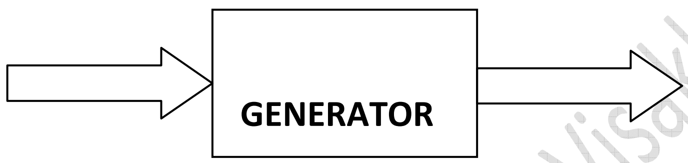
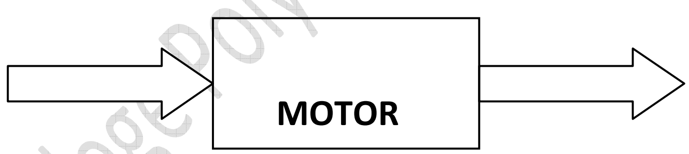
DC MOTORS

1. **DC MOTOR**: An electric motor is a machine which converts electrical energy into mechanical energy. And the electrical side values are DC then the motor is called as DC motor.
2. **The usage of DC machine as a Generator and as a Motor**:
   The machine which converts mechanical energy into electrical energy then the machine is called a generator



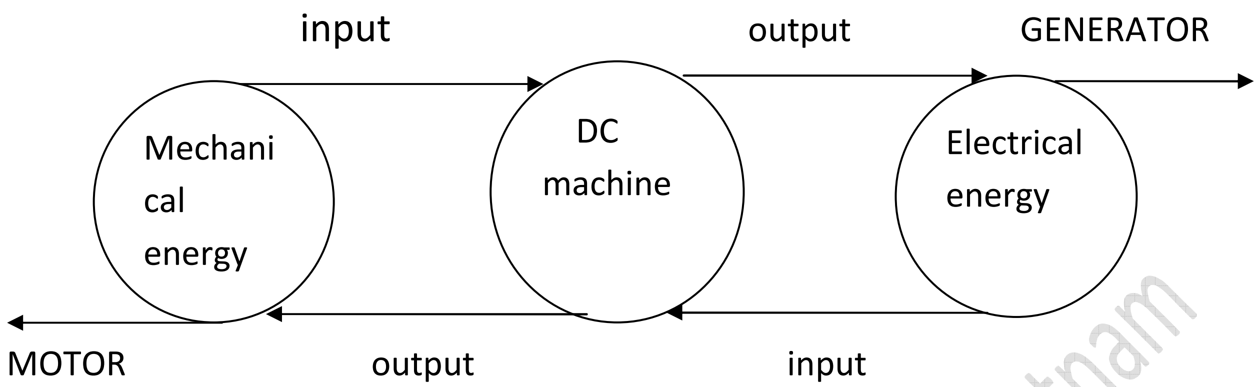
Input mechanical energy (T&W) output electrical energy (V&I)

The machine which converts electrical energy into mechanical energy then the machine is called a motor



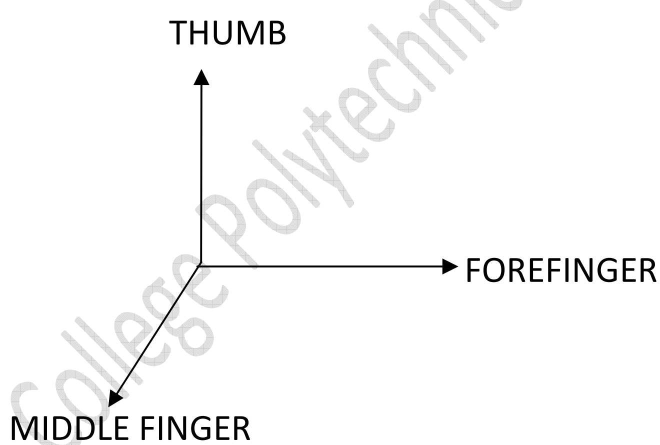
Input electrical energy (V&I) output mechanical energy (T&W)

The machine which operates as a generator can also be operated as a motor with same constructional features. when the DC machine converts mechanical energy into electrical energy called as DC generator. Where as the DC machine converts electrical energy into mechanical energy is called a DC motor. This process is called electro mechanical energy convertion process.



3.**Fleming's left hand rule:**

keep the fore finger, middle finger, and thumb finger of left hand perpendicular to each other , then the fore finger pointing the direction of magnetic field and middle finger pointing the direction of current and thumb finger gives the direction of motion of the conductor.



