

Unit-3. Starting, Speed control & Testing of D.C. Machines

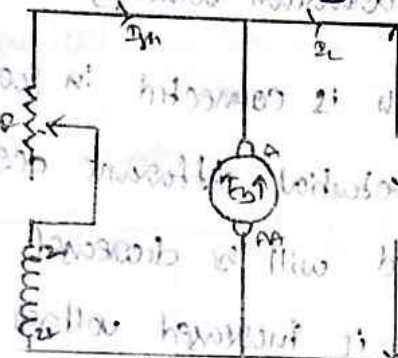
Speed control of D.C. motor:

* The Speed can be controlled by two methods

- Field (or) Flux control method.
- Voltage or armature control method.

Field (or) Flux control method:

* A variable resistor called a field regulator is connected in series with the field winding as shown in below fig.



* When the field resistance is increased, the current passing through field winding decreases so the flux produced by the field is decreased. The induced emf is also decreased. In case, more current flows to the armature circuit. This method of speed control is used for speeds obtained above the rated speed and it is applicable only for shunt & compound motor.

* The speed of D.C. motor is given by relationship

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

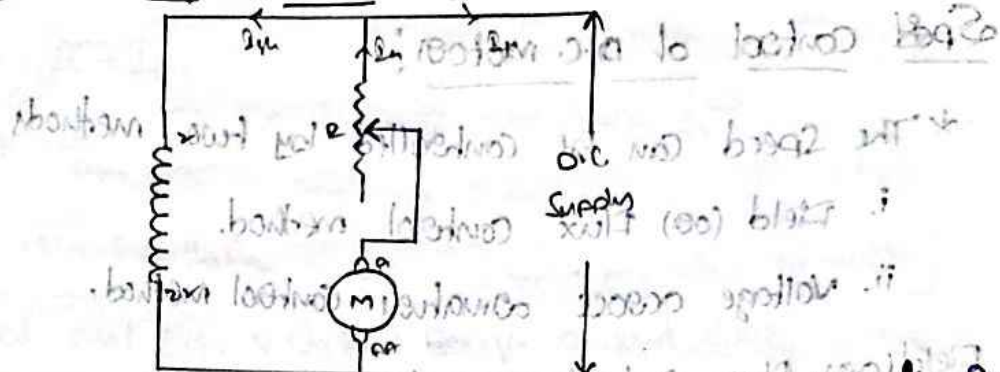
$$N \propto \frac{E_b}{\phi}$$

$$N_1 \propto \frac{E_{b1}}{\phi_1}$$

$$N_2 \propto \frac{E_{b2}}{\phi_2}$$

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

Armature Voltage Control Method



* This method of Speed control is used when the speed required above the normal speed. A variable resistor is connected in series with the normal armature winding as shown in fig.

* The resistance which is connected in series with the armature is increased the potential difference across the armature is decreased so the speed will be decreased.

* If the resistance is increased voltage drop increases, decreases in back emf and field current in the increasing this result is fall of motor speed.

* This method of speed control is used for speed control as it is an efficient and losses involved are less.

