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DC Motors.

A motor is a machine that converts electrical energy into mechanical energy.
The DC motor is very similar to a DC generator in construction.
Generators are usually operated in more protected location & therefore their construction is generally of the open type.
On the other hand motors are generally used in locations where they are exposed to dust, moisture, fumes and mechanical damage & thus motor required protective enclosers.

★ Motor Principle.

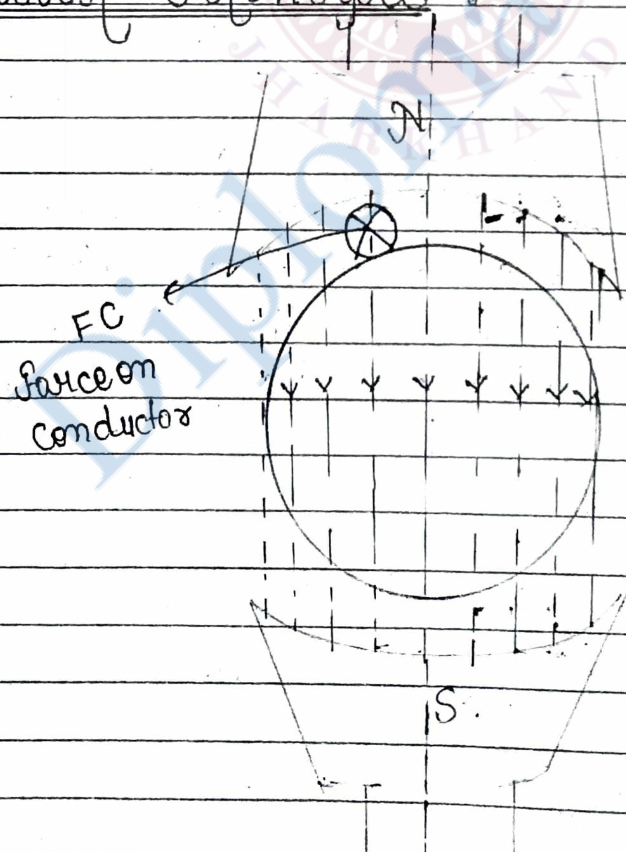

Fig: A current carrying conductor placed in a magnetic field

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DC motors operate on the principle that when a current carrying conductor is placed in a magnetic field it will experience a force and the torque thus provided will move the rotating part of the motor.

Let us consider one such conductor place in a slot of armature and suppose that it is acted upon by the magnetic field from a north pole of the motor.

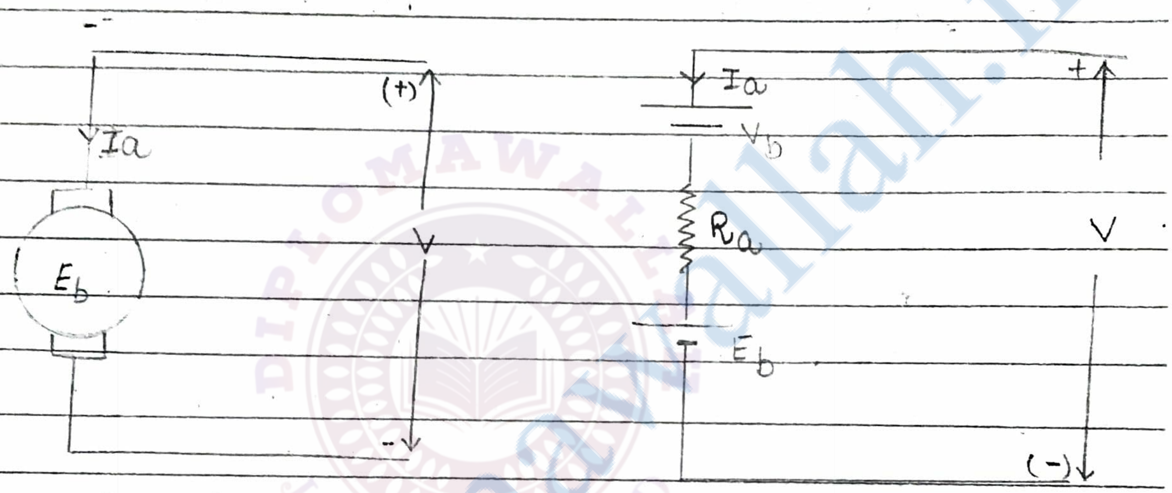
By applying left hand rule it is found that the conductor has a tendency to move to the left hand side. Since, the current is in a slot on the circumference of the rotor, the force Fc acts in a tangetial direction to the rotor. Thus, a torque (turning effect) is developed on the rotor. Similary, torques are produced on all the rotor conductor. Since, the rotor is free to move, it starts rotating in the anticlockwise direction. The torque produces on the rotor is transfered to the shaft of the rotor and can be utilize to drive a mechanical load.

Equivalent Circuit Of a DC motor

Armature

The armature of a DC motor can be represent by an equivalent ckt. It can be represented by three series connected elements, (E_b, R_a and V_b). The element E_b is the back emf, the element R_a is the armature resistance and V_b is the brush contact voltage drop.

The equivalent ckt of the armature of a DC motor is shown in figure.



Equivalent ckt of the armature of a dc motor

In a motor, current flows from the line into the armature against the generated voltage

By KVL,

$$I_a R_a + E_b = V$$

$$V = E_b + I_a R_a \quad \text{——— i)}$$

Where V = motor terminal voltage or supply voltage.

E_b = back emf

I_a = armature current

R_a = armature circuit resistance.

Equation (1) is the fundamental motor equation

It is seen that the back emf (E_b) of the motor is always less than its terminal voltage V

If the voltage drop V_b in the brushes is also considered then by KVL

$$V = E_b + I_a R_a + V_b \quad \text{---} \quad (ii)$$

V.V.I
1(j)

Back Emf or Counter Emf.

When a current carrying conductor is placed in a magnetic field, a force is experienced by it. Since, armature of the DC machine consist of conductors round the periphery A combined torque exerts turning moment and armature begins to rotates.

Now armature conductors are rotating in the magnetic field provided by the field magnet.

According to the Faraday law of electromagnetic induction, an emf is induced in the armature conductor. According to Lenz's law it will be in the opposite direction to the cause by which it is being induced i.e supply voltage. That is why the induced emf in the case of the motor is termed as back emf. This is also known as 'counter emf'.

The magnitude of the back emf in the motor depends upon all those factors which we have discussed in

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the case of generator for generated emf.
So if P = no. of poles
ϕ = flux per pole in weber
Z = total number of armature condu
N = Speed in rpm.
A = no. of parallel path.

Since A = P (In lap winding)
A = 2 (In wave winding)
Similarly to DC generator, EMF induced in DC motor is

$$E_b = \frac{PNZ\phi}{60A} \text{ volts}$$

Torque Equation Of DC (motor) Machine

- When a DC machine is loaded either as a motor or as a generator, the rotor conductors carry current. These conductors lies in the magnetic field of the air gap. Thus each conductor experiences a force. The conductor lie near the surface of the rotor at a common radius from its centre. Hence a torque is produced around the circumference of the rotor and the rotor starts rotating.

When the machine operate as a generator at constant speed, this torque is equal and opposite to that provided by the prime mover. When the machine is operating as a motor the torque is transfered to the shaft of the rotor and drives the mechanical load.

The expression for the torque is the same for the generator and motor. It can be deduce as follows :-

The voltage equation of a DC motor is

$$V = E_b + I_a R_a \quad \text{—— i)}$$

Multiplying both the sides of equation i) by I_a.

$$VI_a = E_b I_a + I_a^2 R_a \quad \text{—— ii)}$$

where VI_a = electrical power input to the armature

$I_a^2 R_a$ = copper loss in the armature

We also know that

$$\text{input} = \text{output} + \text{losses} \quad \text{—— (3)}$$

Comparing eq^n ii) & (3)

$E_b I_a$ = electrical equivalent of gross mechanical power developed by the armature. (electromagnetic power)

Let T = average electromagnetic torque developed by the armature in Nm.

At this value of torque the electromechanical power conversion takes place.

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Mechanical power developed by the armature.

$$\text{Power} = \text{Torque} \times \text{Angular velocity}$$

$$P_m = T \times \omega$$

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

Since,

$$E_b = \frac{PNZ\phi}{60A}$$

$$\frac{PNZ\phi}{60A} I_a = T \times \frac{2\pi N}{60}$$

$$\boxed{T = \frac{PZ\phi}{2\pi A} I_a}$$

$$\boxed{T = 0.159\, \phi Z \frac{P}{A} I_a \quad Nm}$$

For a given dc machine, P, Z and A are constant. Therefore $\left(\frac{PZ}{2\pi A}\right)$ is also a constant.

Let $\left(\frac{PZ}{2\pi A}\right) = k$

$$\therefore \boxed{T = k\phi I_a}$$

$$\therefore \boxed{T \propto \phi I_a}$$

Hence, the torque developed by a DC motor is directly proportional to flux per pole and armature current.