4.**Working principle of DC motor:**

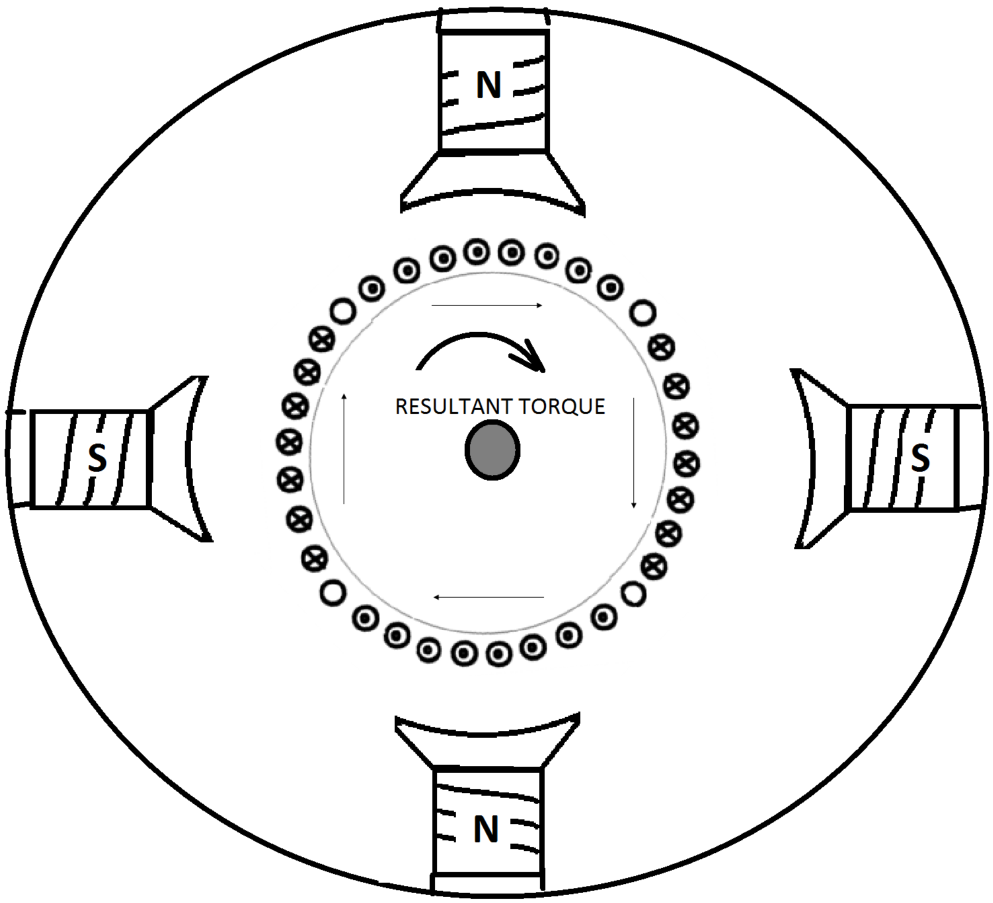
An electric motor is a machine which converts electrical energy into mechanical energy.

"Its action is based on the principle, whenever a current carrying conductor placed in the magnetic field it experiences a mechanical force."

Whose direction is given by Flemings left hand rule and magnitude is given by the equation **F=BIL** (Newtons)

5.**construction of DC motor:** It is similar to DC generator

6.Working of DC motor:



Let us consider a multi polar DC motor as shown in above figure. The field magnets are excited to develop alternate north(N) and south(S) poles and the armature conductors carrying current is placed between magnetic field.

Let the current in the armature conductors be inwards under the N-pole shown by dot and outwards under the S-pole shown by cross **X.**

Apply Flemings left hand rule, the direction of the force on each conductor can be found and is shown by small arrows on each conductor. It will be seen that each conductor experiences a force. Which tends to rotate the armature in clock-wise direction. This force collectively produce a driving Torque to rotate the armature.

7.**<u>significance of BACK E.M.F. and Its Fourmula:</u>**

When the armature of a DC motor rotates the conductors also rotates in between magnetic field.