Let E_{b1} Back emf at no load

E_{b2} Back emf at full load

I_a load current

I_{a1} Armature current at no load

I_{a2} Armature current at full load

V Supply voltage

R_a Armature resistance

R_{se} series field resistance

N_1 Speed of motor at No-load

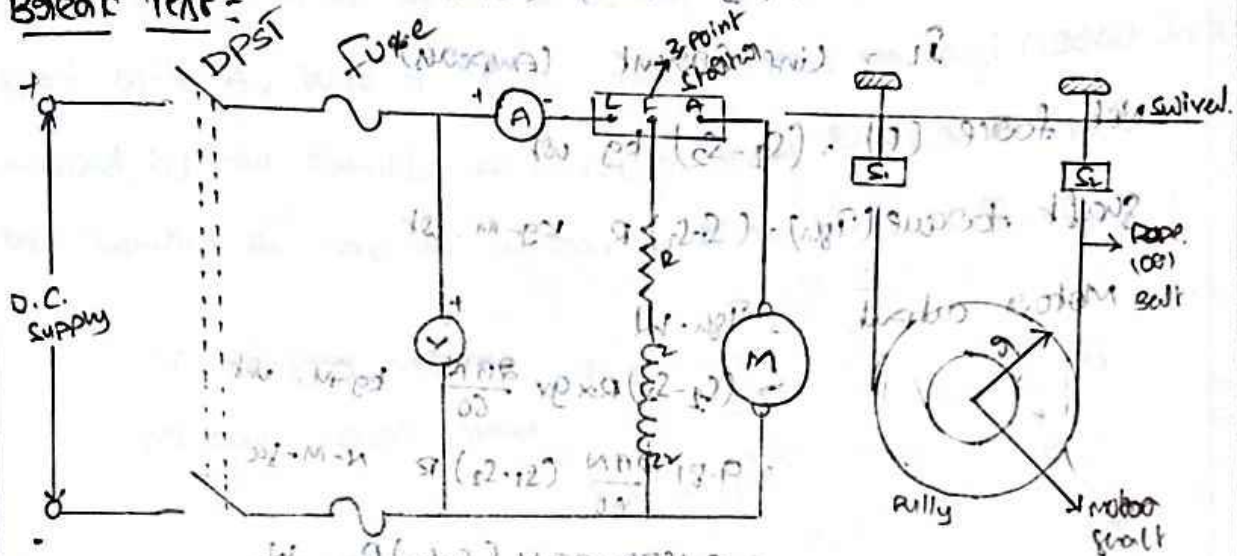
N_2 Speed of motor at full-load

Testing of D.C. Machines :

* D.C. machines can be tested by three different methods namely direct method, indirect method & regenerative method. Direct method of testing of D.C. motor machine also known as brake test will be discussed in detail.

1. Brake test (or) Direct method
2. Swinburn's test (or) No-load test [Indirect method]
3. Hopkinson's test (or) back-to-back test [Regenerative test]
4. Field test
5. Detachation (or) Running down test

Brake Test :



* This method is well suited small motor. The motor is directly loaded by a belt (or) rope loop fixed on the shaft of the motor as shown in above figure.

* The rope (or) belt is wound around pulley and its to ends are fixed two spring balances S₁ & S₂. The load on motor can be increased by adjusting the tension of the rope with the help of weights. The net force acting on the pulley is equal to the difference of two spring balances exerting.

Wheat or

DPT : Double Pole Single through Switch

SPST : Single Pole Single through Switch

S_1 : Spring balance reading

S_2 : Spring balance reading

R : Radius of the pulley (cm)

N : Speed of the motor (rpm)

τ_{sh} : Shaft torque

F : Net force

ω : Angular velocity $= \frac{2\pi N}{60}$

V : Supply voltage (volts)

I_L : Line Current (Amps)

Net force (F) = $(S_1 - S_2)$ kg wt

Shaft torque (τ_{sh}) = $(S_1 - S_2) R$ kg-m. wt

Motor output = $\tau_{sh} \cdot \omega$

= $(S_1 - S_2) R \times \frac{2\pi N}{60}$ kg-m. wt

= $9.81 \frac{2\pi N}{60} (S_1 - S_2) R$ N-m

= $0.1635 \times 2\pi N (S_1 - S_2) R$ W.

Motor Input = $V \cdot I_L$

Efficiency (η) = $\frac{\text{Motor output}}{\text{Motor input}}$

= $\frac{0.1635 \times 2\pi N (S_1 - S_2) R}{V \cdot I_L}$

Nothing is efficiency of the motor can be determined

with no load. $\eta = \frac{0.1635 \times 2\pi N (S_1 - S_2) R}{V \cdot I_L} \times 100$