Note:→

$$E_b = \frac{PNZ\phi}{60A}$$

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

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

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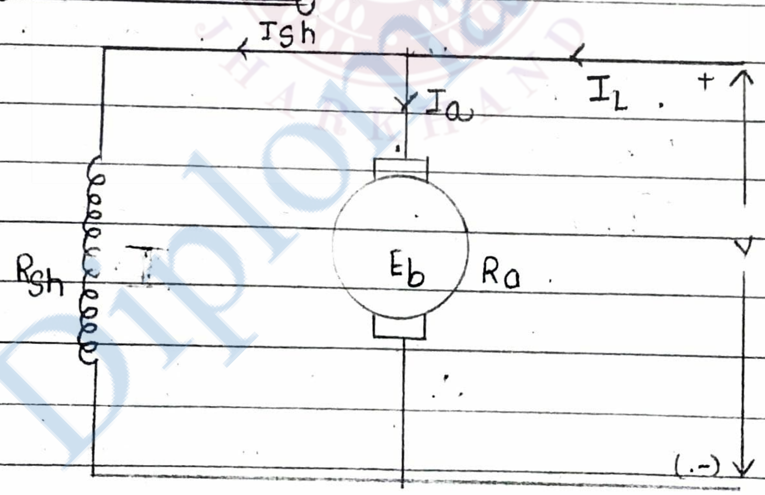
(5) Types Of DC motors.

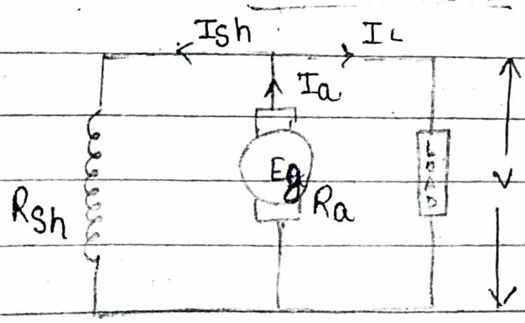
Based on connection between field winding and armature DC motor are classified as

1. Shunt motor
2. Series motor
3. Compound motor
   - Long shunt compound motor
     - Cummulative compound motor
     - Differential compound motor
   - Short shunt compound motor
     - Cummulative
     - Differential

Shunt Motor :



Shunt motor



Shunt generator.

Dc. This is the most common type of DC motor. The field winding is connected in parallel with the armature as shown in figure.

I_L = Line current

I_{sh} = Shunt field current

I_a = Armature current.

$$I_L = I_a + I_{sh} \quad \text{--- i)}$$

Also,

$V = E_b + I_a R_a$ + drop due to brushes

$$V = E_b + I_a R_a \quad \text{--- ii)}$$

Power equation

Power input = mechanical power developed + losses in the armature + losses in the field

$$VI_L = E_b I_a + I_a^2 R_a + I_{sh}^2 R_{sh}$$

$$VI_L = P_m + I_a^2 R_a + I_{sh}^2 R_{sh}$$

$$P_m = VI_L - I_a^2 R_a - I_{sh}^2 R_{sh} \quad \text{--- iii}$$

$$\therefore \quad I_{sh} = \frac{V}{R_{sh}} \quad \text{--- iv)}$$

From eq^n iii)

$$P_m = VI_L - I_a^2 R_a - \frac{V^2}{R_{sh}^2} \cdot R_{sh}$$

$$P_m = VI_L - I_a^2 R_a - \frac{V^2}{R_{sh}} \quad \text{--- (v)}$$

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or

$$P_m = VI_L - I_a^2 R_a - V \cdot I_{sh} \quad \text{--- vi)}$$

$$P_m = V[I_L - I_{sh}] - I_a^2 R_a$$

$$\therefore P_m = VI_a - I_a^2 R_a$$

$$= I_a[V - I_a R_a]$$

$$P_m = E_b I_a \quad \text{--- vii)}$$

From eq^n ii)

$$V = E_b + I_a R_a$$

Now multiplying above eq^n by 'I_a' both side we get

$$VI_a = E_b I_a + I_a^2 R_a$$

$$VI_a = P_m + I_a^2 R_a \quad \text{--- (8)}$$

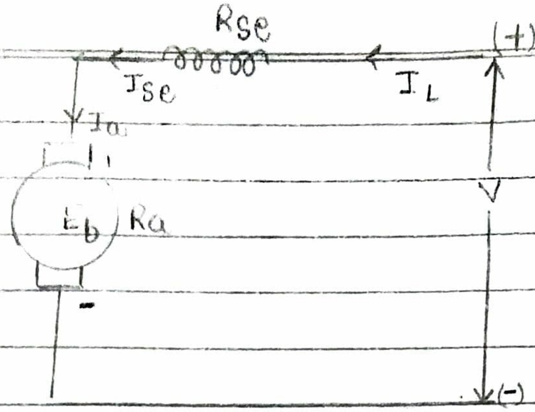
where VI_a = Electrical power supplied to armature of the motor.

Series Motor:

In the series motor the field winding is connected in series with the armature.

$\therefore I_{se}$ = series field current

$$\therefore I_a = I_{se} = I_L \quad \text{--- (1)}$$



Also,

$$V = I_aR_a + E_b + I_{se}R_{se} + \text{drop due to brushes}$$

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

$$V = E_b + I_aR_a + I_aR_{se}$$

$$\boxed{V = E_b + I_a(R_a + R_{se})} \quad \text{——— (2)}$$

Power Equation.

Input power = Mechanical power developed + Losses in armature + losses in field.

$$VI_L = P_m + I_a^2R_a + I_{se}^2R_{se}.$$

$$VI_L = P_m + I_a^2R_a + I_a^2R_{se}.$$

$$\boxed{VI_a = P_m + I_a^2(R_a + R_{se})} \quad \text{——— (3)}$$

Again, from eq^n (2)

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

Multiplying both side by I_a.

$$\boxed{VI_a = E_bI_a + I_a^2(R_a + R_{se})} \quad \text{——— (4)}$$

Comparing eq^n (3) & (4)

$$\boxed{P_m = E_bI_a}.$$

Compound Motor

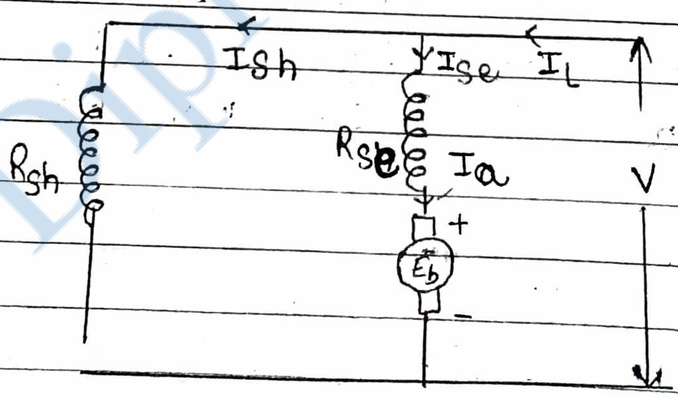
- A DC motor having both shunt and series field windings is called a compound motor. It may be a short shunt compound motor or a long shunt compound motor. By changing connection of a series field winding, motor can be operated in the two modes :-

1. Commulative compound motor and differential compound motor.

→ When series field flux acts in the same direction of shunt field flux, then the motor is called as commulative compound motor.

→ When series field flux opposes the shunt field flux then the motor is called as differential compound motor

(a) Long shunt compound motor



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

$$I_{se} = I_a$$

$$I_L = I_a + I_{sh} \quad \text{——— (1)}$$

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

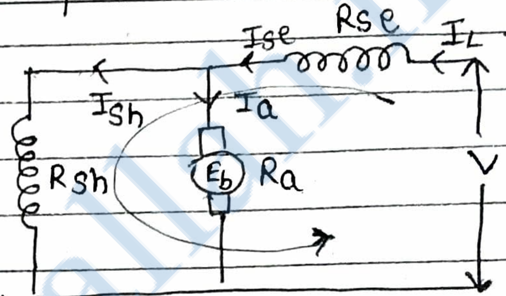
Again,

$V = E_b + I_a R_a + I_{se} R_{se}$ + drop due to brushes

$V = E_b + I_a R_a + I_a R_{se}$ + drop due brushes

$$V = E_b + I_a (R_a + R_{se}) \quad \text{--- (3)}$$

Short Shunt Compound Motor



$I_{se} = I_L$ --- (1)

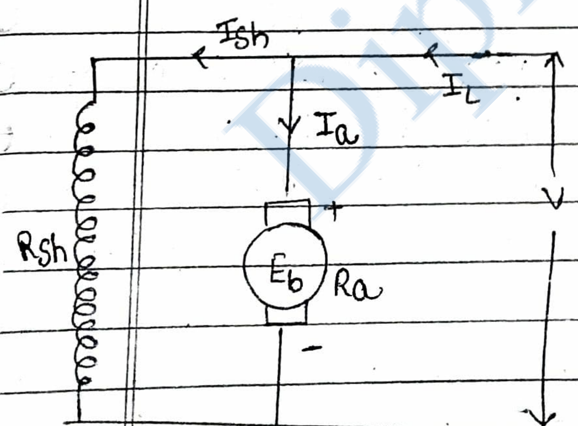
$I_L = I_a + I_{sh}$ --- (2)

$V = E_b + I_a R_a + I_{se} R_{se}$ + drop due to brushes --- (3)

$$I_{sh} = \frac{V - I_{se} R_{se}}{R_{sh}} \quad \text{--- (4)}$$

$$I_{sh} = \frac{E_b + I_a R_a}{R_{sh}}$$

Condition for Maximum Power.