According to the Faraday's laws of electro magnetic induction an EMF is induced in the armature conductors, and it's direction is opposition to the applied voltage (found by Fleming's right hand rule)

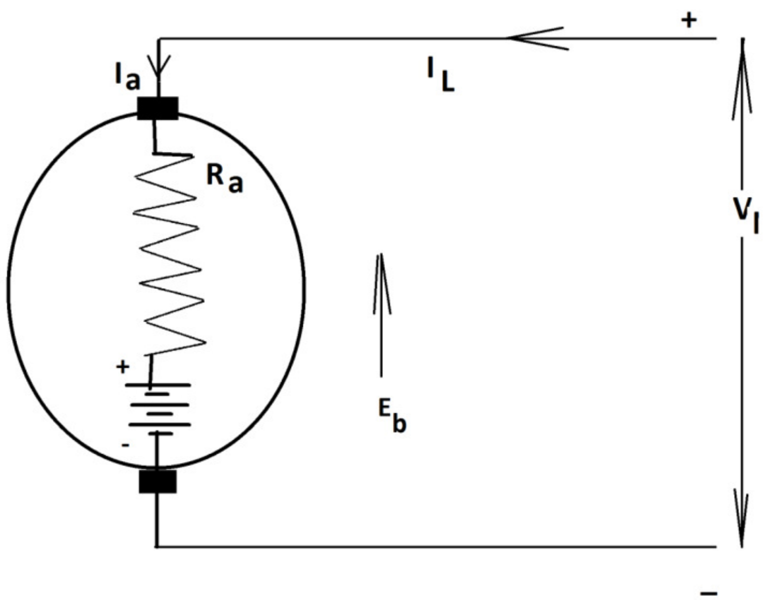
Because of it's opposing direction it is refered as BACK E.M.F. or counter E.M.F. Denoted by (**E_b**).

$$E_b = \left(\frac{\phi PN}{60}\right) * \frac{Z}{A} \text{ Volts}$$

<u>8. Equivalent circuit of a DC motor:</u>

$$V_L = E_b + I_a R_a$$

$$I_a = (V_L - E_b)/R_a$$



9.Excitation: To produce the flux by circulating current in the field winding is called excitation.

10.Classification of motors based on it's excitation:

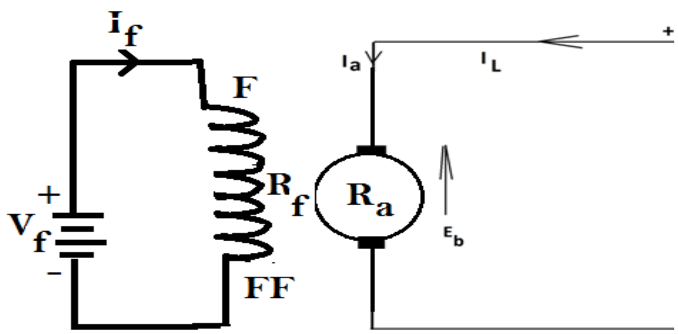
DC motors are classified depending upon the method of excitation of field.

DC Motors

- Separately excited DC motor
- self excited DC motor
  - Shunt motor
  - series motor
  - compound motor
    - long shunt compound motor
    - Short shunt compound motor

11.Equivalent circuit of various DC motors with current and voltage equations:

- Separately excited DC motor:: When the field winding is excited by separate DC source is called Separately excited DC motor.



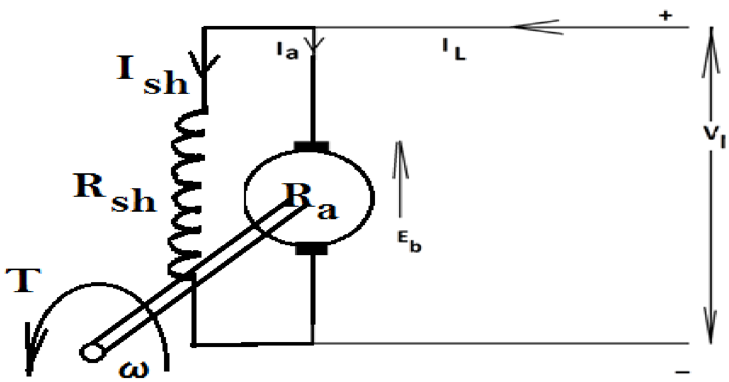
$I_f=v_f/R_f$

$I_L=I_a$

$V_L=E_b+I_aR_a+v_d$

$E_b= V_L-I_aR_a-v_d$

- Shunt motor:: The field winding is connected in parallel with the armature is called shunt motor. The shunt field winding have large turns and carries full load voltage.