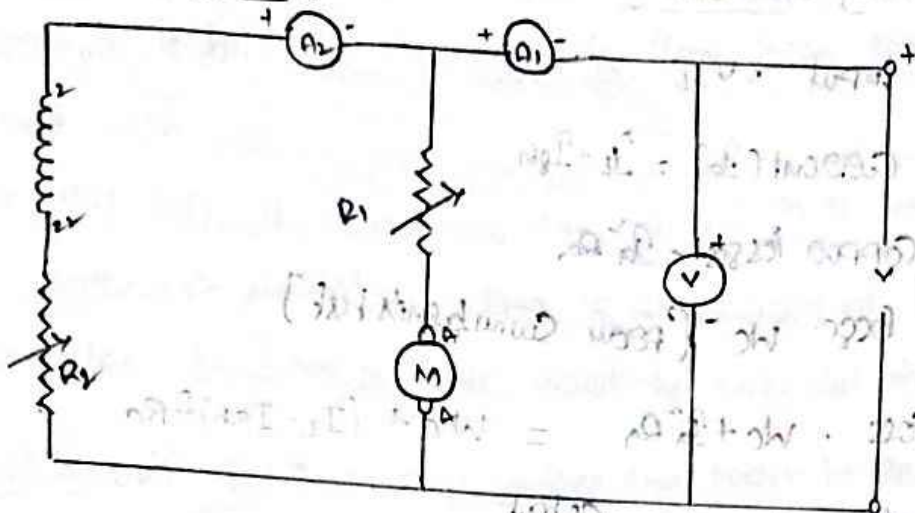
with no load. $\eta = \frac{0.1635 \times 2\pi N (S_1 - S_2) R}{V \cdot I_L} \times 100$

estimated efficiency of the motor can be determined

with no load. $\eta = \frac{0.1635 \times 2\pi N (S_1 - S_2) R}{V \cdot I_L} \times 100$

estimated efficiency of the motor can be determined

Swinburne's Test:



The circuit diagram of the Swinburne's test is shown in figure. The machine is run as a motor on no-load at its rated voltage specified on the name plate. The speed is adjusted to the rated speed with the help of a rheostat. The no-load current I_{00} is measured by the ammeter A_1 when the shunt field current I_{sh} is given by ammeter A_2 . Now the no-load armature current is $I_{a0} = (I_0 - I_{sh})$

Let,

V = Supply voltage

No load power input = $V I_0$ W

= $V (I_0 - I_{sh})$

Power input to shunt = $V I_{sh}$

Knowing the constant losses of the

The armature input supplies the following losses:

* Iron losses in the armature core

* Friction losses in the bearings

* Windage losses

* Armature copper losses $[I_a^2 R_a = I_0^2 R_a - I_{sh}^2 R_a]$

* Constant losses (W) = Iron losses + mechanical losses + shunt field copper losses

$W_c = V I_0 - I_a^2 R_a$

By knowing the constant losses of the machine the efficiency

of any load can be determined as given below.

When Running as motor:

CRAZY NOTES JNTUK

$$\text{Motor input} = V I_L$$

$$\text{Armature Current } (I_a) = I_L - I_{sh}$$

$$\text{Armature Copper loss} = I_a^2 R_a$$

Constant loss W_c (from Swinburn's test)

$$\text{Total loss} = W_c + I_a^2 R_a = W_c + (I_L - I_{sh})^2 R_a$$

$$\text{Motor efficiency } \eta_m = \frac{\text{Output}}{\text{Input}}$$

$$\text{efficiency } (\eta\%) = \frac{\text{Input} - \text{total losses}}{\text{Input}}$$

$$\eta_m = \frac{V I_L - (W_c + I_a^2 R_a)}{V I_L}; \eta\% (\eta) = \frac{V I_L - [W_c + (I_L - I_{sh})^2 R_a]}{V I_L}$$

When running as generator:

$$\text{Generator output } (P) = V I_L$$

$$\text{Armature Current } (I_a) = I_L + I_{sh}$$

$$\text{Armature Copper loss} = I_a^2 R_a$$

$$\text{Constant loss} = W_c + (I_L + I_{sh})^2 R_a$$

$$\text{Total losses} = W_c + I_a^2 R_a$$

$$\eta_g = \frac{\text{Output}}{\text{Input}}$$

$$\eta_g = \frac{V I_L}{V I_L + (W_c + I_a^2 R_a)}; \eta\% (\eta_g) = \frac{V I_L}{V I_L + (W_c + I_a^2 R_a)} \times 100$$

