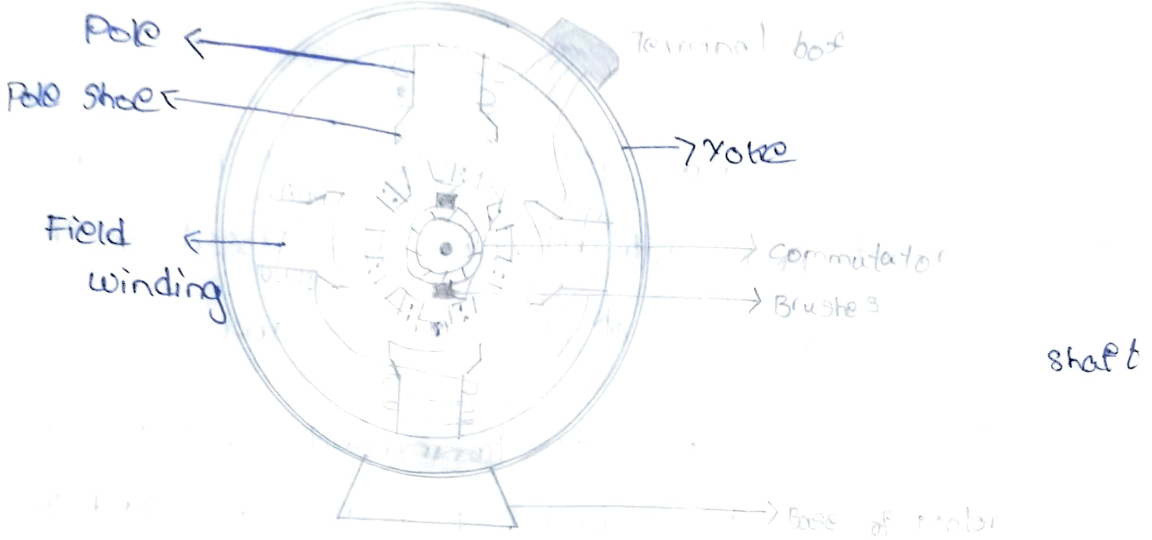
Date
23-01-20

Module - 2

DC Machines



A D.C Machine mainly consist of two parts statio[nary] part, rotating part.

→ The stationary part produces constant magnetic flux and Rotating part converts mechanical energy into electrical energy.

→ The stationary part & rotating part are separated by Small air gap.

→ The stationary part consist of yoke, main poles along with the pole shoes, Base plate.

→ Rotating part consist of Armature coil, commutator, shaft and brushes.

York :-

→ York is the outer core of D.C machine and is cylindrical in shape. For small generators it is madeup of caste iron & for large generator is madeup of caste steel.

-> Base plate & terminal box are intergated with york Base plate enables the machine to be placed on the ground, The terminal box contains output terminals.

-> Main pole : The main poles are madeup of steel of high permeability. poles are fixed to the yoke with the help of bolt or welding

-> Pole Shoes : pole shoes are laminated and fixed to pole core with screws. It helps to spreads the flux uniformy in the our Gap and reduces reluctance of the path.

-> pole coils are connected to pole shoes and produces main flux when dc current pass through it.

-> Armature : Armature consist of Armature core & Armature winding.
Armature core is madeup of silicon steel laminat and they are slots & cut uniformly and the outer ferri ferri to place Armature Conductor.
The Armature conductors are placed in the slots of Armature core forms Armature widing.

-> Commutator : Commutator converts alternative emf generator in Armature winding into D.C emf.

Shaft ÷ Shaft of DC generator is rotator by prime ~~over~~ mover. for small generator roller bearings are used at the both end of the shaft and for larger generator roller bearing are used for driving and ball bearings are used at other ends

Date
25-01-20

Equation for induced emf [dc generator] :

Let P = Number of Poles of generator

ϕ = flux produced by each pole in webers.

N = speed of armature (rpm).

Z = total number of conductors in the slots of armature.

A = Number of parallel paths.

According to Faraday's law of electromagnetic induction

induced emf = Rate of cutting of magnetic flux.

$$e = \frac{d\phi}{dt} \longrightarrow (1)$$

total flux (ϕ) = flux produced by each pole $\times$ Number of poles

$$\text{total } (\phi) = \phi \times P \longrightarrow (2)$$

Time required for one revolution $= \frac{60}{N} \rightarrow (3)$

Substitute (2) and (3) in (1)

$$e = \frac{\phi \times P}{\frac{60}{N}} = \frac{\phi P N}{60} \longrightarrow (4)$$

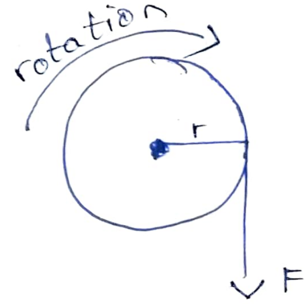
Z conductors are distributed in A parallel paths effectively $\frac{Z}{A}$ conductors need to be multiply with emf induced in one conductor.

Total emf induced

$$\boxed{E = \frac{\phi P N}{60} \times \frac{Z}{A}}$$ volts.