$I_L=I_a+I_{sh}$

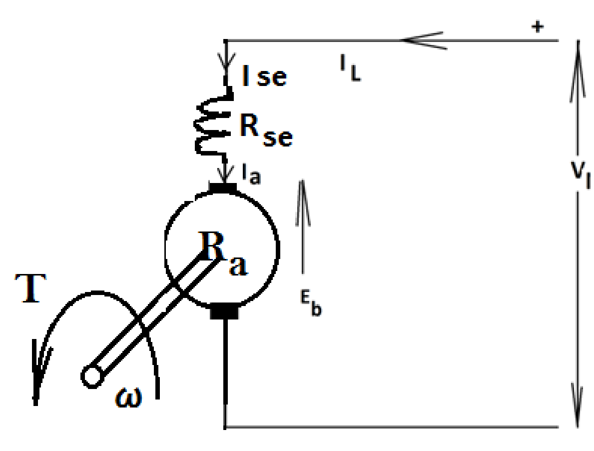
$I_{sh}= V_L/R_{sh}$

$V_L=E_b+I_aR_a+v_d$

$E_b= V_L-I_aR_a-v_d$

in series with the armature is called series motor. The series field

current.



$I_L=I_{se}=I_a$

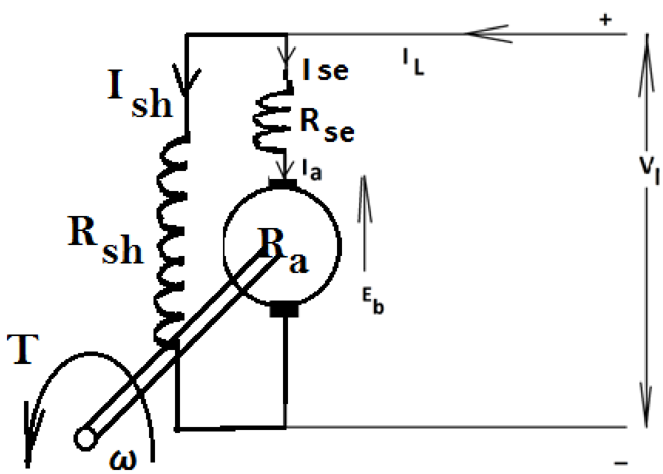
$V_L=E_b+I_aR_a+I_{se}R_{se}+v_d$

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

$E_b= V_L-I_aR_a-I_{se}R_{se}-v_d$

$E_b= V_L-I_a(R_a+R_{se})-v_d$

- <u>long shunt compound motor</u>:: The shunt field winding is connected in parallel with the both armature and series field winding is called long shunt compound motor.



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

$I_{se}=I_a$

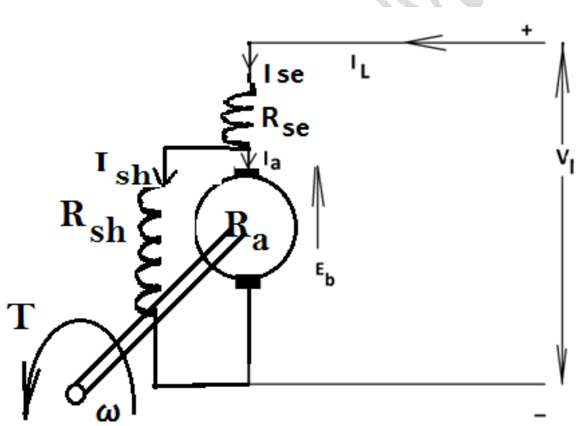
$I_{sh}= V_L/R_{sh}$

$V_L=E_b+I_aR_a+I_{se}R_{se}+v_d$

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

$E_b= V_L-I_a(R_a+R_{se})-v_d$

- <u>Short shunt compound motor</u>:: The shunt field winding is connected in parallel with the armature only is called short shunt compound motor.