From the ckt,

$V = E_b + I_a R_a$ --- (1)

Multiplying both side of eqn (1) by 'I_a' we get.

$$V I_a = E_b I_a + I_a^2 R_a$$

where, $V I_a$ = electrical power input to arm

$E_b I_a$ = ~~ele~~ mechanical power developed in ar

$I_a^2 R_a$ => copper losses in armature

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$$V I_a = P_m + I_a^2 R_a$$

$$\boxed{P_m = V I_a - I_a^2 R_a} \quad \text{—— (2)}$$

Differentiating eq^n (2) with respect to 'I_a' and equating the result to zero we get.

$$\frac{dP_m}{dI_a} = 0$$

$$\frac{d}{dI_a}\left[V I_a - I_a^2 R_a\right] = 0$$

$$V - 2 I_a R_a = 0$$

$$V = 2 I_a R_a$$

$$\boxed{I_a R_a = \frac{V}{2}} \quad \text{—— (3)}$$

From eq^n (1)

$$V = E_b + \frac{V}{2}$$

$$E_b = V - \frac{V}{2}$$

$$\boxed{E_b = \frac{V}{2}} \quad \text{—— (4)}$$

Thus, gross mechanical power developed by a motor is maximum when back emf is equal to half the applied voltage. This condition is however not realized in pratices because in that case current would be much beyond the normal current of the motor. Moreover half the input would be wastage in the form of heat & taking other losses (mechanical & magnetic losses) into consideration

The motor efficiency will be well below 50%

i.e $\eta \leq 50\%$

Shaft Torque / Useful Torque.

The torque, which is available for doing useful work, is known as shaft torque. It is so called because it is available at the shaft.

The motor output is given by —

$\therefore$ output = $T_{sh} \times 2\pi n$ watt

$T_{sh} = \frac{\text{output in watt}}{2\pi n}$ ($\because n$ = speed in rps.)

$$T_{sh} = \frac{\text{output in watt}}{\frac{2\pi N}{60}}$$

where N = speed in rpm $\therefore n = \frac{N}{60}$

Also,

$$T_a = 0.159\, \frac{Z\phi P}{A} I_a$$

$$T_{sh} = 9.55\, \frac{\text{output in watt}}{N}$$

The difference $T_a - T_{sh}$ is known as Loss Torque and is due to iron and friction losses of the motor.

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Note: • The torque which is available at break drum is called as shaft torque or useful torque.

- At no load condition shaft torque is zero since, no mechanical output is obtained but armature torque is not zero. Since, the rotor rotating required some torque.

- T_A is greater than T_{sh} ($T_A > T_{sh}$).

Speed Of A DC Machine

From the voltage equation of a DC motor, we get

$$E_b = V - I_a R_a$$

$$\because \quad E_b = \frac{PNZ\phi}{60A}$$

$$\therefore \quad \frac{PNZ\phi}{60A} = V - I_a R_a$$

$$N = \frac{60A\,(V - I_a R_a)}{PZ\phi}$$

$$N = \frac{60A}{PZ}\left(\frac{E_b}{\phi}\right)$$

$$\boxed{N = k\,\frac{E_b}{\phi}}$$

where, $k = \frac{60A}{PZ}$ = a constant

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

It shows that speed is directly proportional to back emf and inversely to the flux ϕ

For Series Motor.

Let N_1 = speed in the first case

I_{a1} = armature current in the first case

ϕ_1 = flux per pole in the first case

N_2, I_{a2}, ϕ_2 = corresponding quantities in the second case.

Using the relation we get $N_1 \propto \frac{E_{b1}}{\phi_1}$

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where $E_{b1} = V - I_{a1}R_a$.

Similarly

$N_2 \propto \frac{E_{b2}}{\phi_2}$ where $E_{b2} = V - I_{a2}R_a$

From the above we can write

$$\boxed{\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{\phi_2}{\phi_1}}$$

Unsaturation region

Prior to saturation of magnetic poles

$\phi \propto I_a$

$$\boxed{\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{I_{a2}}{I_{a1}}} \quad \left(\because N \propto \frac{E_b}{I_a}\right)$$

Saturation region:

ϕ = constant

$$\therefore \boxed{\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}} \quad (N \propto E_b)$$

- **For Shunt motor**

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

If V = constant, R_{sh} = constant

I_{sh} = constant, ϕ = constant

$\therefore N \propto E_b$.

i.e, $$\boxed{\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} = \frac{V - I_{a1}R_a}{V - I_{a2}R_a}}$$

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Torque Of a DC machine.

We know that torque

$$T \propto \phi I_a$$

For shunt motor

$$\phi = \text{constant}$$

$$T \propto I_a$$

$$\frac{T_1}{T_2} = \frac{I_{a1}}{I_{a2}}$$

★ For series motor

★ Unsaturation, $\phi \propto I_a$

$$T \propto I_a^2$$

$$\frac{T_1}{T_2} = \left(\frac{I_{a1}}{I_{a2}}\right)^2$$

★ Saturation

$$\phi = \text{constant}$$

$$T \propto I_a$$

$$\frac{T_1}{T_2} = \frac{I_{a1}}{I_{a2}}$$

Speed Regulation

The speed regulation is defin[ed] as the change in speed from no load to full load expressed as a fraction or a % of the full load speed. It can be written as per unit speed regulation.

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$$\text{Per unit speed regulation} = \frac{N_{nl} - N_{fl}}{N_{fl}}$$

$$\% \text{ Speed Regulation} = \frac{N_{nl} - N_{fl}}{N_{fl}} \times 100$$

where N_{nl} = no load speed
N_{fl} = full load speed.

Note: A motor which has nearly constant speed is said to have a good speed regulation.

Motor Characteristics

The characteristics curve of a motor are those curves which shows relationship between the following quantities —

1. Torque and armature current. (T_a / I_a)
   It is known as electrical characteristics
2. Speed and armature current (N / I_a)
3. Speed and torque characteristics &
   It is known as mechanical characteristics

While discussing motor characteristics the following two relation should always be kept in mind.

$$T \propto \phi I_a$$

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

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A(a) Characteristics Of Series Motor :-

a) Torque and Armature current characteristic

We know that, $T_a \propto \phi I_a$

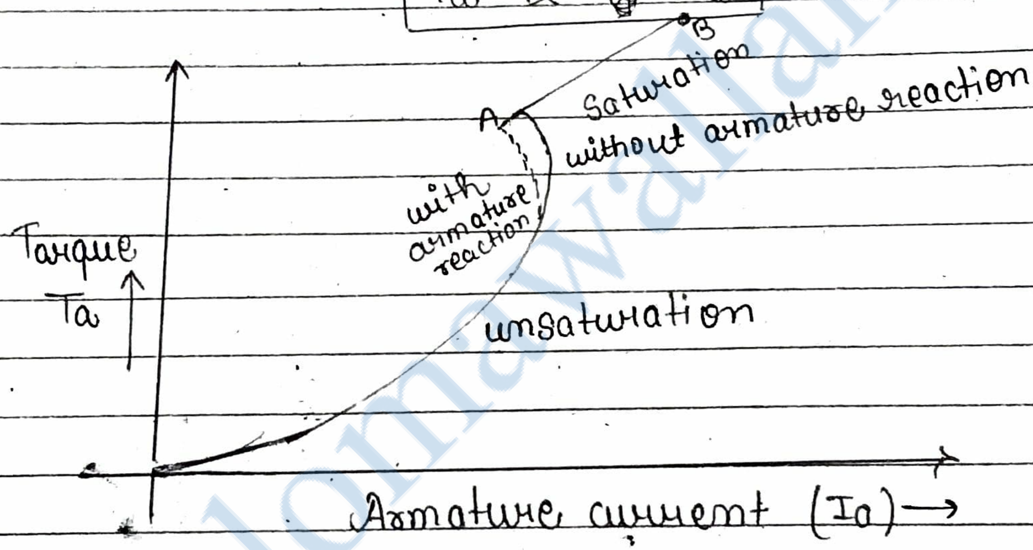
* Unsaturation, $\phi \propto I_a$

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

Load ↑ I_a ↑ I_{se} ↑ ϕ ↑

* Saturation, ϕ = constant

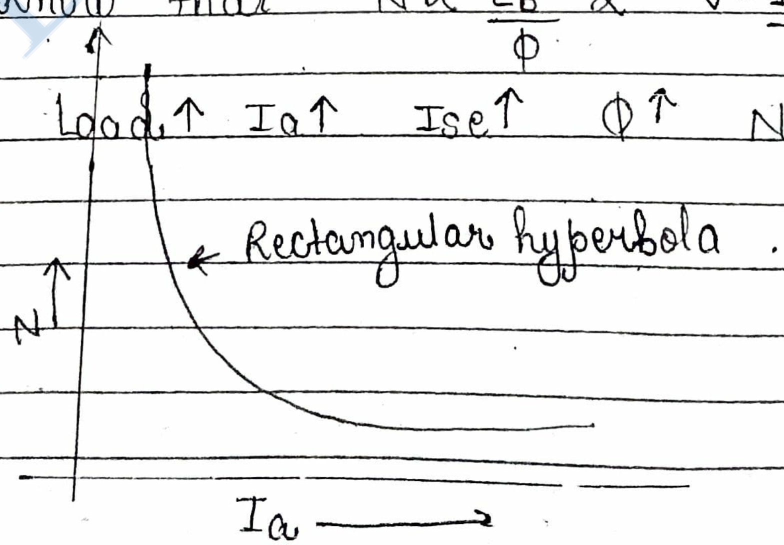
$$\boxed{T_a \propto I_a}$$



b) Speed and armature current characteristics (N

We know that $N \propto \frac{E_b}{\phi} \propto \frac{V - I_a(R_a + R_{se})}{\phi}$

Load ↑ I_a ↑ I_{se} ↑ ϕ ↑ N ↓



Series motor cannot be start at no load. Since, at no load, series field flux is very small and thereby the speed is very (dangerously) high. In practical system, series motor is always started with load.