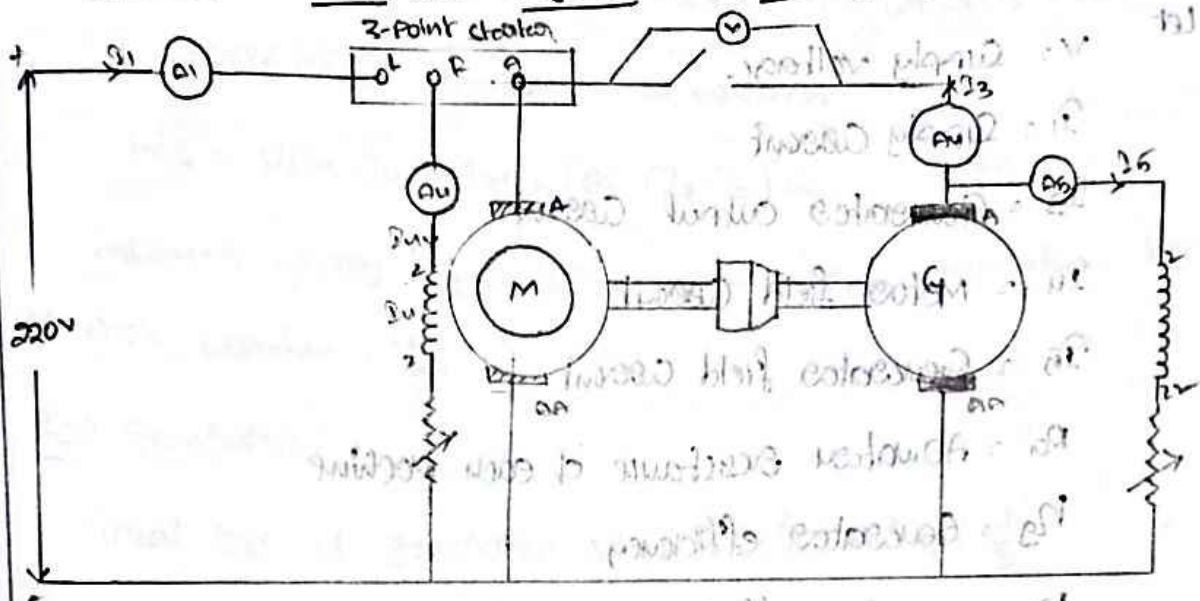
Advantages:

1. It is convenient and economical because power requirement for a load is small i.e., only no-load input power.
2. The efficiency can be re-determined at any load because constant losses are known.

Disadvantages:

1. No account is taken of the change in iron losses from no-load to full-load.
2. Since the test is conducting on no-load, it is not possible to know whether commutation would be satisfactory at full load & whether the temperature rise would be within the specified limit.

3. Hopkinson's Test (or) Regenerative (or) Back to Back Test:



⇒ In this method two machines mechanically coupled or shown in above figure. The mechanically coupled electrical output of generator is motor. These are the generator part of the input of motor. These would have run without any external energy if there was no loss in motor. But due to losses generator output is not sufficient to drive the motor & vice versa. The losses are supplied from the main. The starting procedure is as follows.

⇒ Motor 'M' is started first from supplying main with help of starter and switch 'S' is kept open. The speed is adjusted to normal value by adjusting field regulation. The motor drives generator and its generator voltage which can be varied with the

The voltage of generator is adjusted to zero value by adjusting its field regulator. Then by ensuring that its voltage is same both magnitude and polarity as that of main supply. Then the switch is closed to connect both the machines in parallel. The load can be adjusted by adjusting their field regulator current. As supply by generator can be adjusted any desired value by increasing excitation or any by reducing the excitation of motor.

Let

V = Supply voltage.

I_1 = Supply current.

I_2 = Generator output current

I_3 = Motor field current

I_4 = Generator field current

R_a = Armature resistance of each machine

η_g = Generator efficiency

η_m = Motor efficiency

Motor input = $V(I_1 + I_2)$ (or) $V(I_2 + I_3 + I_4)$

Motor output = Efficiency $\times$ Motor input

$\eta_m \times V(I_2 + I_3)$

Generator output = Efficiency $\times$ generator input

$\eta_g \times \eta_m \times V(I_2 + I_3)$

Assuming both the machines are same efficiency i.e. $\eta_g = \eta_m$

From the above equation $V I_2 = \eta^2 \times V(I_2 + I_3)$

Dividing both sides by V and I_2 we get $\eta^2 = \frac{I_2 + I_3}{I_2}$

or $\eta^2 = 1 + \frac{I_3}{I_2}$

$I_1 = I_2 + I_3$

Generated Armature Copper losses $= (I_3 + I_5)^2 R_a$

Motor Armature Copper losses $= (I_2 + I_3)^2 R_a$

Generator Shunt Copper losses $= V \cdot I_5$

Motor Shunt Copper losses $= V \cdot I_4$

Total losses = Copper loss + stray losses

The power drawn from the supply = total losses + $V(I_2 + I_4)$

$\therefore V(I_2 + I_4) = (I_3 + I_5)^2 R_a + (I_2 + I_3)^2 R_a + V I_5 + V I_4$ + stray losses