Torque equation of (DC Motor):

Torque is turning the point above it's axis, It is equal to the product of the force and the radius at which it acts consider the armature of DC motor to have radius r and F is the force acting tangentially on it



$$\boxed{\text{Torque} = F \times r} \text{ Nm} \longrightarrow (1)$$

$T_a = F \times r$ N-m

Work done by the F in one revolution

W = force × distance moved

$W = F \times 2\pi r \longrightarrow (2)$

Total power developed by armature

$$P = \frac{\text{work done}}{\text{time}}$$

$$P = \frac{F \times 2\pi r}{\frac{60}{N}}$$

$$\boxed{P = \frac{F \times r\, 2\pi N}{60}}$$

* The power in armature is ~~equal to~~ = power at output

$$E_b \times I_a = \frac{T_a\, 2\pi N}{60}$$

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

$$T_a = \frac{1}{2\pi} \frac{\phi P I_a Z}{A}$$

$$\boxed{T_a = \frac{0.159\, \phi P I_a Z}{A}} \text{ N m}$$

$$\frac{1}{2\left(\frac{22}{7}\right)}$$

$$\frac{1}{\frac{44}{7}} = \frac{7}{44}$$

Date 28-01-20

Types of dc machines based on excitation.

1. Separately excited dc machine.
2. Self excited dc machine.

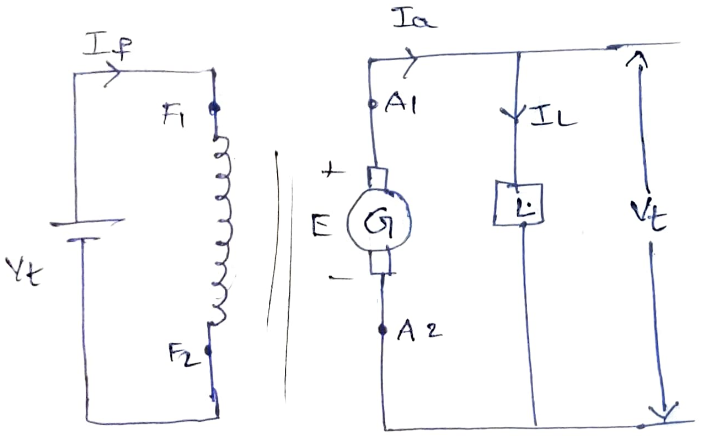
Self excited dc machine :- * Generated emf is due to residual magnetism of the machine.

* Separate dc supply is used to excite the field circuit in separately excited dc machine

Types of dc generator based on excitation

1. separately excited dc generator
2. self excited dc generator
   - 1) shunt generator (Parallel)
   - 2) series generator
   - 3) compound generator
     - 1) long-shunt generator
     - 2) short-shunt generator.

1) Separately excited dc generator :-



$V = IR$

$I_a = I_L$

$E - I_a R_a - V_t = 0$

$\boxed{E = I_a R_a + V_t}$

Current and voltage relationship.

$\boxed{E = I_a R_a + V_t}$

where E = induced emf $E = \frac{\phi Z P N}{60 A}$

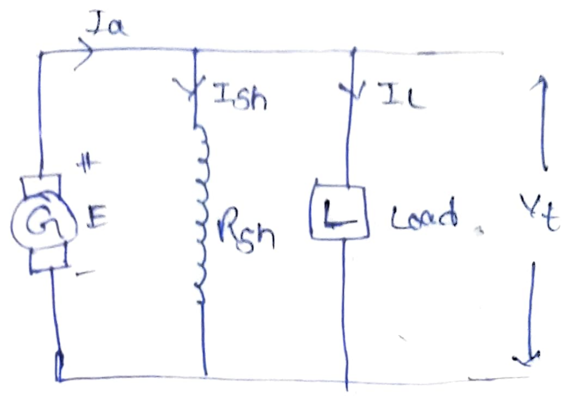
I_a = armature current

R_a = internal resistance of armature

V_t = terminal voltage.

self generated generator:-

② **Shunt generator :-**



In shunt generator field widening is parallel with armature winding

current and voltage relationship.

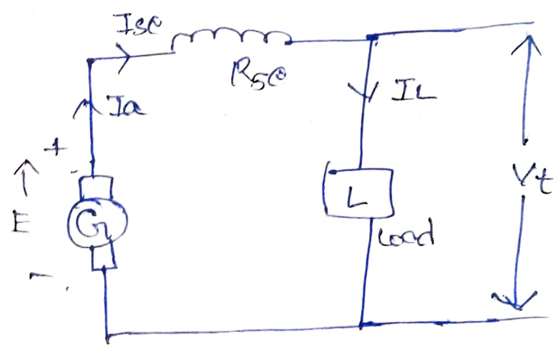
$$I_a = I_{sh} + I_L$$

$$\boxed{\cancel{V_t = E - I_a R_a}}$$

$$E - I_a R_a - V_t = 0$$

$$\boxed{E = I_a R_a + V_t}$$

3) **Series generator :-**



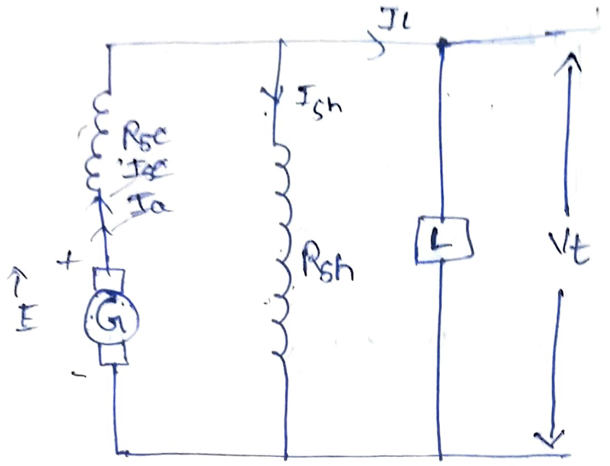
$$I_a = I_{se} = I_L$$

$$E - I_a R_a - I_{se} R_{se} - V_t = 0$$

$$\boxed{E = I_a R_a + I_{se} R_{se} + V_t}$$

Compound generator :

i) Long shunt generator .