c) Speed and Torque characteristics.

$$T_a \propto \phi I_a$$

★ Unsaturation

$$\phi \propto I_a$$

$$T_a \propto I_a^2$$

$$T_a = k I_a^2$$

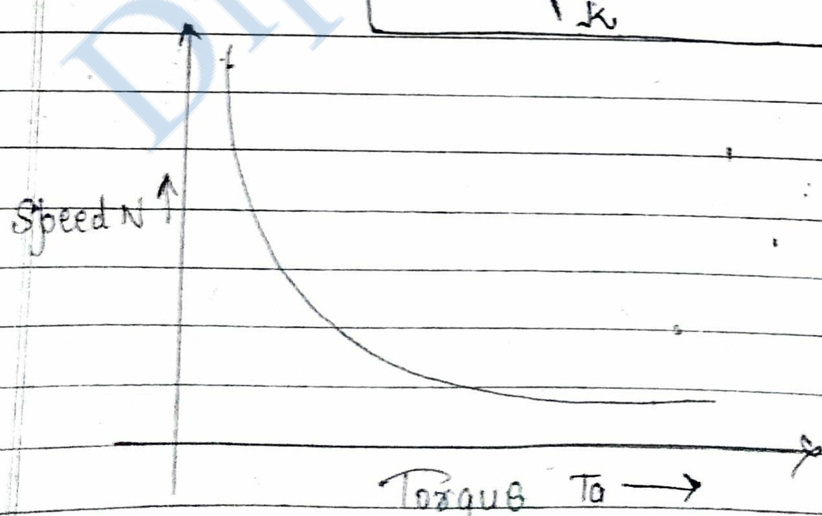
$$I_a = \sqrt{\frac{T_a}{k}} \quad \text{--- (1)}$$

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a(R_a + R_{se})}{\phi}$$

$$N \propto \frac{V}{I_a} - \frac{I_a(R_a + R_{se})}{I_a}$$

$$\boxed{N \propto \frac{V}{I_a} - (R_a + R_{se})}$$

$$\therefore \boxed{N \propto \frac{V}{\sqrt{\frac{I_a}{k}}} - (R_a + R_{se})}$$



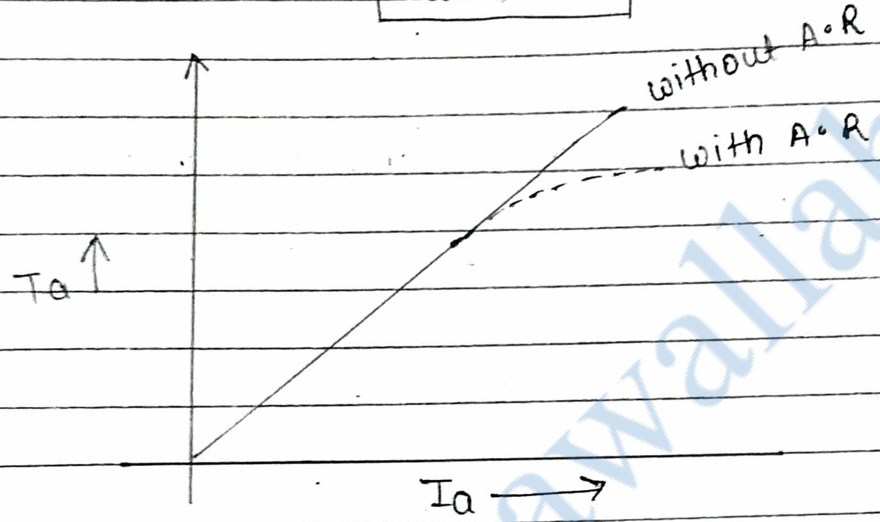
Characteristics Of Shunt Motor.

* Torque and armature current characteristic

Assuming 'ϕ' to be pratically constant.

$$T_a \propto \phi I_a$$

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

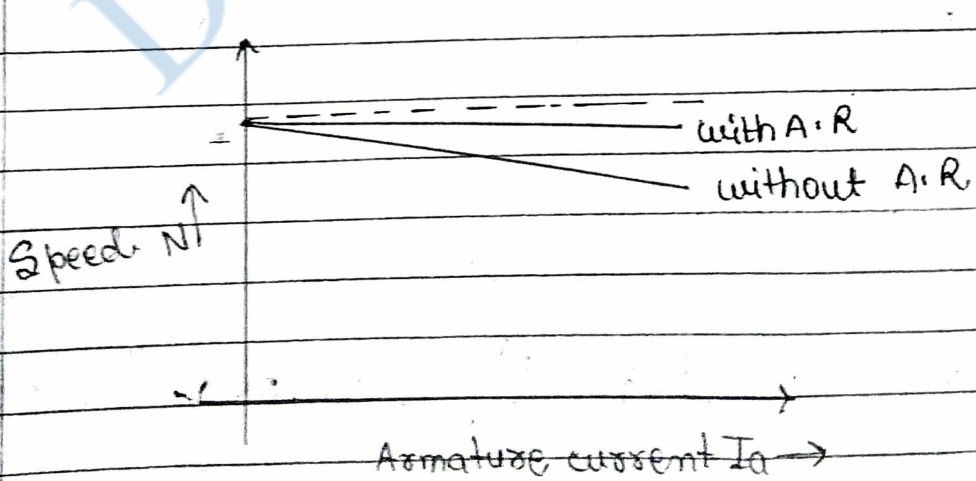


* Speed and armature current characteristic

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$$

Load ↑ I_a ↑ $I_a R_a$ ↑ $(V - I_a R_a)$ ↓ E_b ↓ N ↓

I_a ↑ N ↓



The variation of the speed of shunt motor from no load to full load is very less approximately 5 to 10 % of rated speed. So, this motor is also called as constant speed motor.

* Speed Torque characteristics (N/Ta)

$T_a \propto \phi I_a$

ϕ = constant (in shunt motor)

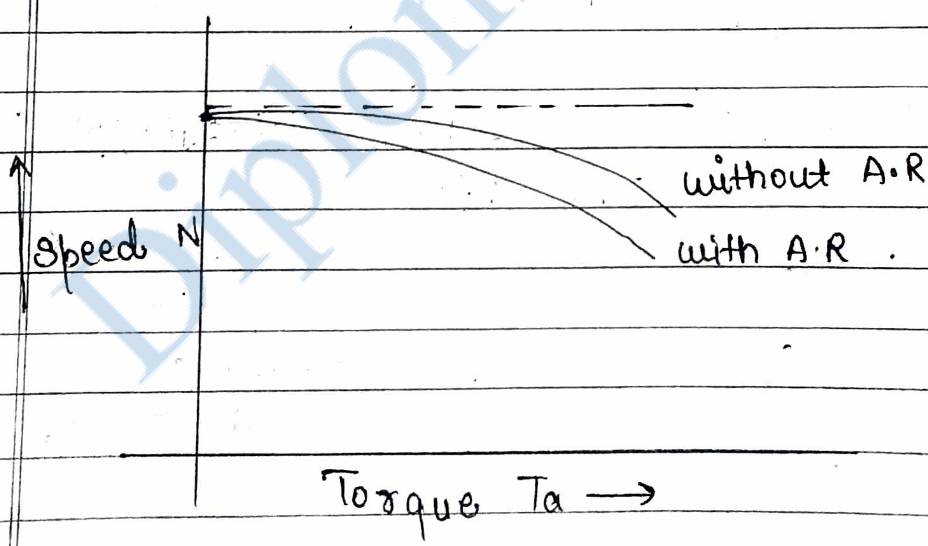
$T_a \propto I_a$

$$T_a = k I_a \quad \text{--- (1)}$$

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$$

$N \propto V - I_a R_a$

$$N \propto \left(V - \frac{T_a}{k} R_a\right) \quad \text{--- (2)}$$



Characteristics Of Compound Motor.

These motor have both series & shunt winding

If series excitation helps the shunt excitation i.e series flux is in the same direction, then the motor is said to be commulative compound.

If on the other hand series field oppose the shunt field then the motor is said to be differential compounded.

The chacteristics of such motor lies between those of series & shunt motor.

Combined Characteristics.

Torque and armature current characteristics

$T_a \propto \phi I_a$

Cummulative compound.