$\therefore$ stray losses on both the machines

$W_s = V(I_2 + I_4) - (I_3 + I_5)^2 R_a - (I_2 + I_3)^2 R_a - V I_5 - V I_4$

Assuming stray loss of both the machines is same then loss of each machine = $\frac{W_s}{2}$

For Generator:

Total loss of generator $W_g = (I_3 + I_5)^2 R_a + V I_5 + \frac{W_s}{2}$

$$\eta_g = \frac{V \cdot I_3}{V \cdot I_3 + W_g}$$

Total loss of motor $W_m = (I_2 + I_3)^2 R_a + V I_4 + \frac{W_s}{2}$

$$\eta_m = \frac{V(I_2 + I_3 + I_4) - W_m}{V(I_2 + I_3 + I_4)}$$

Advantages:

1. Power generated for test only losses of both the machines
2. As the machines are fully loaded the temperature rise and commutation effects can be observed.
3. Because of full load condition change in power loss due to flux distortion at full load is being taken in to the account

Disadvantages:

1. It needs M-G sets feasible identical machines
2. Availability of two identical shunt machines

Retardation Test (or) Running down test

This method is applicable to small motor and generator and is used for finding steady losses. Then knowing the constant armature and small copper losses at a given load current, efficiency can be calculated.

The machine under test is speed slightly beyond its normal speed and then supply is cut off from the armature while keeping the field excited consequently the armature slows down and its kinetic energy is used to meet the rotational losses i.e. calculation of the iron losses.

Kinetic energy of the armature is $K.E. = \frac{1}{2} I \omega^2$

where I = moment of inertia of the armature

ω = Angular velocity

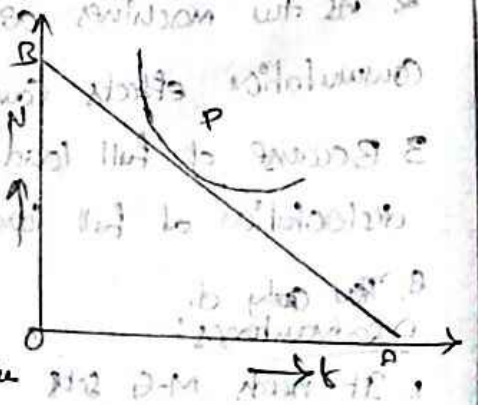
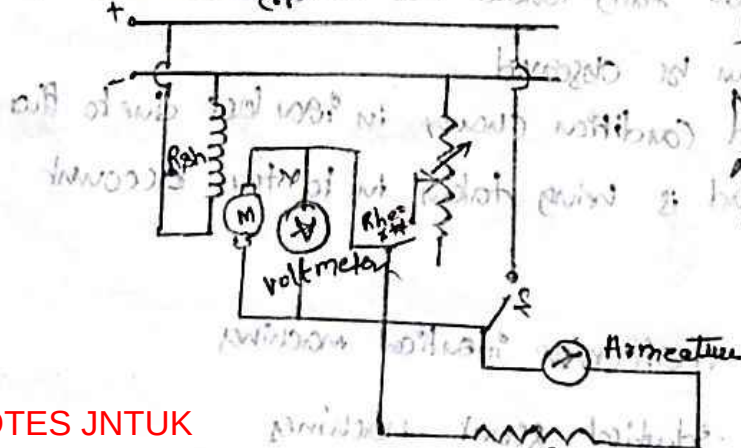
$\therefore$ Rotational losses = Rate of loss of K.E.