Long shunt compound generator here shunt field winding is connected in parallel with both series field winding and Armature winding :

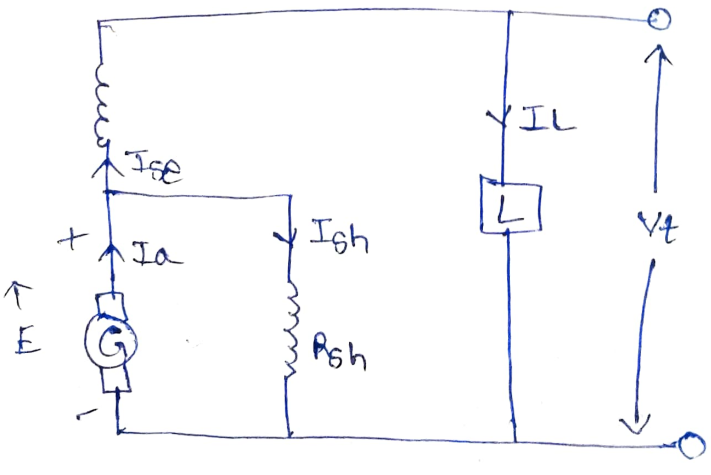
$$I_a = I_{se}$$

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

$$E - I_a R_a - I_{se} R_{se} - V_t = 0$$

$$\boxed{\therefore E = I_a R_a + I_{se} R_{se} + V_t}$$

ii) Short shunt compound generator :



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

$$\boxed{E = I_a R_a + I_{se} R_{se} + V_t}$$

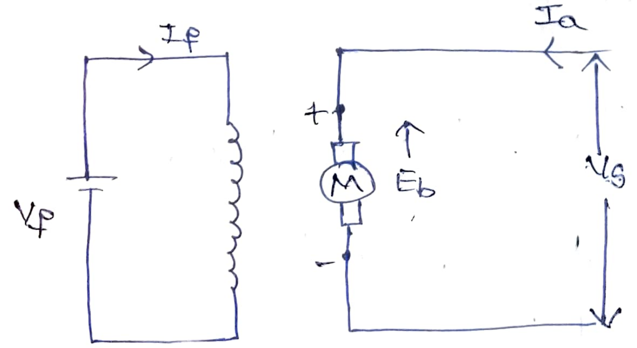
Date 30-01-20

Types of dc motors based on excitation

1. separately excited dc motor
2. self excited dc motor → shunt motor, series motor, compound motor

compound motor → long shunt, short shunt.

