

Unit-III

3. starting, Speed control and Testing of DC Machine

* Speed Control Methods of DC Machine:-

$$E_b = \frac{\phi Z N}{60} [P/A]$$

Z, P, A are constants

$$E_b \propto \phi N$$

$$N \propto \frac{E_b}{\phi} ; E_b = U - I_a R_a, \text{ very small value negligible}$$

$$E_b \approx U$$

$$\boxed{N \propto E_b \propto U \propto \frac{1}{\phi}}$$

Thus the factors effecting the speed of the DC-motor

are

1. The flux
2. voltage across the Armature
3. The applied voltage

depending upon these factors the various speed control methods are

1. the change in the flux (ϕ) by controlling the current through the field winding is called flux control method.

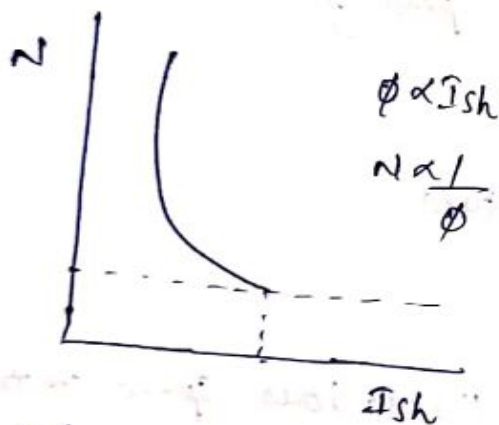
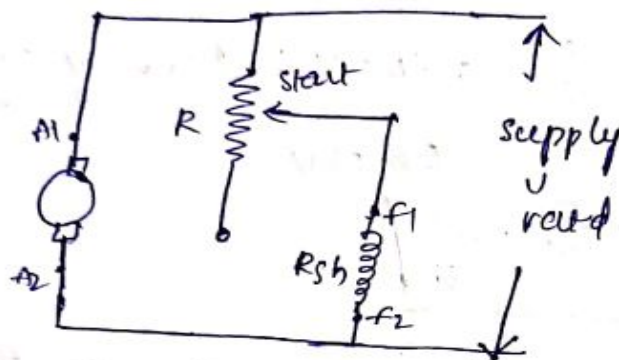
2. change in the armature path resistance which in turn changes the voltage applied across the Armature

is called "rheostatic control method" or Armature control method

3. change in the applied voltage called applied voltage control Method.

* Speed control of DC - Shunt Motors —

* flux control Method:-



$$\phi \propto I_{sh}$$

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

this method is for above rated speed machines

(rectangular hyperbola)

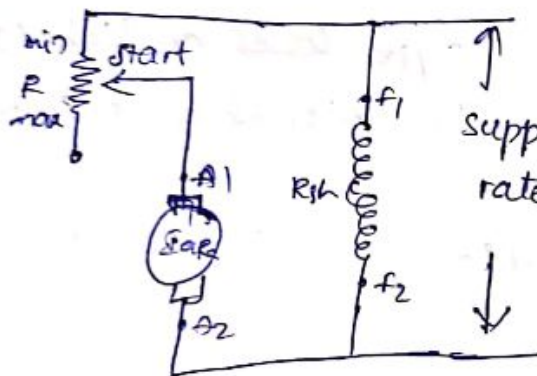
Advantages:-

- It provides relatively smooth and easy control.
- Speed control above rated speed is possible.
- As field winding resistance is high, the field current is small. Hence power loss is very small, which makes method more economical and efficient.
- As the field current is small, the size of the rheostat is small.

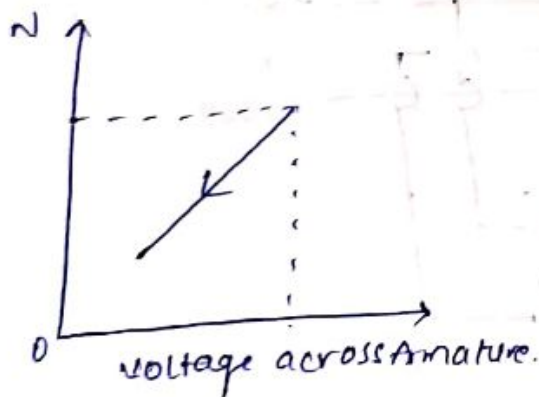
Disadvantages:-

- The speed control below normal rated speed is not possible as flux can be increased upto only its rated value.
- As flux reduces, speed increases. But high speed effects the commutation making motor operation unstable.