$I_L=I_{se}$

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

$I_{sh}= (V_L+ I_{se}R_{se})/R_{sh}$

$V_L=E_b+I_aR_a+I_{se}R_{se}+v_d$

$E_b= V_L-I_aR_a-I_{se}R_{se}-v_d$

<u>12.Torque and equation for Torque of a DC motor</u>:

By the term torque is meant turning or twisting moment of a force about its own axis. It is measured by the product of force and radius at which force act.

Torque T=F x r in N-m

- Derivation of torque

Power developed in armature **P**=T x ω-----------(1)

But we known angular velocity $\boldsymbol{\omega} = \frac{2\pi N}{60} - - - (2)$

From equation (1)&(2)

The power developed in armature **P**=T x $\frac{2\pi N}{60}$ ----------(i)

Electrical equivalent of mechanical power developed in armature

P= E_b x I_a-----------(a)

But we known the back E.M.F. $\mathbf{E_b} = \left(\frac{\Phi PN}{60}\right) * \frac{Z}{A}$ Volts-----(b)

From equation (a)&(b)

The power developed in armature **P**=$\left(\frac{\Phi PN}{60}\right) * \frac{Z}{A}$ x I_a--------(ii)

Equating the above equation (i) & (ii)

$$T \times \frac{2\pi N}{60} = \left(\frac{\Phi PN}{60}\right) * \frac{Z}{A} \times I_a$$

$$T \times 2\pi = \Phi P \times \frac{Z}{A} \times I_a$$

$$T = \frac{1}{2\pi} \times (\Phi \times I_a) \times (P \times \frac{Z}{A})$$

$$T = 0.159 \times (\Phi \times I_a) \times (P \times \frac{Z}{A}) \quad \text{N-m}$$

This torque is called armature torque or gross torque denoted by the letter T_a or T_g.

$$T_a = 0.159 \times (\Phi \times I_a) \times (P \times \frac{Z}{A}) \quad \text{N-m}$$

Here $T_a \alpha (\Phi \times I_a)$

For shunt motor $T_a \alpha I_a$ (since Φ is constant **)**

For series motor $T_a \alpha I_a^2$ (since $\Phi \alpha I_a$)

13.Formula for armature Torque, shaft torque, and loss torque of a DC motor:

- armature Torque(T_a or T_g)::The torque developed at the armature of a motor is called armature torque or gross torque.

$$T_a = 0.159 \times (\Phi \times I_a) \times (P \times \frac{Z}{A}) \quad \text{N-m}$$

- shaft torque(T_{sh}):: The torque which Is available at the motor shaft for doing useful work is known as shaft torque.

$$\text{Output} = \frac{2\pi N}{60} \times T_{sh}$$

$$T_{sh} = \text{Output} \times \frac{60}{2\pi N}$$

$$T_{sh} = 9.55 \times \frac{\text{Output}}{N} \quad \text{N-m}$$

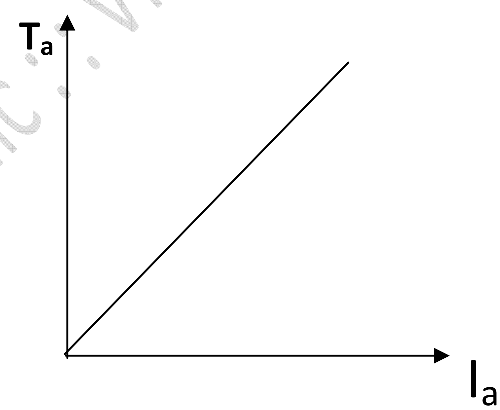
Loss torque(T_L):: The difference in armature torque and shaft torque is known as loss torque. $T_L = T_a - T_{sh}$

14.Characteristics of DC-motors: The characteristic curves of a motor are those curves which shows relationship between the following quantities,

(i) T_a (Vs) I_a characteristics are known as Electrical characteristics.
(ii) N (Vs) I_a characteristics are known as Speed characteristics.
(iii) N (Vs) T_a characteristics are known as mechanical characteristics.