1. separately excited dc motor :-

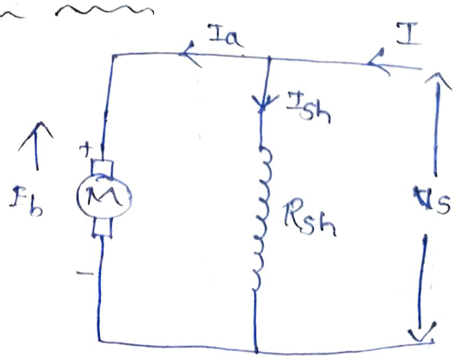


$V_s - I_a R_a - E_b = 0$

$$\boxed{V_s = I_a R_a + E_b}$$

2. Self excited dc motor :-

1) Shunt motor :-



$V_s - I_a R_a - E_b = 0$

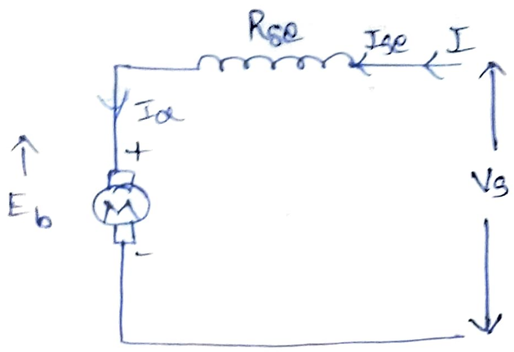
$V_s = I_a R_a + E_b$

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

$$V_s - I_a R_a - E_b = 0$$

$$\boxed{V_s = I_a R_a + E_b}$$

2) Series Motor :-



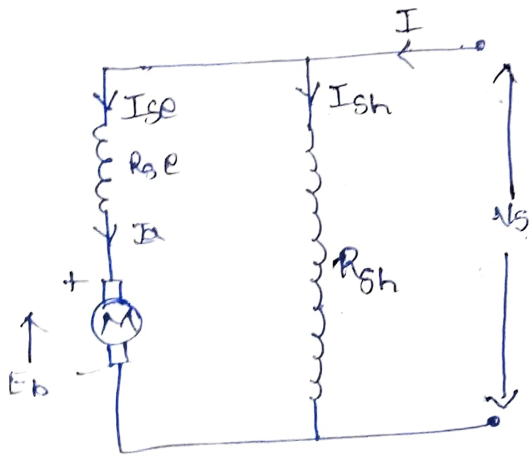
$$\boxed{I_a = I = I_{se}}$$

$$V_s - I_{se} R_{se} - I_a R_a - E_b = 0$$

$$\boxed{V_s = I_a (R_{se} + R_a) + E_b}$$

③ Compound Motor :-

i) Long- shunt Motor :-



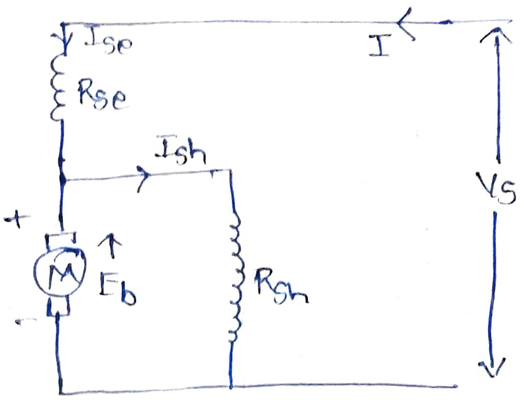
$$\boxed{I = I_{se} + I_{sh}}$$

$$\boxed{I_{se} = I_a}$$

$$V_s - I_{se} R_{se} - I_a R_a - E_b = 0$$

$$\boxed{V_s = I_{se} R_{se} + I_a R_a + E_b}$$

ii) Short - shunt Motor :-



$$\boxed{I = I_{se}}$$

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

$$V_s - I_{se} R_{se} - I_a R_a - E_b = 0$$

$$\boxed{V_s = I_{se} R_{se} + I_a R_a + E_b}$$

Performance characteristics of DC Machines

The speed of DC machine operated as a generator is operated by fixed prime mover. The generated performance deals primarily with relational among excitation, terminal voltage. The relation can be executed graphically by mean of curves is known as DC generator characteristics. The characteristic can be describe based on behaviour of generator under different load condition.

DC generator characteristics :

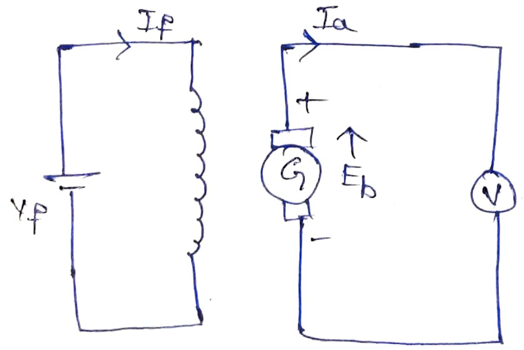
They are three important characteristics

1) open circuit characteristics (OCC)

2) Load characteristics → Internal characteristics
   → External characteristics

separately excited DC machine

1) open circuit characteristics [OCC]



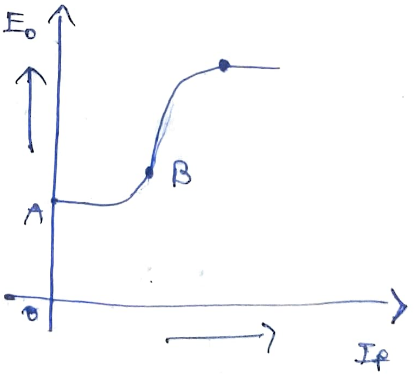


Fig: OCC characteristics of separately excited dc generator

Observation:

① When field current is zero some emf is generated due to residual magnetism in the field poles.

② Upto point B in the curve the relationship b/w E_0 & I_f is linear because reluctance of Iron is negligible.

③ After point B on the curve the reluctance of Iron comes into the picture then curve deviates from linear relationship.

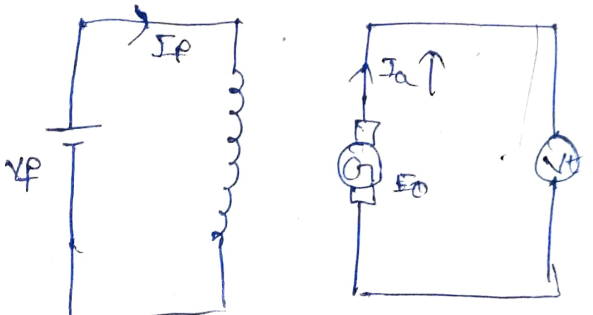
④ After point C, the magnetic saturation of pole begin & E_0.

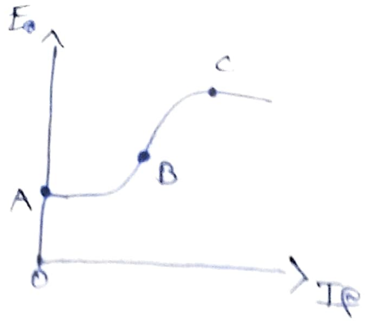
Date 31-01-20

Performance characteristics of separately excited dc generator

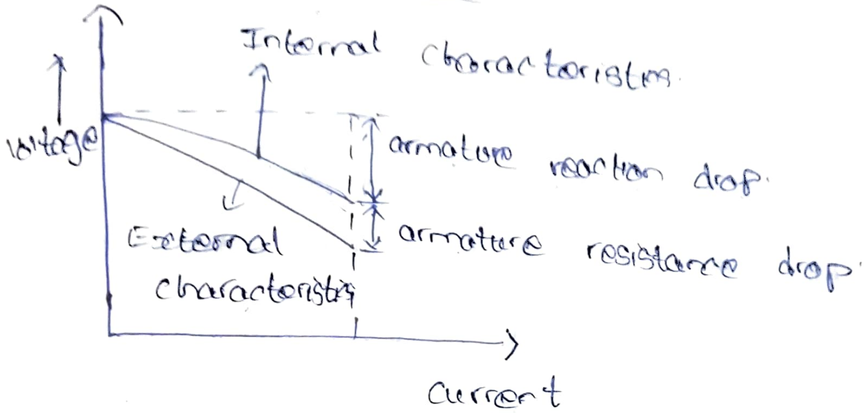
1) Open circuit characteristics [OCC] No load — E_0 / I_f