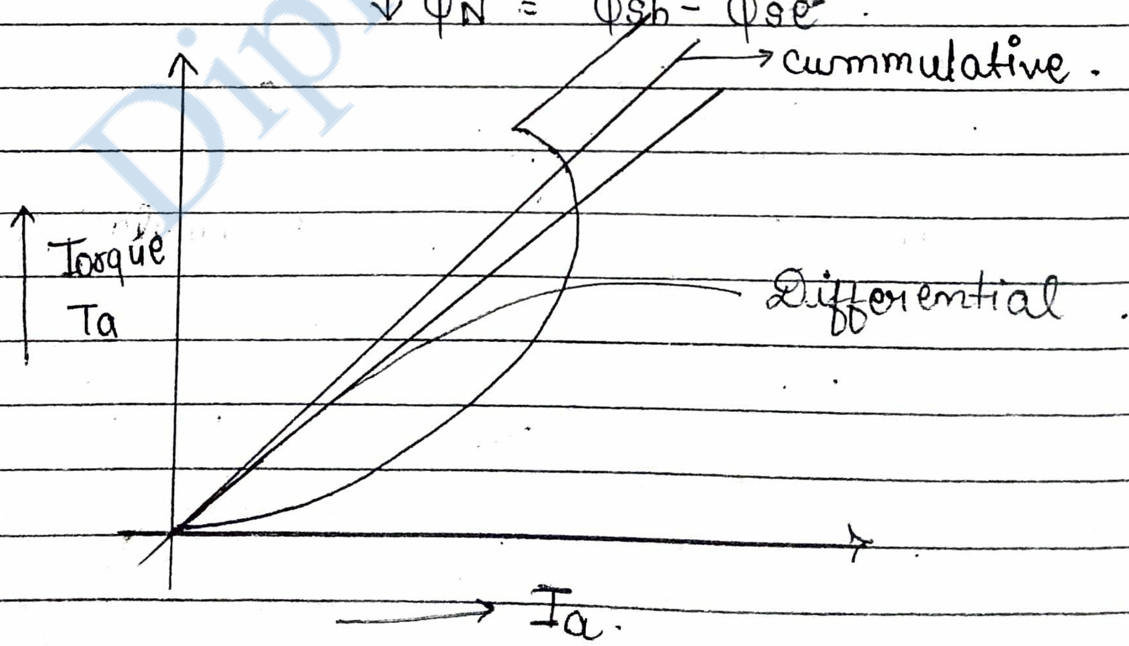
Load ↑ I_a ↑ I_{se} ↑ ϕ_{se} ↑

↑ $\phi_N = \phi_{sh} + \phi_{se}$.

Differential compound.

Load ↑ I_a ↑ I_{se} ↑ ϕ_{se} ↑

↓ $\phi_N = \phi_{sh} - \phi_{se}$.



→ Strength of the series field flux of the series motor is higher then the strength of the series field flux of the compound motor

→ Any characteristics of cummulative compound motor is lies between shunt and series motor characteristics.

★ Speed and armature current Characteristics. (N/Ia)

In compound motor (at rated condition)

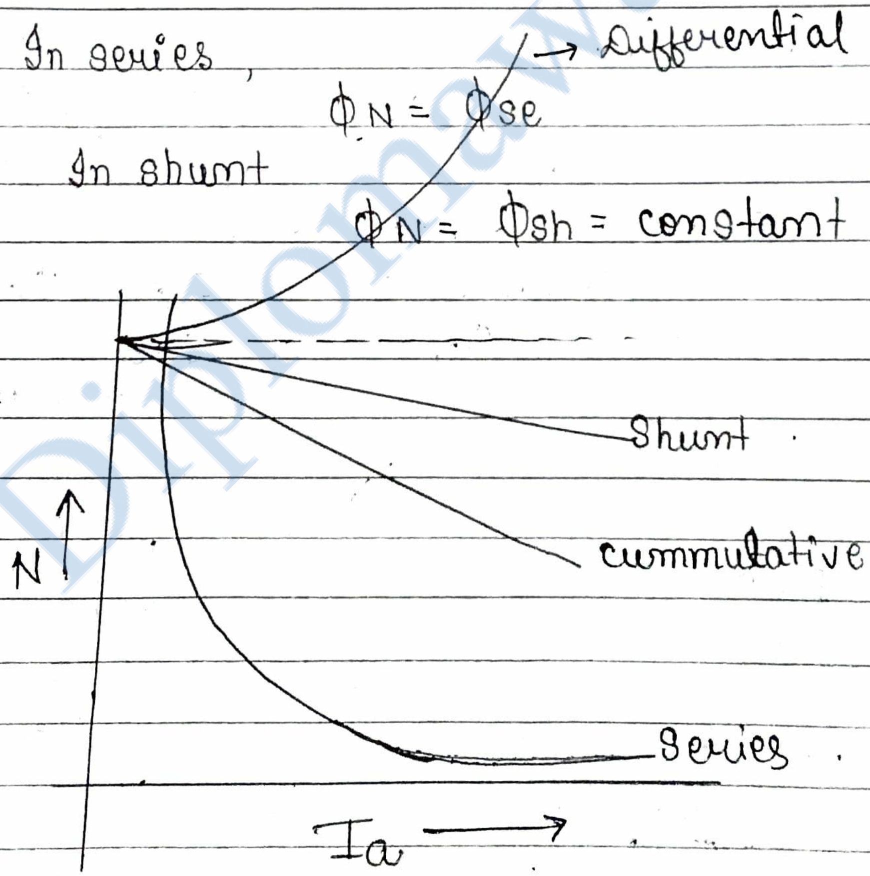
$$\phi_N \rightarrow \begin{cases} \phi_{sh} \ (80\%) \\ \phi_{se} \ (20\%) \end{cases}$$

In series,

$\phi_N = \phi_{se}$

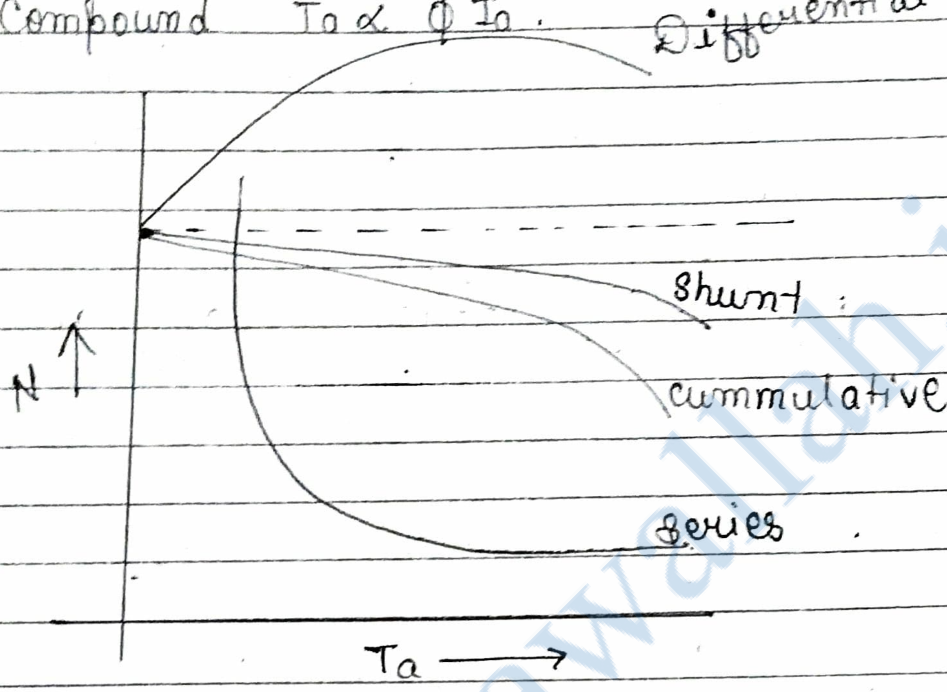
In shunt

$\phi_N = \phi_{sh} = \text{constant}$.



★ Speed and Torque Characteristics :–

Shunt , $T \propto I_a$.
Series , $T_a \propto I_a^2$.
Compound $T_a \propto \phi I_a$.



Speed Control Of DC Motor.

The speed of a DC motor is given by the relation.

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

$$N \propto \frac{V - I_a R_a}{\phi} \quad \text{——— i)}$$

Equation (i) shows that the speed is dependent upon the supply voltage V, the armature ck resistance Ra and the field flux ϕ which is produced by the field current. In practise the variation of these three factors is used for speed control. Thus, there are three general methods of speed control of DC motor

1. Variation of resistances in the armature ckt.
This method is called armature resistance control or rheostatic control.

2. Variation of field flux ϕ (This method is called field control method or flux control method.

3. Variation of applied voltage / armature voltage
This method is called voltage control method or armature voltage control