* Rheostatic control Method / Armature Control Method:-



$$N \propto E_b \propto V - I_a R_a$$

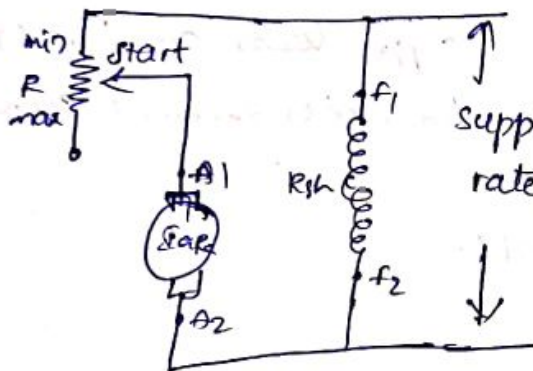


It does n't support the armature to zero.

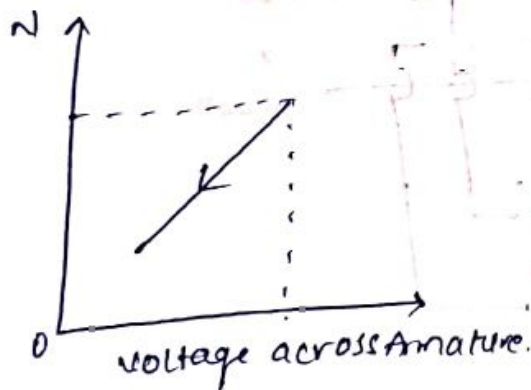
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* Rheostatic control Method / Armature Control Method:-

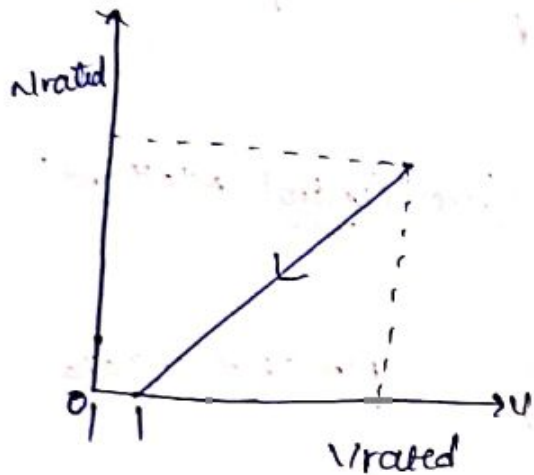
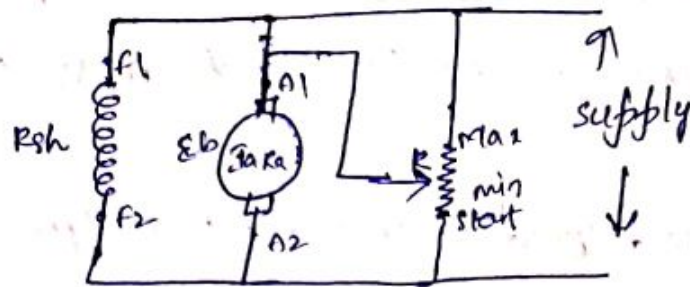


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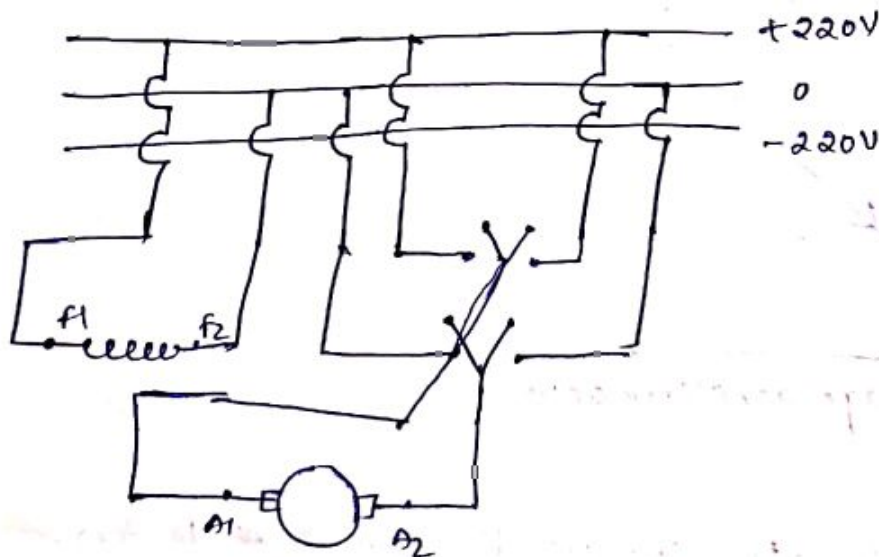
* potential divider control:-



It take some time to start the motor. it doesn't becomes zero.