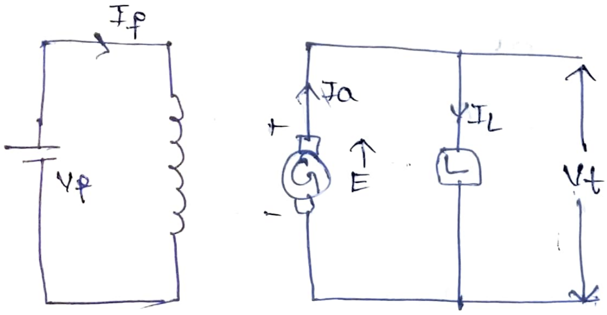
2) Load characteristic
- Internal characteristics — E/I_a
- External characteristics — V / I_L





Load characteristics





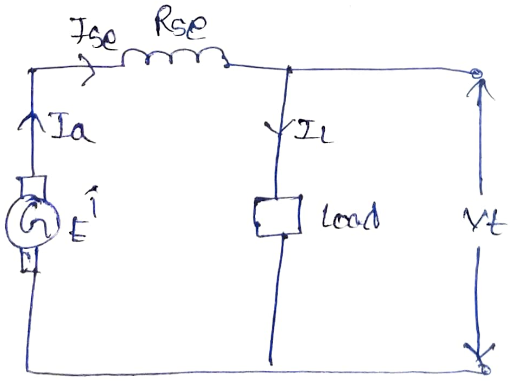
$E - I_a R_a - V_t = 0$

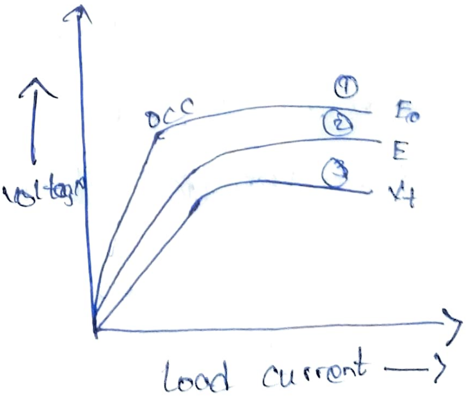
$\boxed{V_t = E - I_a R_a}$

$\boxed{I_a = I_L}$

$$\boxed{V_t = E - I_a R_a}$$

Performance characteristics of series generator :





$I_a = I_{se} = I_L$

$$\boxed{E_0 > E > V_t}$$

curve ① - OCC chara

curve ② - Internal char

curve ③ - external char

① **OCC** :-

Curve one shows the open circuit characteristic of series generator. It can be obtained experimentally by disconnecting field winding from the machine & exciting from separate DC source.

② **Internal characteristic** :-

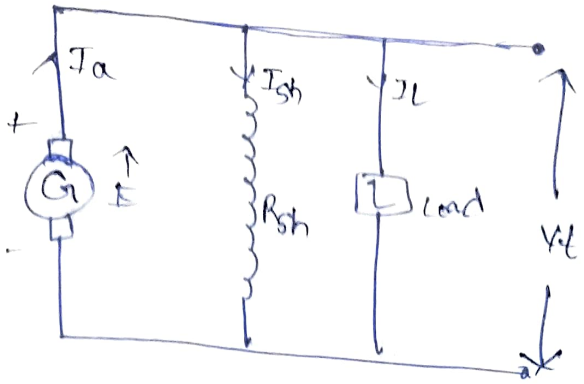
Curve two shows internal characteristic of series generator. It gives relationship b/w generated emf E on load & armature current. Due to armature reaction, the flux in the machine will be less than flux at no load. Hence the emf generator under no load generator E_0 is greater than Emf generated on load E. Consequently the internal characteristic curve lies below occ curve, the difference b/w them representing the effect of armature reaction.