1. Armature resistance Control

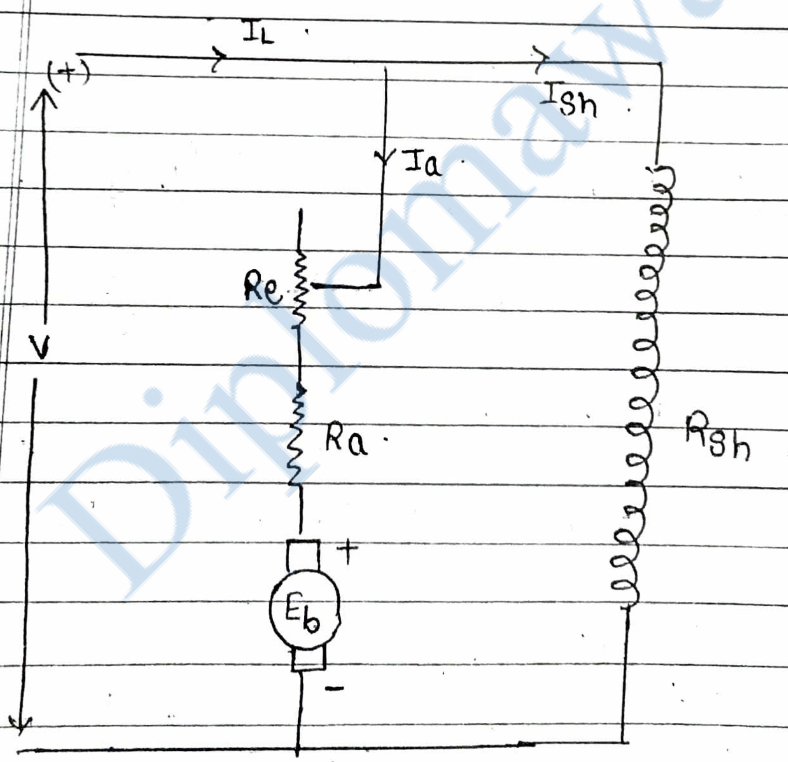
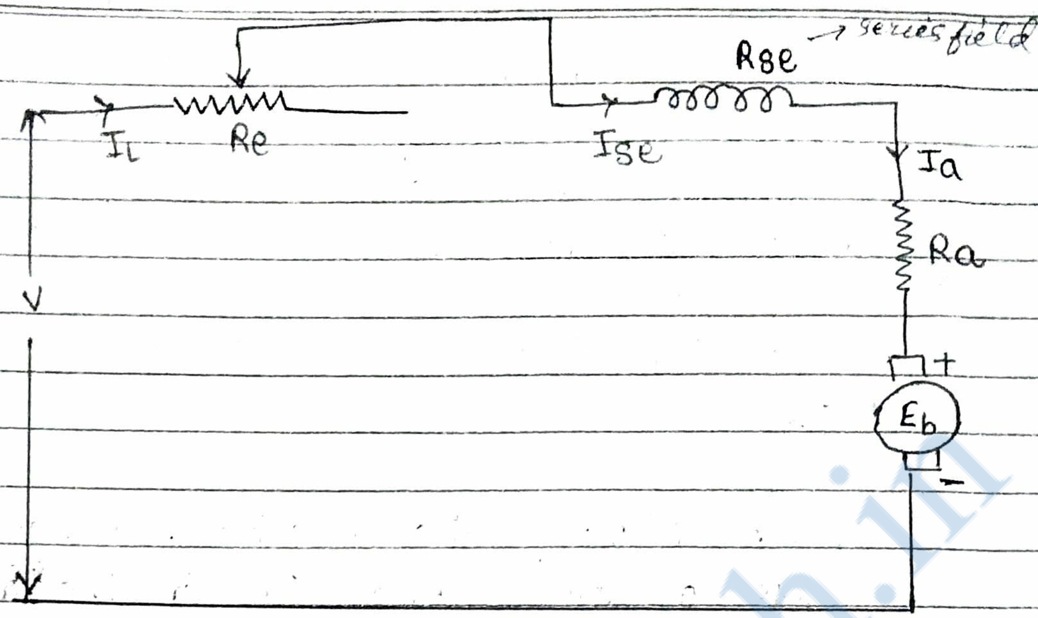


fig (a) speed control of dc shunt motor by armature resistance control



Fig(b) speed control of DC series motor by armature resistance control.

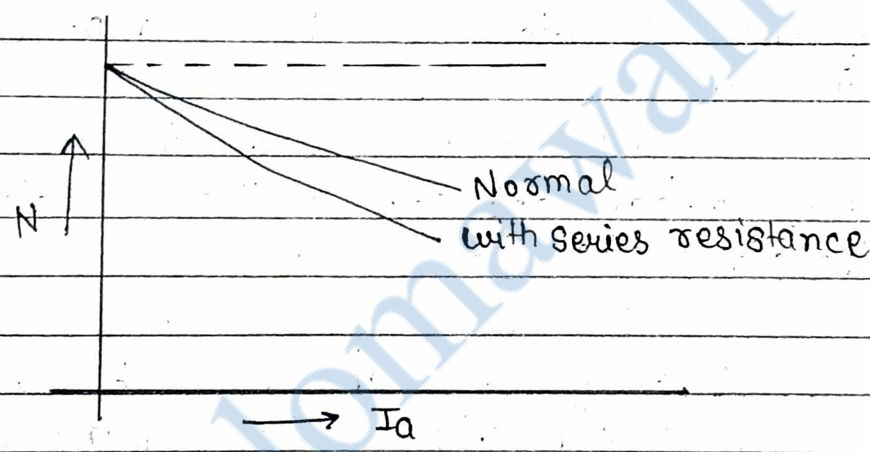


fig (c): speed / current characteristics of DC shunt motor.

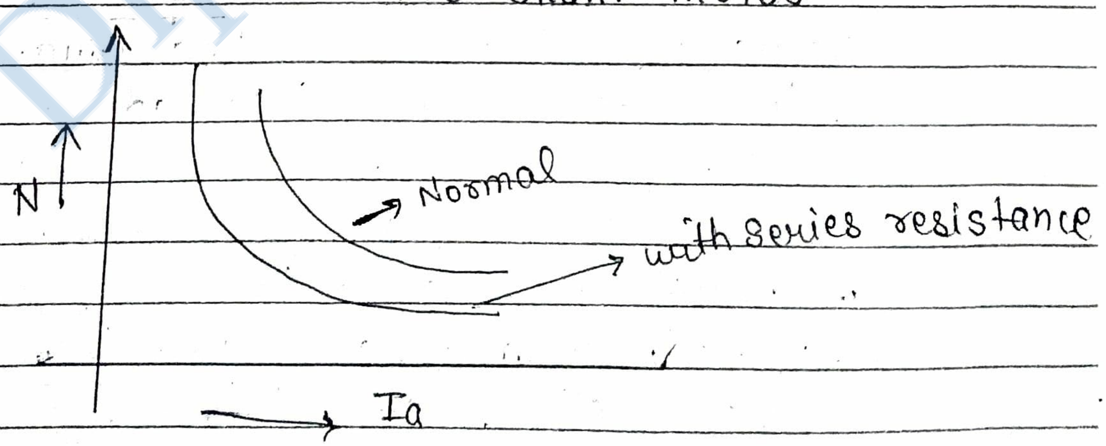


Fig (d) speed current characteristics of DC series motor.

In this method a variable series resistance Re is put in the armature circuit. Figure A shows the method of connection for a shunt motor. In this case, the field is directly connected across the supply and therefore the flux ϕ is not affected by variation in Re.

Fig (B) shows the method of connection of external resistance Re in the armature circuit of a DC series motor. In this case the current and flux are affected by the variation of the armature circuit resistance.

The voltage drop in Re reduces the voltage applied to the armature and therefore the speed is reduced.

$N \propto \frac{1}{Re}$

Fig (c) and fig (D) shows typical speed current characteristics for shunt & series motor respectively. In both the cases, the motor runs at a lower speed as the value of Re is increased and only below rated speed are obtained while torque is constant.

Since, Re carries full armature current it must be design to carry continously the full armature current.

This method suffers from following drawback

i) A large amount of power is wastage in the external resistance Re.

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ii) Control is limited to give speed below normal and increase of speed cannot be obtaine by this method.

iii) For a given value of Re the speed reducti is not constant but varies with motor loa

iv) Efficiency value is varies for every variatio of external resistance (output is variable)

v) Cost of the system is high.

vi) When external resistance is constant if the moto is operated from no load to full load bad regulation is obtained.

vii) This method is only used for small moto

Fig (a) For shunt motor.

$R_{se}\uparrow$ $R_a + R_{se}\uparrow$ $I_a\downarrow$ $T \propto I_a\downarrow$

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

$$E_b = V - I_a(R_a + R_e)\uparrow$$

$$\therefore \downarrow N \propto \frac{\downarrow E_b}{\phi} = \frac{V - I_a(R_a + R_e)\uparrow}{\phi}$$

Now, (load ↑ Re constant)

$$I_a = \frac{V - E_b\downarrow}{R_a + R_e}$$ here $E_b\downarrow$ $V - E_b\uparrow$

$V - E_b\uparrow$ then $I_a\uparrow$

$\uparrow T \propto I_a\uparrow$

$\therefore T =$ constant.

Fig (B).

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

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

$R_e\uparrow$ $I_a(R_a + R_{se} + R_e)$

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

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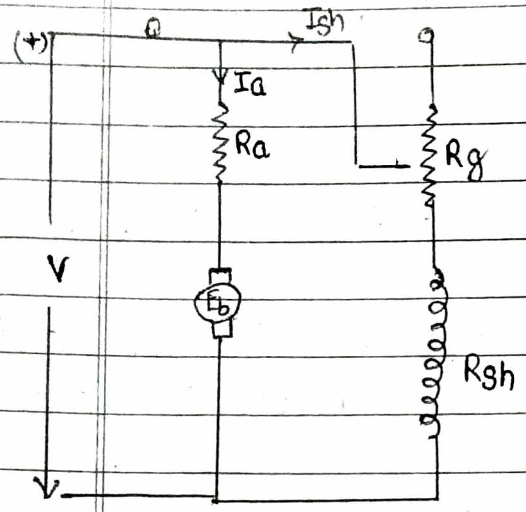
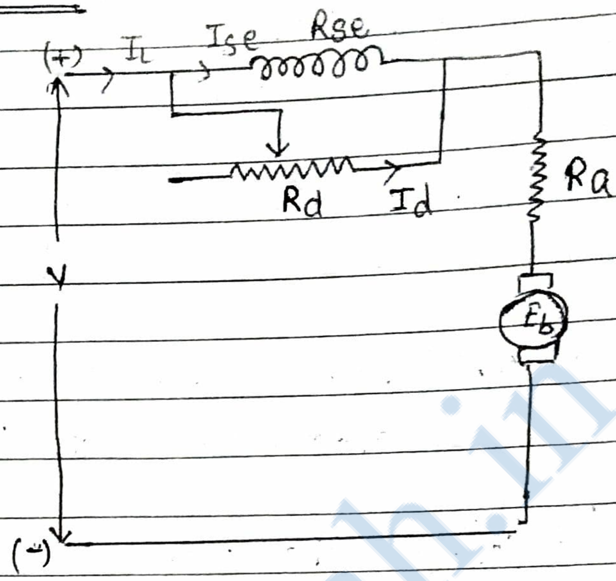
7(b) Field flux Control



Fig(a) speed control of dc shunt motor by variation of field flux.