$$\omega = \frac{d}{dt} \left(\frac{1}{2} I \omega^2 \right)$$

$$\omega = I \omega \cdot \frac{d\omega}{dt} \quad \text{--- (1)}$$

Two quantities need be known (i) moment of inertia (ii) $\frac{d\omega}{dt}$ because ωdN . These can found as follows:

(a) Finding $\frac{d\omega}{dt}$



As shown in above fig. a voltmeter V is connected across the counter. This voltmeter is used as speed indicator by suitable graduation of its scale. When supply is cut off the counter speed and hence voltmeter reading falls. By noting different amount of voltage fall in different amount of time, a curve is drawn b/w time and the speed from any point A which corresponds to normal speed a tangent AB is given by

Then $\frac{dN}{dt} = \frac{OB \text{ (in RPM)}}{OA \text{ (in sec)}}$

From above $w = I \omega \frac{dw}{dt}$

Let $\frac{2\pi N}{60} = \omega$ $\therefore \frac{d\omega}{dt} = \frac{2\pi}{60} \frac{dN}{dt}$

$$W = \left(\frac{2\pi}{60}\right)^2 I N \frac{dN}{dt}$$

$$= 0.011 I N \frac{dN}{dt} \rightarrow \text{②}$$

2. Finding Moment of Inertia:

a. First method - When "I" is calculated:

First slowing down curve is drawn with diagram above. Next, a fly-wheel of known moment of inertia I_1 is keyed onto the shaft and slowing down curve is drawn again. Obviously, slowing down time will be longer due to combined increased moment of inertia of the two. For any given speed $\left(\frac{dN}{dt}\right)$ and $\left(\frac{dN}{dt}\right)$ are determined as before. It should be noted that the losses in both cases would be almost the same, because addition of a fly-wheel will not make much difference to the losses.

From equation ② above

In first case $W = \left(\frac{2\pi}{60}\right)^2 I_1 N \left(\frac{dN}{dt}\right)$

In second case $W = \left(\frac{2\pi}{60}\right)^2 (2+D_1) N \left(\frac{dN}{dt}\right)$
 $(2+D_1) \left(\frac{dN}{dt}\right) = 2 \left(\frac{dN}{dt}\right) (2+D_1) \left(\frac{dN}{dt}\right) / \left(\frac{dN}{dt}\right)$
 $2+D_1 = \frac{dN/dt}{(dN/dt) - (dN/dt)}$
 $2+D_1 = \frac{dt}{dt - dt}$

(b) Second Method. where D is eliminated:

In this method time taken to slow down, say by 5%, is noted with armature slow. Next a retarding torque - mechanical (or) reversible electrical, is applied to the armature and again time is noted. The method using electrical torque is shown in above fig.

The double-throw switch S while cutting off the armature from the supply, automatically joins it to a non-inductive resistance R as shown. The power drawn by this resistance acts as a retarding torque on the armature thus by making it slow down comparatively quickly. The additional loss is $I_a^2 R$.

Where I_a = Average current through R.

V = Average voltage across R.