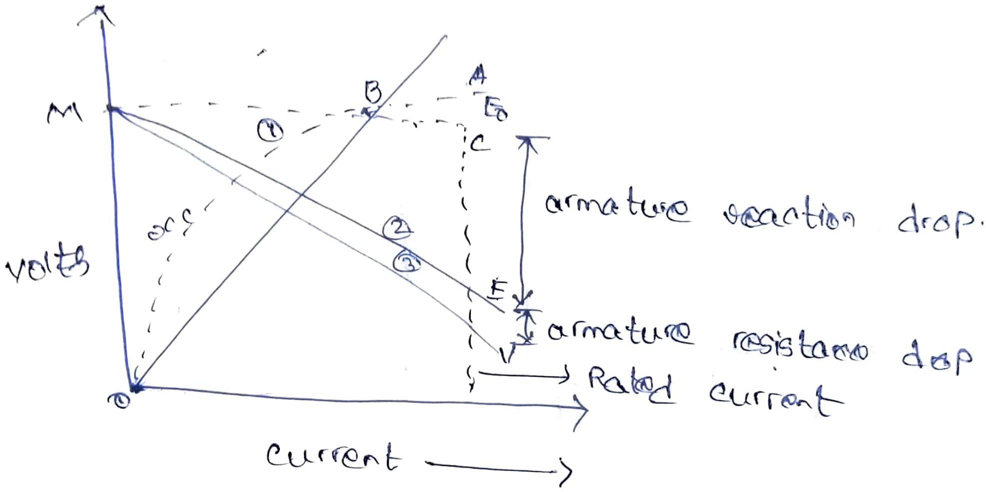
③ **External characteristic** :-

Curve three shows external characteristic of series generator. It gives the relationship b/w terminal voltage V_t & load current I_L. Therefore the external characteristic curve will lie below Internal characteristic curve.

$$\boxed{V_t = E - I_a (R_a + R_{se})}$$

Performance characteristic of shunt generator :-





① occ characteristics.

② internal characteristics.

③ external characteristics

① OCC Characteristics :-

The line OA represent shunt field resistance. When the generator is run at normal speed, it build up the voltage (om) at no load

② Internal characteristic :-

When the generator is loaded, flux per pole is reduced due to armature reaction. Therefore emf E generator on load is less than Emf generated at no load.

③ External

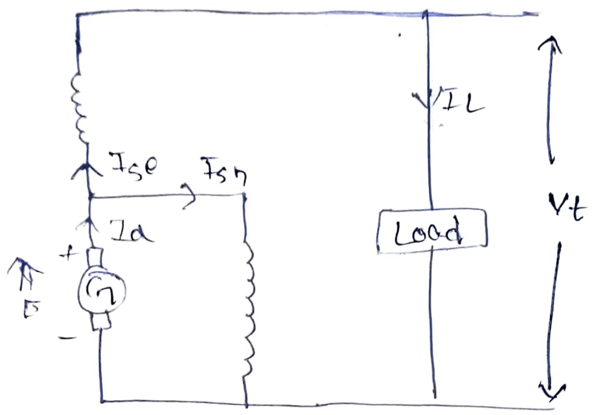
Curve 3 show the external characteristics of shunt generator

$$\boxed{V_t = E - I_a R_a}$$

Therefore external characteristic will lie below the internal characteristic because $V_t < E$

Date 1.02.20

Performance characteristic of compound generator.



In compound generator, the shunt winding can be connected either across armature or across armature & series field. It may be noted that external characteristic of long shunt & short shunt generator are almost identical

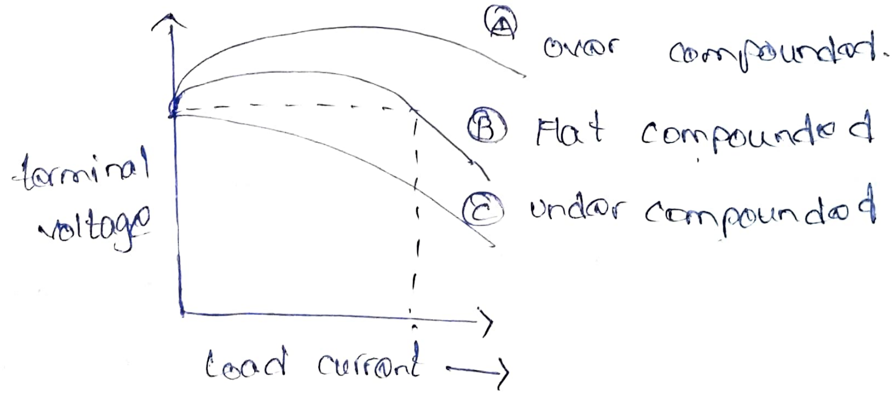


Figure shows external characteristic of compound generator. The series excitation aids the shunt excitation. The degree of compounding depends upon series excitation with increasing load current.

1) ~~If~~ over compounded :-

If series winding turns are adjusted such a way that with the increasing load current, the terminal voltage increases and it is called over compounded generator. As load current increases flux in the machine also increases & hence generator voltage also increases. The increasing generator voltage is greater than I_aR_a drop so that instead of decreasing, the terminal voltage increases as shown by curve (A) in the figure.

2) Flat compounded

If series winding turns are adjusted such that with the increase in load current, the terminal voltage remains constant and it is called Flat compounded generator. The series winding such of generator has lesser no. of turn than in over compounded machine & therefore flux is not increased for the given load current. it is shown by curve (B) in the figure

3) under compounded

~~If~~ the series winding as lesser no. of turns than that of Flat compounded machine, the terminal voltage falls with increasing load current as indicated by curve C.

Date
4-02-20

Performance characteristic of dc motor

The performance of dc motor can Judge from its characteristics curves known as Motor characteristics.

i) **Torque & armature current characteristic [T_a/I_a]**

It is the curve b/w armature Torque (T_a) and armature current (I_a) of dc motor. It is also known as electrical characteristics of dc motor.