Fig(b) speed control of dc series motor by variation of field flux (diverter in parallel)

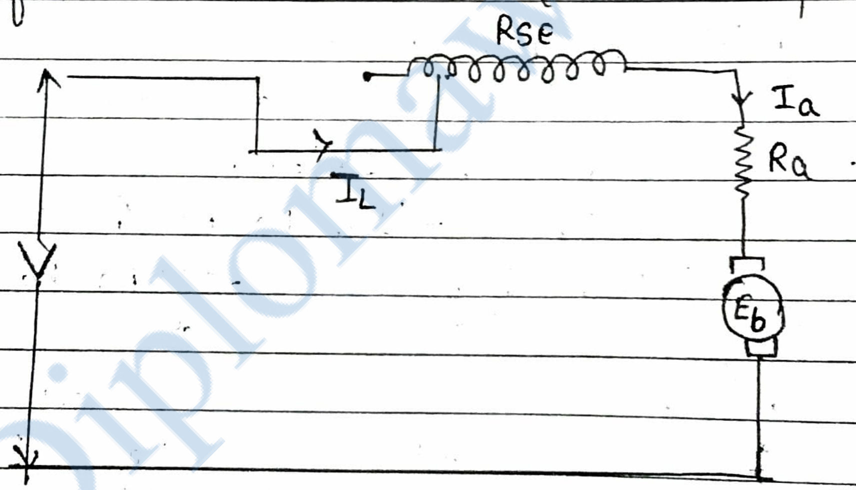


Fig (c) Speed control of dc series motor by tapped field control.

Since, the flux is produced by the field current. Control of speed by this method is obtained by control of the field ~~current~~. In the shunt motor this is done by connecting a variable resistor R_g in series with the

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shunt fielding winding as shown if fig a.
The resistor Rg is called the shunt field regulat
The shunt field current is given by

$$I_{sh} = \frac{V}{R_{sh} + R_g \uparrow}$$

$$I_{sh} \downarrow \quad \phi \downarrow \quad N \uparrow$$

$$N \propto \frac{1}{\phi}$$

The connection of Rg in the field reduces the field current & hence, flux ϕ is also reduced The reduction in flux ϕ will result in an incr e in the speed. Thus, the motors runs at a speed higher than the normal speed. For this reason, this method of speed control i used to give motor speeds above normal o to correct for a fall in speed due to loa

The variation of field current in a series motor is done by any one of the followi method.

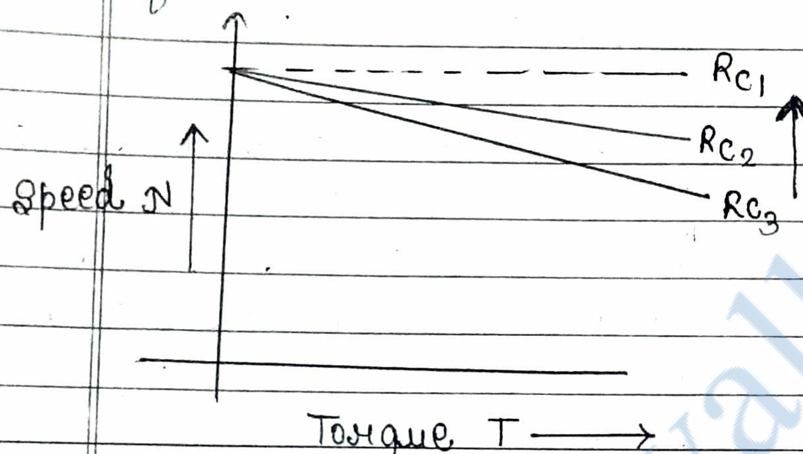
i) A variable resistance R_D is connected in ||r with series field winding as shown in fig(b)
The parallel resistor is called the divertor A portion of the main current is diverted through R_D. Thus, divertor reduces the current flowing through the field winding. This reduce the flux & increases the speed.

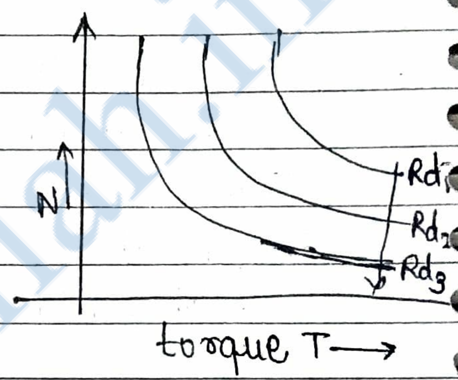
$$I_{se} \downarrow \quad \phi_{se} \downarrow \quad N \uparrow$$

ii) The second method uses a tapped field control as shown in fig (c).

Here the ampere turns are varied by varying the numbers of field turns. This arrangement is used in electric traction.

Fig d and (e) shows the typical speed torque curve for shunt and series motor respectively whose speed are control by the variation of the field flux.





Fig(d) speed / Torque curve for shunt motor.

$\therefore Rc_1 > Rc_2 > Rc_3$.

Fig(e): Speed torque curve for series motor

$Rd_3 > Rd_2 > Rd_1$

The advantage of field control are as follows:

This method is easy and convinent.

Since, shunt field current Ish ↓ is very small low, the power loss in shunt field is small

→ The efficiency of regulation of the machine is not affected much.

→ In this method motor speed above normal speed can be obtained.

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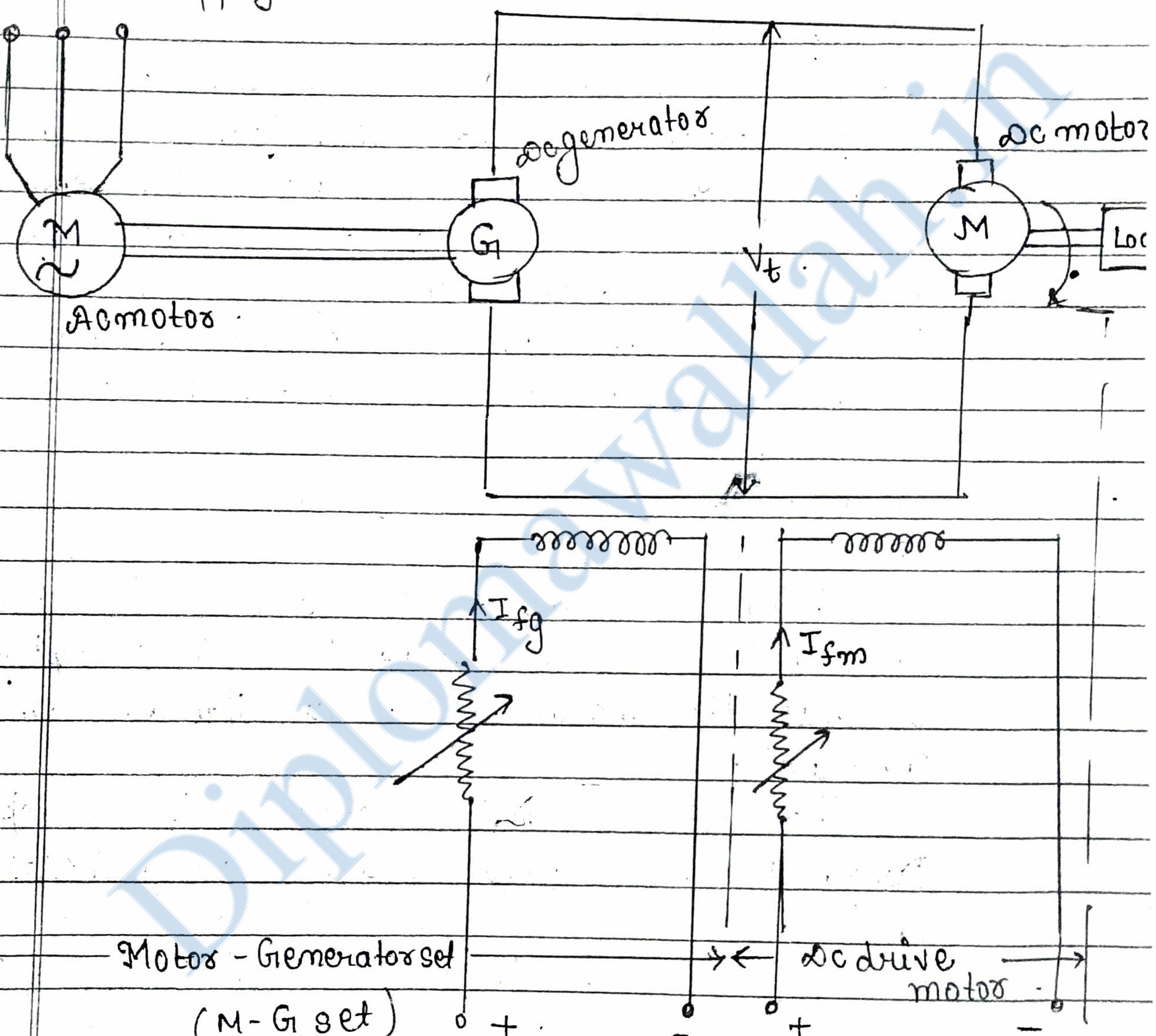
Aramature Voltage Control or Ward Leonard Method.

