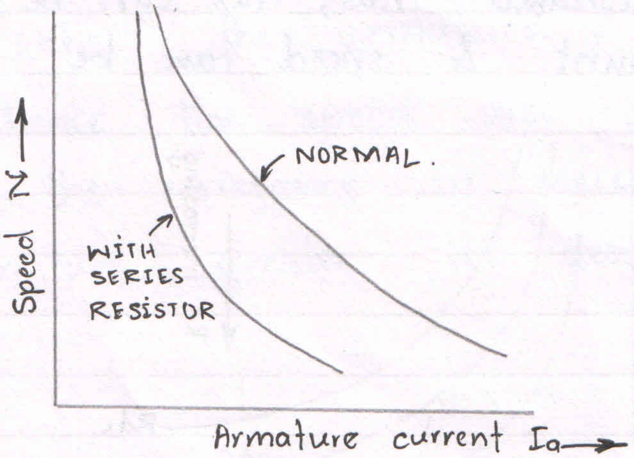


Speed torque curves (Series motor).

- **ARMATURE RESISTANCE CONTROL:**



By introducing resistance in series with the armature, voltage across the armature can be reduced. And, hence, speed reduces in proportion with it.



Speed / current characteristics.

DC GENERATOR APPLICATIONS

The advent of various types of controlled rectifiers, has declined the importance of d.c. generators. Some of the applications of DC generators are:-

i) The commonly used generators are separately excited generators for wide output voltage control and cumulatively compounded self excited generators for maintaining constant terminal voltage.

ii) The principal applications of separately excited dc generators are:

a) to serve as an excitation source for alternators in power generating stations

b) to serve as control generator in Ward-Leonard system of speed control

c) to serve as auxillary and emergency power supplies.

iii) The power from electroplating can be obtained from ac supply from dc generators. When electro-plating is required in expensive equipment like aircrafts, bombers etc., an uninterrupted and constant dc voltage is essential. This supply, is usually taken from several dc generators running in parallel

iv) Some of the other applications are dynamometers (for measuring torque), dc welding generators, control type dc generators for closed loop systems, permanent magnet dc generators (ie tachogenerators) etc.