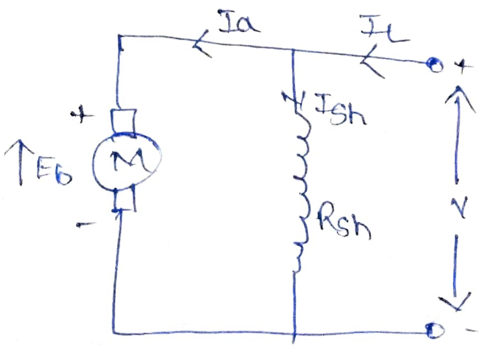
ii) **Speed & armature current characteristic [N/I_a]**

It is the curve b/w speed (N) & armature current (I_a). It is very important characteristic which serves as deciding factor for the selection of motor for

iii) **Speed and torque characteristic [N/T_a]**

It is the curve b/w speed (N) & armature Torque [T_a]. It is also known as mechanical characteristic of dc motor.

Characteristics of shunt motor.



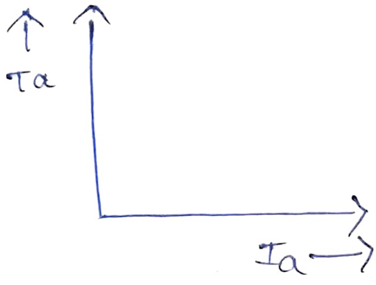
$$V = E_b + I_a R_a$$

$V > E_b$

$$E_b = V - I_a R_a$$

Figure shows the connection dc shunt motor. The field current I_{sh} is constant since the field winding is directly connected to supply which is assume directly constant. Hence the flux in the motor is approximately constant.

i) Torque & armature current of shunt motor :-



W.K.T

$$T_a = 0.159 \phi Z I_a (P/A)$$

$$\boxed{T_a \propto I_a}$$

Since the motor is operating from the constant supply, flux ϕ is almost constant. Hence T_a/I_a curve is straight line passing through origin.

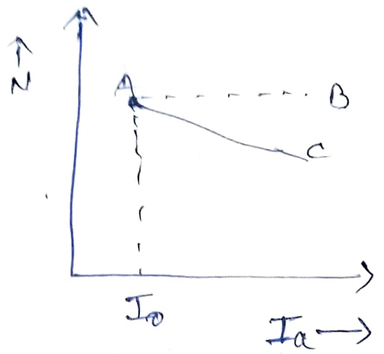
i) speed & armature current characteristic [N/Ia] :-

The speed of the motor is given by $\boxed{N \propto \frac{E_b}{\phi}}$

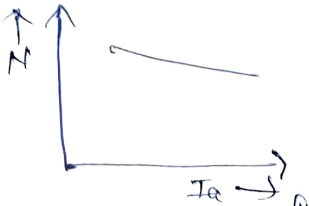
The flux ϕ & back emf in shunt motor is almost constant under normal conditions. Therefore speed of the shunt motor remain constant as armature current varies indicated by line AB in fig. when load is increase,

$E_b = V - I_a R_a$ & ϕ decreases due to armature resistance & reaction drop. However E_b decreases

~~slighting~~ slightly more than ϕ : so that speed of motor also decreases indicated by line AC in fig.

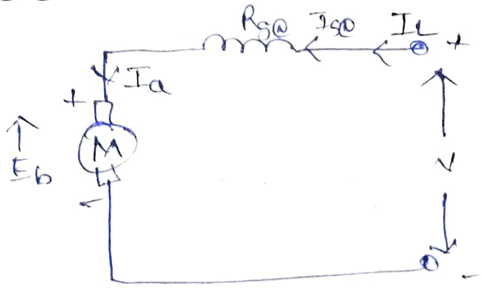


iii) <u>speed</u> & <u>armature</u> <u>torque</u> : (N/Ta)



It may be observe from the curve that speed decreases as low torque increases.

Characteristics of series motor :-



$$V - I_a R_a - E_b - I_{se} R_{se} = 0$$

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

Figure shows the connection of series motor note that the current passing through field winding is same as that of in armature.

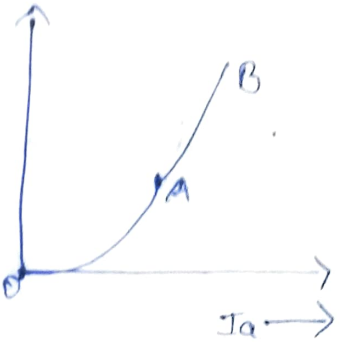
If mechanical load on the motor increase, armature current also increases, Hence flux in series motor increases with increasing in the armature current

i) Torque and current (Ta / Ia) :-

$T_a \propto I_a$ $\boxed{T_a \propto \phi I_a}$

Till magnetic saturation

$\boxed{T_a \propto I_a^2}$



After magnetic saturation

ϕ is constant $\boxed{T_a \propto I_a}$

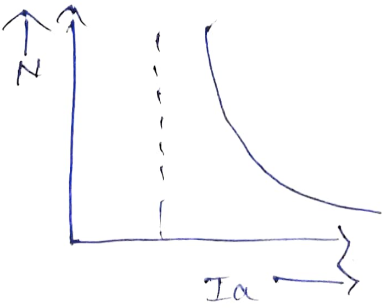
upto magnetic saturation

Therefore Ta/Ia curve is parabola upto saturation point OA in the fig. After magnetic saturation Torque is directly proportional to armature current. Hence Ta/Ia is straight line after saturation point i.e line AB in the figure.

ii) Speed & current characteristic [N/Ia] :-

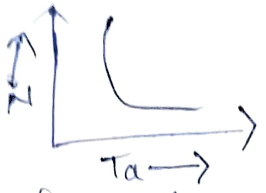
$\boxed{N \propto \frac{E_b}{\phi}}$

when armature current increases, the back emf E_b decreases due to $I_a(R_{se}+R_a)$ drop. while magnetic flux ϕ increases. The drop $I_a R_{se}+R_a$ is small & it can be neglected $\boxed{N \propto \frac{1}{\phi}}$



Upto magnetic saturation N/Ia curve follow hyperbolic path as shown in the figure. After saturation ϕ remains constant & so does the speed also does the same.