Let W be the power then from (1) above

$$W = \left(\frac{2\pi}{60}\right)^2 2 N \frac{dN}{dt}$$

} dN is the same

$$W = \left(\frac{2\pi}{60}\right)^2 2 N \frac{dN}{dt}$$

$$W = W' \times \frac{dt}{dt}$$

$$W = W' \times \frac{dt}{dt}$$

where $\frac{dN}{dt}$ = Rate of change of speed without extra load

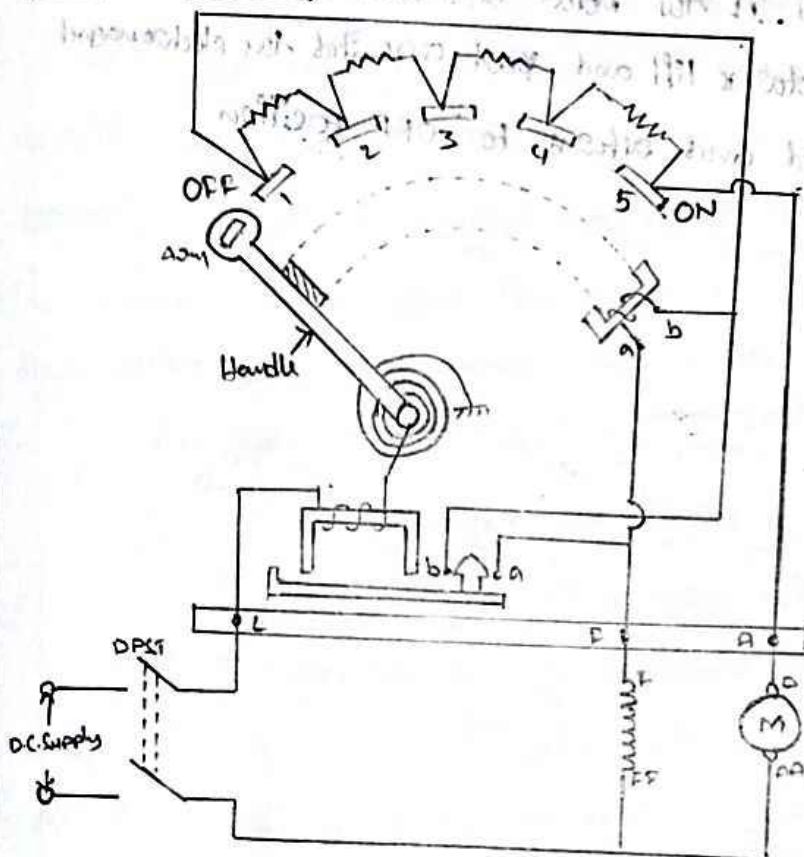
$\frac{dN}{dt}$ = Rate of change of speed with extra load

Starters:

At starting when the motor is stationary, there is no back EMF in the armature. Consequently if the motor is directly switched on to the mains.

Purpose: To limit the starting current.

3-Point starter:



The internal wiring diagram of a starter is shown in fig. The three terminals of the starter box are L, F&A. One line is directly connected to all armature terminals which are tied together. The other line is connected to F&A which is further connected to the starting arm through overhaul release coil.

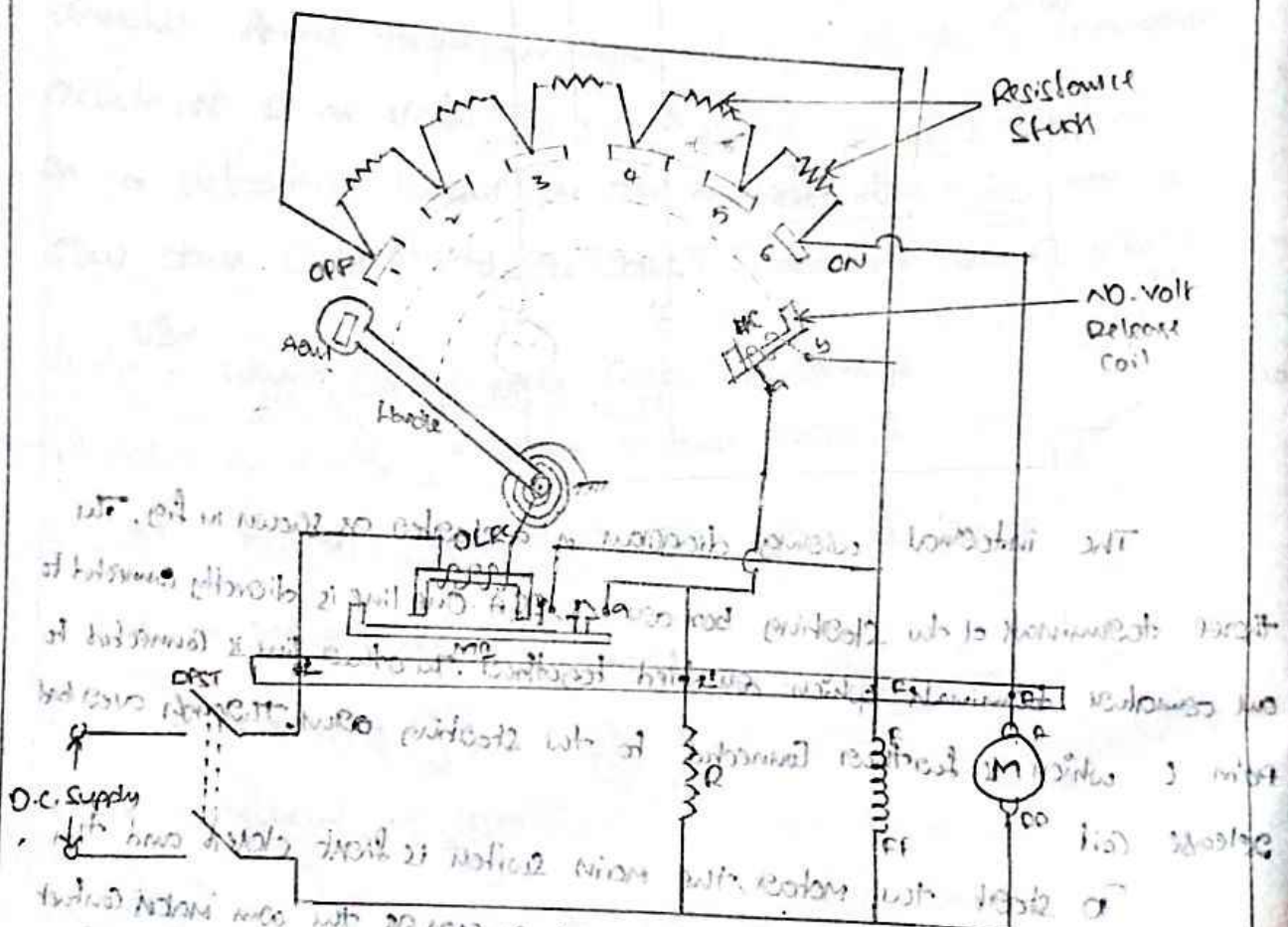
To start the motor, the main switch is first closed and the starting arm is slowly moved to the right. As soon as the arm makes contact with stud 1, the field current is directly connected across line A at the same time full starting resistance R_5 is placed in series with the armature. The starting current drawn by the armature is $\frac{V}{R_a + R_5}$.