Copper losses are high ($I^2 R$) due to series Rheostat connection.

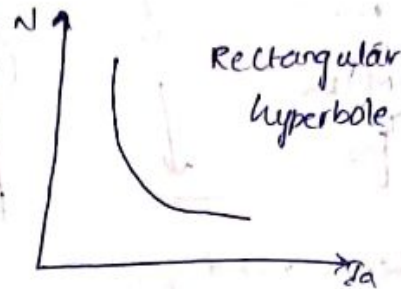
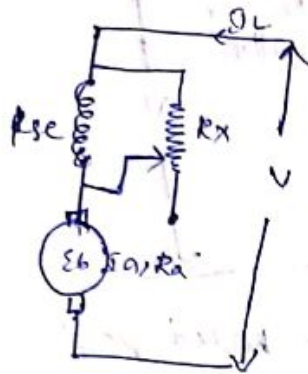
* Applied voltage Control:-



Speed control of DC-Series Motor:-

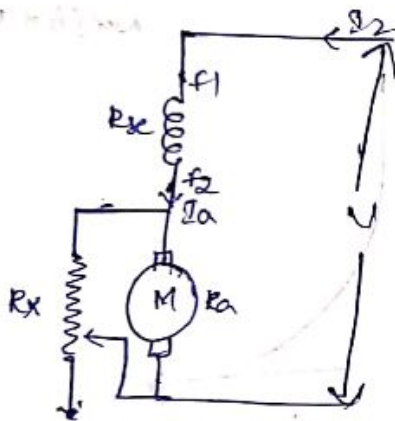
i) flux control Method

i) field diverter Method



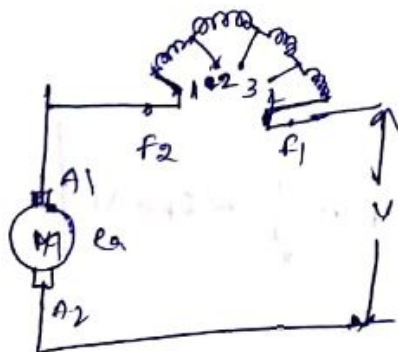
Above rated Speed

ii) Armature diverter Method:-



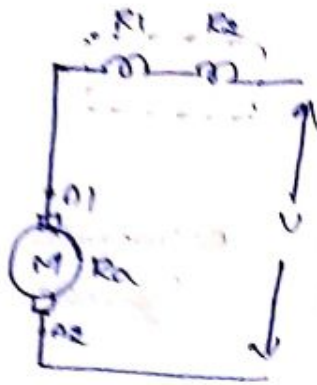
$T \propto \phi I_a$ (below rated speeds)

iii) Tapped field Method:-

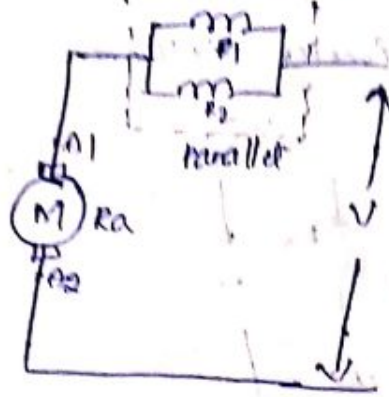


above rated Speeds

iv) Series parallel connection of field:

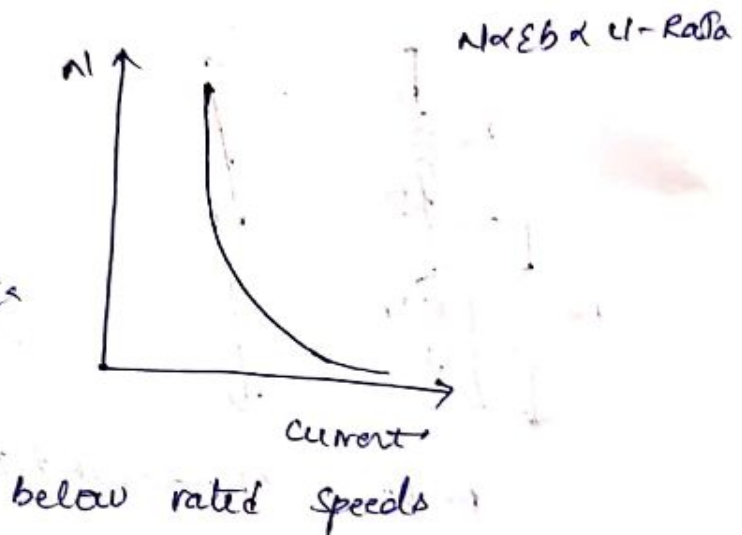
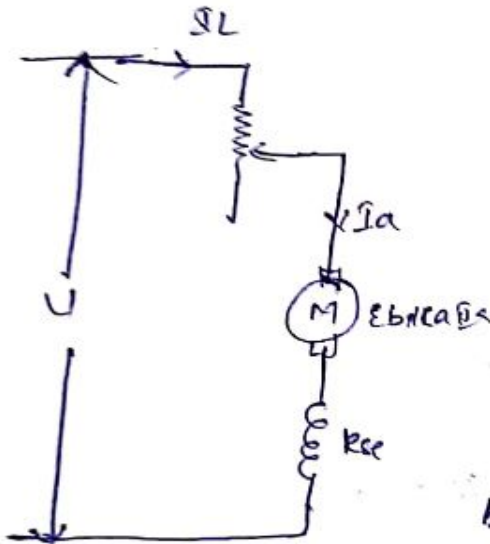


below rated speed

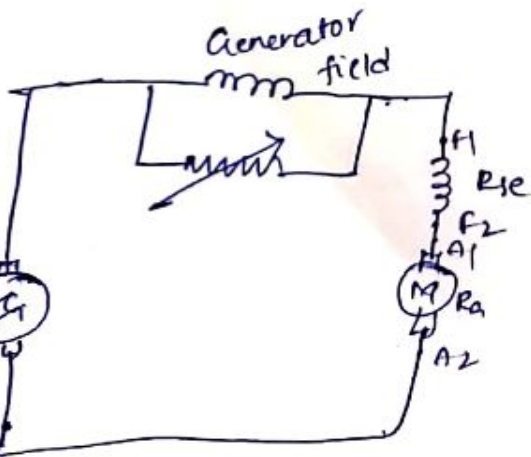


above rated speed

* Armature Control Method (or) Rheostat Control Method:-



* Applied voltage control:-



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

* Starting Methods of D.C. Motors -

$$E_b = V - I_a R_a$$

$$E_b = 0 \text{ (starting)}$$

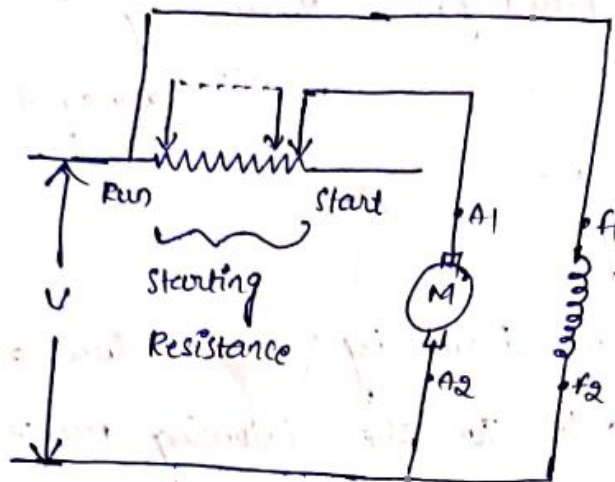
$$V = I_a R_a$$

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

due to high current at the starting the winding will be damaged.

- Such high current drawn by the armature at start is highly objectionable for the following reasons.
- In a constant voltage system, such high inrush currents may cause tremendous line voltage fluctuations this may affect the performance of other equipment connected to the same line.
- Such excessively high currents, blows out the fuses.
- If motor fails to start due to some problems with the field winding, then a large armature current flowing for a longer time may burn the insulation's of the armature winding.
- As the starting armature current is 10-15 times more than the full load current, the torque developed which is proportional to the armature current will also be 10-15 times. Due to such high currents, the shaft and other accessories are then subjected to large mechanical stresses. These

stresses may cause permanent mechanical damage to the motor.