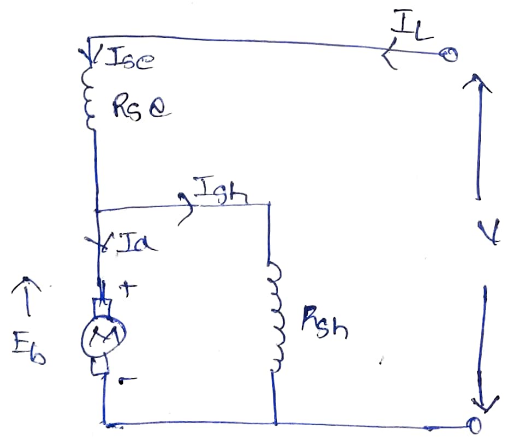
iii) Speed & torque characteristic : (N/T_a) :-



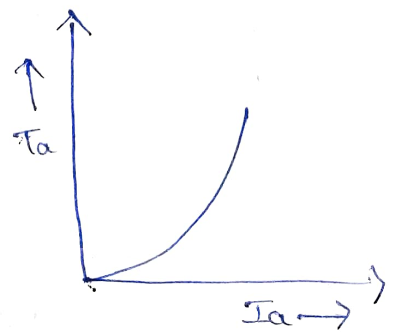
It is clear from the figure that the motor develops high Torque at low speed & vice versa. It is because an increase in torque requires increasing in armature current, which is also the field current. The result is flux is strength and speed drops.

Date
6-02-20

Performance characteristics of cumulative compound motor :

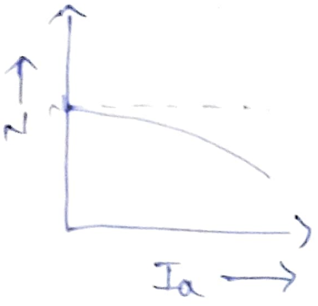


i) T_a/I_a characteristic :-



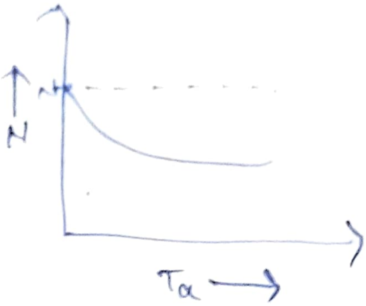
$T_a \propto \phi I_a$

ii) N/I_a Characteristic :



$$\boxed{N \propto \frac{E_b}{\Phi}}$$

iii) N/T_a characteristic



Losses in dc machines :-

i) copper Loss

ii) Iron or Core losses

iii) Mechanical losses

i) **copper Loss :-**

This loss is due to resistance present in the field winding & Armature winding.

a) copper loss produced in armature due to armature resistance & armature current is given by $I_a^2 R_a$.

b) Copper loss produced in shunt field winding is $I_{sh}^2 R_{sh}$.

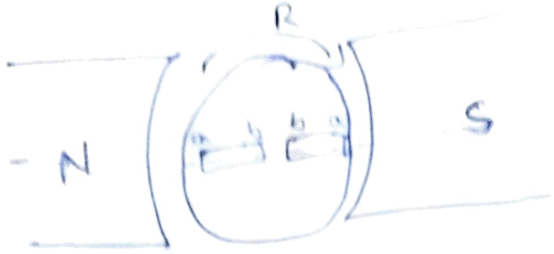
c) copper loss produce in series winding is $I_{se}^2 R_{se}$.

ii) **Iron Losses :-**

a) Hysterisis loss.

b) Eddy current loss.

a) Hysteris loss :-



Hysteris loss occur in the armature of DC machine since any given part of armature is subjected of magnetic field reversal as it passes under successful poles. In order to revers continuous the molecular magnet in armature rek some amount of power to be spend it is call Hysteris loss.

$$\boxed{P_h = \eta B_{max}^{1.6} f V \text{ watts}}$$

where P_h - hysterisis loss

B_{max} - Maximum flux density in armature.

f - Frequency of magnetic reversal.

V - Volume of core in m^3.

η - steinmetz hysteris coefficient.

b)

In order to reduce hysteris loss, armature core is madeup of such material which have less value of hysteris coefficient.

Eg:- silicon steel.

b) Eddy current loss :

when armature rotates in the magnetic field an emf is induced which circulates current in the armature. The power loss due to this current is called Eddy current loss.

$$\boxed{P_e = K_e B_{max}^2 f^2 t^2 V \text{ watts}}$$

where K_e - constant

B_{max} - maximum flux density in armature

f - frequency of magnetic reversal.

t^2 - thickness of lamination

V - volume of core in m^3.

These loss can be reduced by building armature core by thin laminations insulated from each other.

iii) Mechanical losses :

a) frictional loss : Eg: bearing friction, brush friction

b) windage loss : Eg: air friction of rotating armature

Constant and variable losses :

Constant losses are the losses which remain constant at all modes.

Eg: 1) Iron ~~losses~~

2) mechanical loss

3) shunt field loss