Fig (a) schematic diagram of ward leonard method



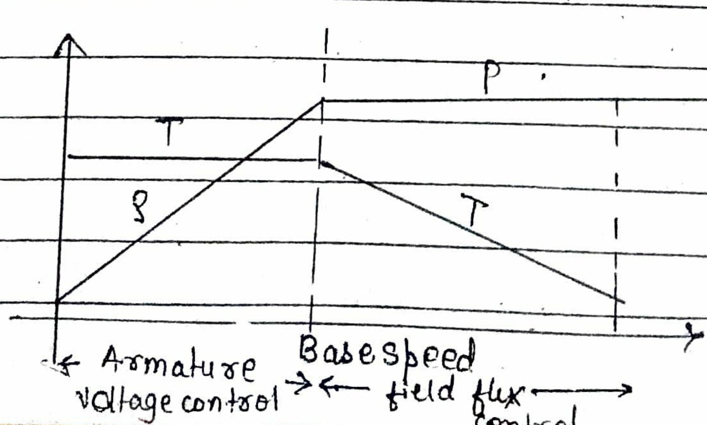


Fig (b) : Torque & power char. is combined for armature voltage & ~~voltag~~ field control

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Speed control of DC motor can also be obtained by varrying the applied voltage to the armature Ward Leonard system of speed control is based on this principle.

The schematic diagram of the ward Leonard method of speed control of DC shunt motor is shown if fig.

→ In this system M is the main DC motor whose speed is to be controlled & G is the separately excited DC generator. The Generator G is driven by a 3ϕ Driving motor; which may be an induction motor or a sychronous motor. The combination of AC driving motor and DC generator is called the (M-G set). By chaging the generator field current, the generated voltage is changed. This voltage when applied directly to the armature of the main DC motor 'M' change its speed. The motor field current I_{fm} is kept constant so that the motor field flux ϕ_m also remain Constant.

The motor armature current I_a is kept equal to the rated value during the speed control. The generotor field current I_{fg} is varied such that the armature voltage V_t changes from 0 to its rated value. The speed will change from 0 to its base speed.

Since, speed control is carried out with rated current & with constant motor field flux ϕ_m, a constant torque $T \propto \phi_m I_a$

upto base speed is obtained. Since the power is proportional to speed (P = Torque × speed). It increases with speed hence, the armature voltage control method constant torque & variable power drive is obtain for speed below the base speed. This is shown in figure.

For speed control above base speed, field flux control is used. In this mode of operation the armature current I_a is maintained constant at its rated value & the generator voltage V_t is kept constant. The motor field current I_{fm} is decreased, therefore flux ϕm is decreased. Thus, the field is weakens to obtained higher speed. Since, V & I_A remains constant or EI_a remain constant so power is constant. The torque is directly proportional to ϕm. It decreases as $\phi m \downarrow$ decreases. Therefore, the torque decreases as the speed increase. Thus, in the field control mode, on variable torque is obtained for speed above base speed.

Starter.

Starter is a device to start and accelerate a motor. The main function/purpose of a starter is to limit the starting current. The armature current of [illegible] motor is given by $I_a = \frac{V - E_b}{R_a}$. When a motor is first switched the armature is stationary. So the back emf is zero i.e. $E_b = 0$ $I_{as} = \frac{V}{R_a}$. $R_a < 1\Omega$

Since, the armature resistances of a motor is very small generally less than 1 Ω therefore the starting armature current I_{a} is very large. This large current could damage the brushes, commutator and windings.

As the motor speed increases the back emf increases & the difference $V - E_b$ goes on decreasing. This results in decrease in I_a until the motor attains its stable speed and corresponding back emf.

Since, the starting current is very large, at the time of starting of all DC motor an extra resistance must be connected in series with the armature. This will limit the initial current to a safe value until the motor has built up stable speed and back emf.

5(a) 3- Point Starter.

Fig show a 3-point starter. It consist of a graded resistance $R_1 = R_1 + R_2 + R_3 + R_4$ to limit the starting current. Prior to starting the handle 'h' is kept in the off position by a spring S.

For starting the motor, the handle H is moved manually and when its makes contact with the resistance stud 1. It is in the starting positing. In this position, the field winding receives

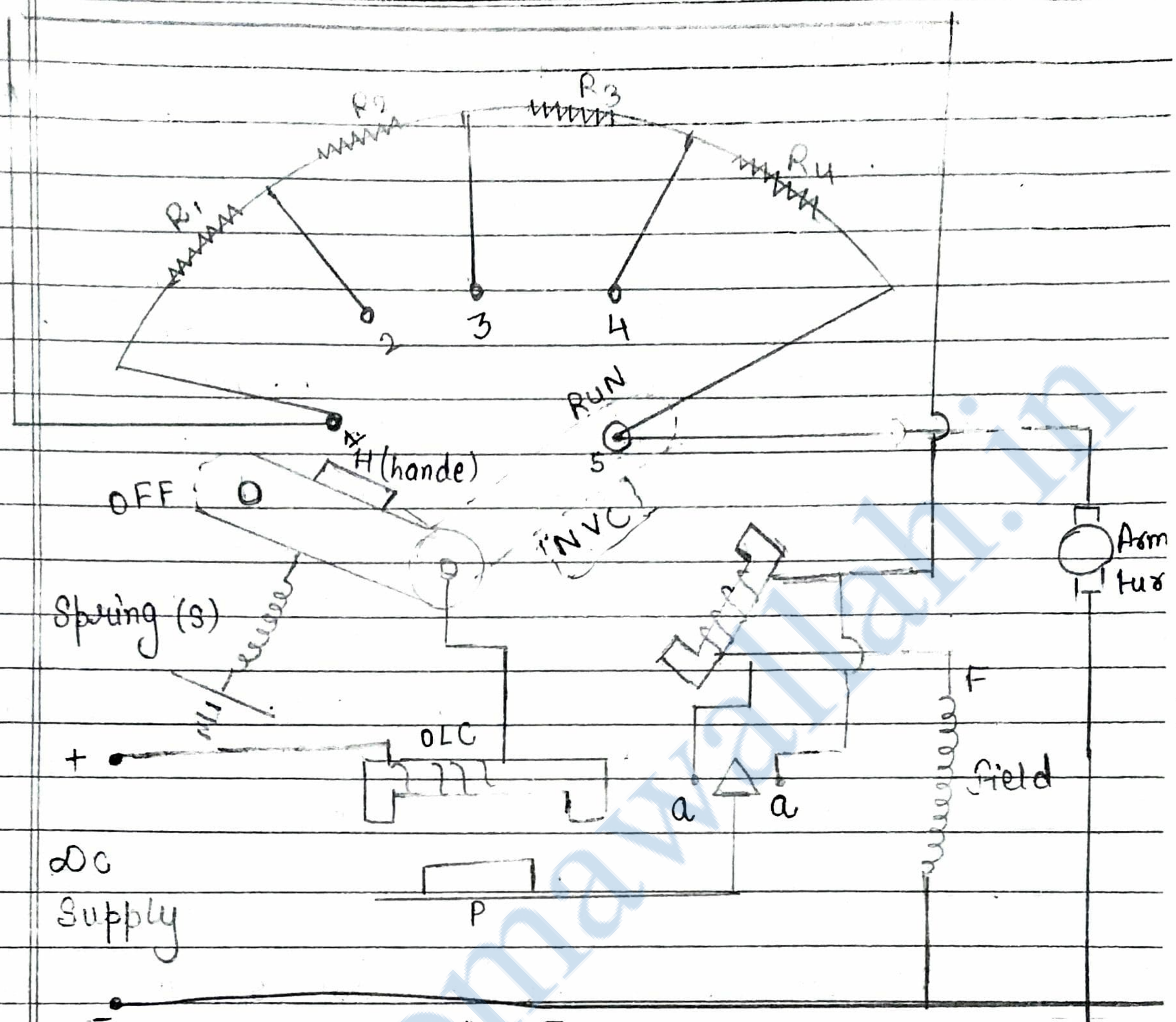

Fig : 3-point starter

the full supply voltage but the armature curr is limited by the graded resistance 'R'. The starter handle is then gradually moved from stud to stud allowing the speed of the moto to build up until it reaches the run positi

In this position, the motor attains full speed The resistance 'R' is completely cut off & th supply is directly connected across both the winding of the motor.

The hande 'H' is held in run position b an electromagnetic energised by an NVC (no voltag trip coil). The NVC is connected in series wi the field winding of the motor - In the event of switching off or when the supply falls below a predetermined value or a complete failure of supply, NVC is deenergized. This result in the release of the handle which is then pulled back to off position by the action of the spring.

Overload protection is provided by the OLC (overload tip coil) and the NVC. The overload tip coil is a small electromagnet. It carries the armature current and for normal values of armature current, the magnetic pull of OLC is insufficient to attract the strip P. When the armature current exceeds the normal rated value P is attracted by the OLC and closes the contact 'a'a'. Thus, NVC is short ckted. This results in the release of the handle H which returns to the off position and the motor supply is cut off.

Uses Of DC Motor :

For constant speed drive application shunt motor is used.

1. Fans, air circulator, centrifugal pump, hydrolic pump, Leath machine, blowers, paper
2. machine, printing maching, drilling machine, milling machine.

4.(a) ~~Speed~~ Series motor can be used as constant power drive.

(1) Locomotive, Crane, Lift, hoist, traction system, conveyers, trolley cars, trolley bus, diesel electric locomotive.

Cummulative Compound

Elevator, Rolling mills, punches, shears, planers

Differential Compound.

~~Shears~~ The speed of this motor will increase with the increase in load, which leads to an unstable operation. Therefore, we cannot use this motor for any practical application