15.Characteristics of DC shunt motor:

- **T_a (Vs) I_a** characteristics::



we know $T_a \alpha (\Phi \times I_a)$

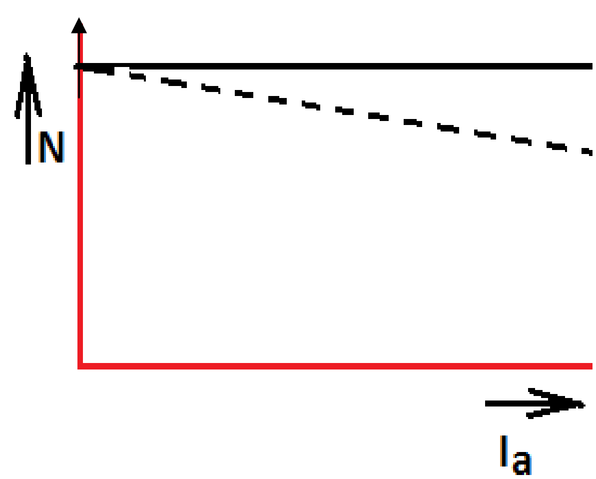
for shunt motor 'Φ' is constant.

so $T_a \alpha \Phi$

Hence its characteristic curve is a straight line passing through origin.

- **N (Vs) I_a** characteristics::

we know $N \alpha \dfrac{E_b}{\Phi}$

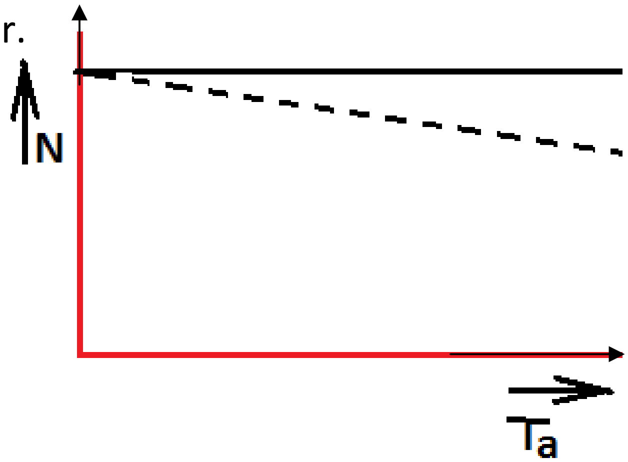


For shunt motor

Φ and E_b are constant so speed directly proportional to constant.

But practically ϕ and E_b decreases

with increase in load, hence speed also decreases. The actual speed curve is slightly drooping as shown by dotted lines. But practically shunt motor is taken as a constant speed motor.

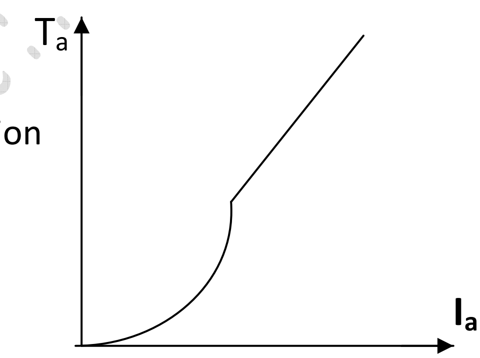


- **<u>N (Vs) T_a</u>** <u>characteristics::</u>

This curve is obtained by plotting the values of N and T_a for various armature currents.

<u>16.Characteristics of DC series motor:</u>

- **<u>T_a (Vs) I_a</u>** <u>characteristics::</u>



We know $T_a \alpha (\phi \times I_a)$

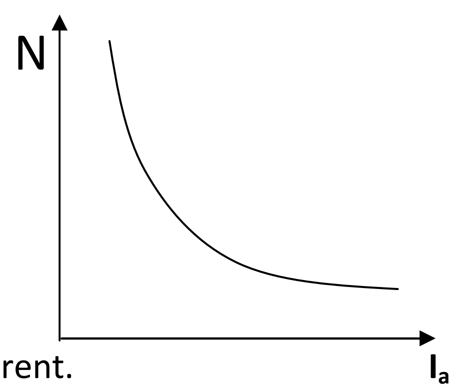
For series motor $\phi \alpha I_a$ upto its magnetic saturation

After magnetic saturation 'ϕ' is constant.