As the arm is further moved, the starting resistance is gradually cut off and the arm reaches running position. Then all resistance is cut off. The arm is return it to OFF position. It is known as NOVRC & OLRC.

No-volt Release coil: The function of this coil is to hold the starting arm in full running position. But in case of disconnection of supply, the break is de-energised. The arm is release to spring to the "OFF" position.

Overload Release coil: The overload release consists of an electromagnet connected in the supply line. If the motor becomes overloaded to certain predetermined value, the motor is lift and short circuit the electromagnet. Hence the arm is released and returns to "OFF" position.

4-point starter:



For variable speed motor the resistance R_f is connected in series with the field winding as shown in above fig. The speed can be increased by reducing the field current (or) $\frac{1}{\phi}$.

by increasing the value of resistance R. If this resistance is too low, the field current will become too small and the hold-on coil will fail to hold the arm in ON position against the pull of the spring. The motor will be switched off from the supply. This is an undesirable feature of the 3-point starter. Hence it has been replaced by a 4-point starter for such applications.

The internal wiring diagram of a 4-point starter is shown in figure. It is similar to a 3-point starter but that the No-volt release coil has been taken out of the field circuit and connected directly across the main supply through a protective resistance as shown in figure. The starter also works similar to a 3-point starter. In 4-point starter, when the moving arm touches the stud 1, then the line current will have three paths, namely,

1. Through the starting resistance and commutator,
2. Through the shunt field winding & shunt rheostat,
3. Through the No-voltage release coil

The variation in the resistance of the field rheostat to control the speed of the motor will not affect the electromagnetic pull of the No-volt release coil and will always be large enough to prevent the arm to spring back to the "OFF" position.

Key points on DC Machines:

Starter: starter is a device, it limits the starting current

D.C. shunt motor:

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

$$V = E_b + I_a R_a$$

$$E_b = V - I_a R_a$$

D.C. series motor:

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

$$V = E_b + I_a R_a + I_{sh} R_{sh} \quad \therefore I_a = I_{sh}$$

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

Long shunt compound motor:

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

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

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

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

Short shunt compound motor:

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

$$V = E_b + I_a R_a + I_{sh} R_{sh}$$

$$E_b = V - I_a R_a - I_{sh} R_{sh}$$

Back emf: $E_b = \frac{\phi Z N}{60} \times \frac{P}{a}$