$T_a \alpha I_a^2$ [upto its magnetic saturation]

$T_a \alpha I_a$ [After magnetic saturation]

- **<u>N (Vs) I_a</u>** <u>characteristics::</u>



We know $N \alpha \frac{Eb}{\phi}$

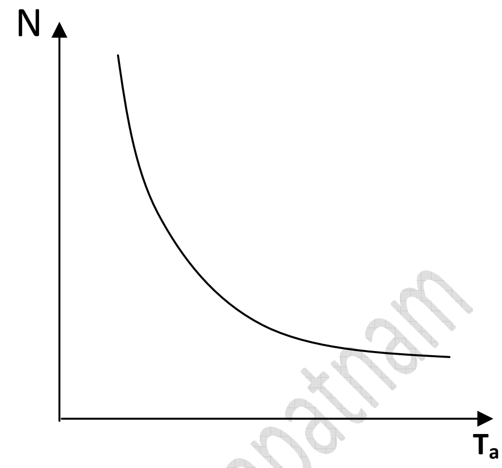
And $\phi \alpha I_a$

So $N \alpha \frac{1}{Ia}$ at constant back emf.

hence speed varies inversely with armature current.

"when load is means I_a is high hence speed is low. If load current is **'0'** or small the speed becomes dangerously high. Hence series motor must start with load."

- **N (Vs) T_a** characteristics::



We know $\mathbf{N \; \alpha \; \frac{Eb}{\phi}}$

And $T_a \; \alpha \; (\phi \times I_a)$

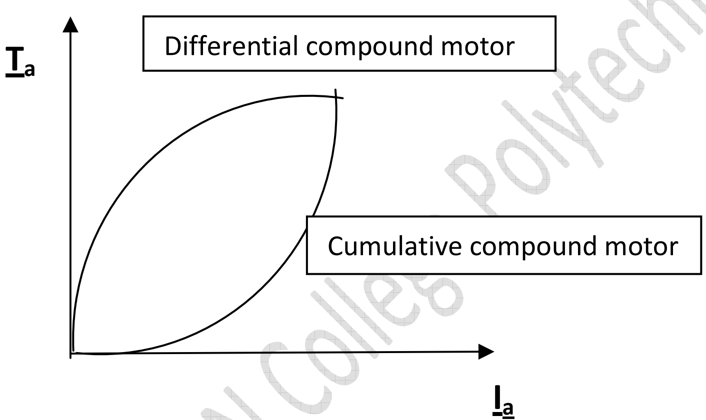
At constant armature current and back emf

$$N \; \alpha \; \frac{1}{Ta}$$

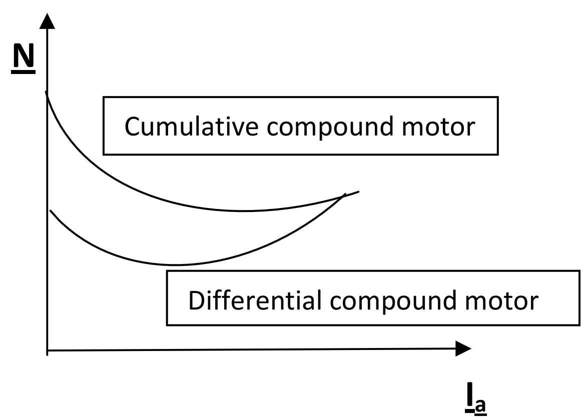
When speed is high torque is low vice – versa.

17.Characteristics of DC compound motor:

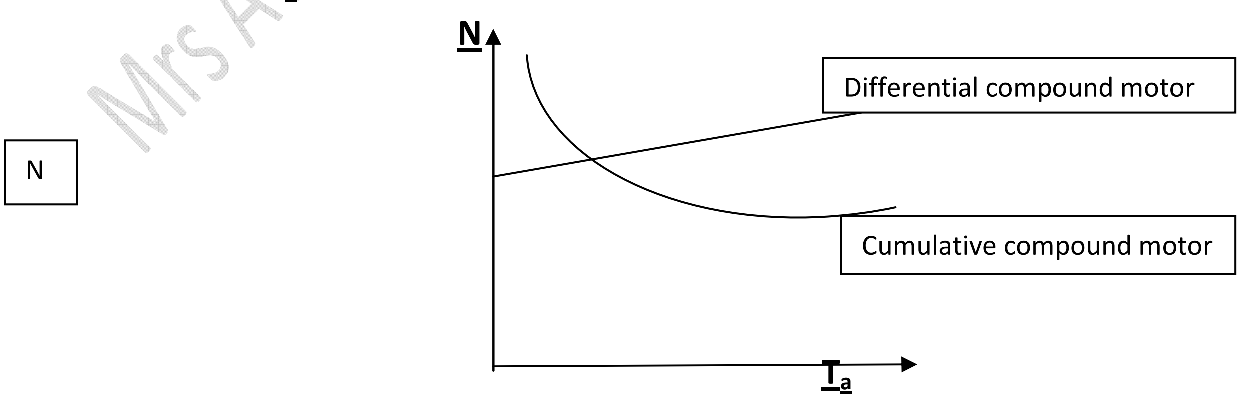
- **T_a (Vs) I_a** characteristics::



N (Vs) I_a characteristics::



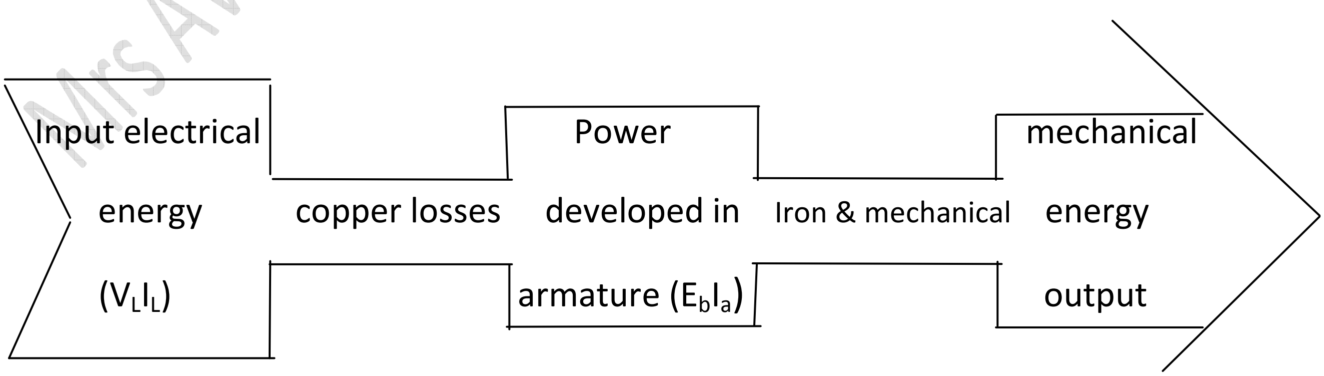
- **N (Vs) T_a** characteristics::



18.Different losses in DC-motor:

- Total losses
  - Copper losses
    - Armature cu loss($I_a^2 R_a$)
    - shunt field cu loss($I_{sh}^2 R_{sh}$)
    - Series field cu loss($I_{se}^2 R_{se}$)
  - Iron (or) core (or)magnetic loss
    - Hysterisis loss ($W_h = \eta B_m^{1.6} f v$)
    - Eddy current loss ($W_e = K_e B_m^2 f^2 t^2 v$)
  - Mechanical loss
    - Frictional loss
    - Windage loss

19.Power stages in DC-motor:



$$\text{Electrical efficiency } (\eta_{ele}) = \frac{\text{Power developed in armature } (E_b I_a)}{\text{Input electrical energy } (V_L I_L)}$$

$$\text{Mechanical efficiency } (\eta_{mech}) = \frac{\text{Mechanical energy output}}{\text{Power developed in armature } (E_b I_a)}$$

$$\text{Overal efficiency } (\eta_{overal}) = \frac{\text{Mechanical energy output}}{\text{Input electrical energy } (V_L I_L)}$$

20. Applications of DC-motors:

- Shunt motor:: Lathes, printing presses, centrifugal pumps, fans,
- Series motor:: Electric locomotives, cranes, conveyors, trolley cars
- Cumulative compound motor:: Rolling mills, Air compressors, elevators, punchers, conveyors
- Differential compound motor:: used in limited applications for research work and experimental work etc…