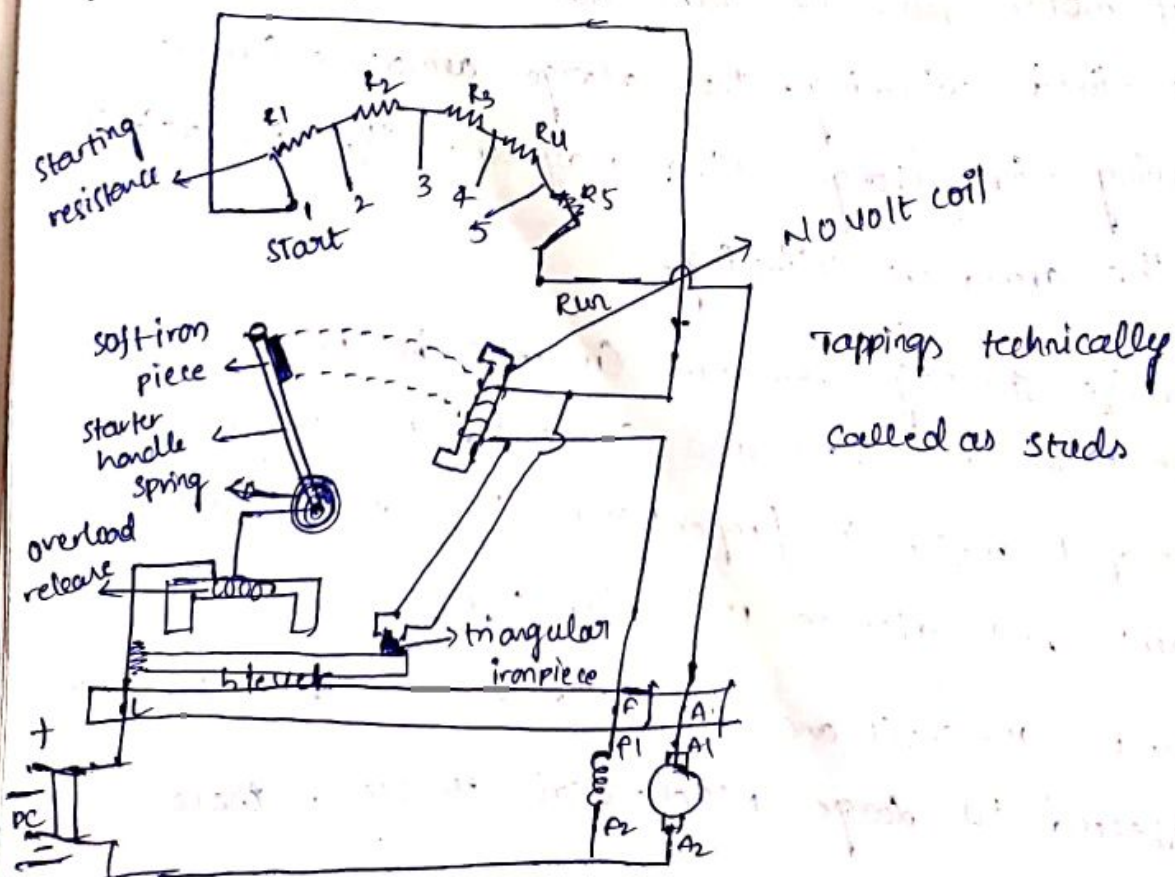


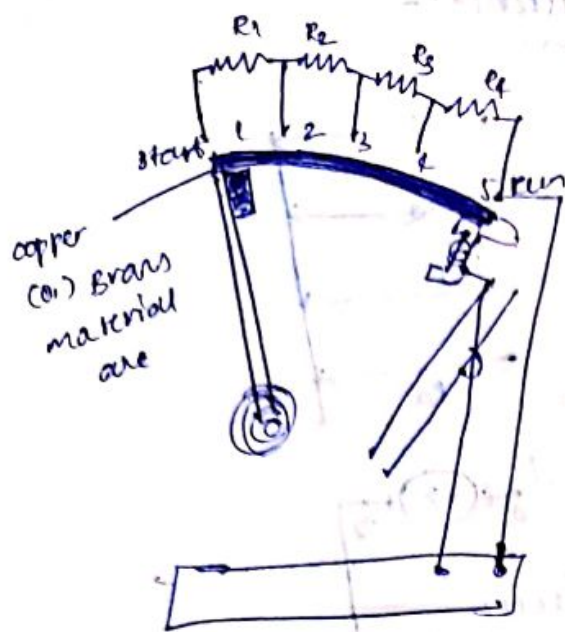
- There are two types of starters

i. three point starter

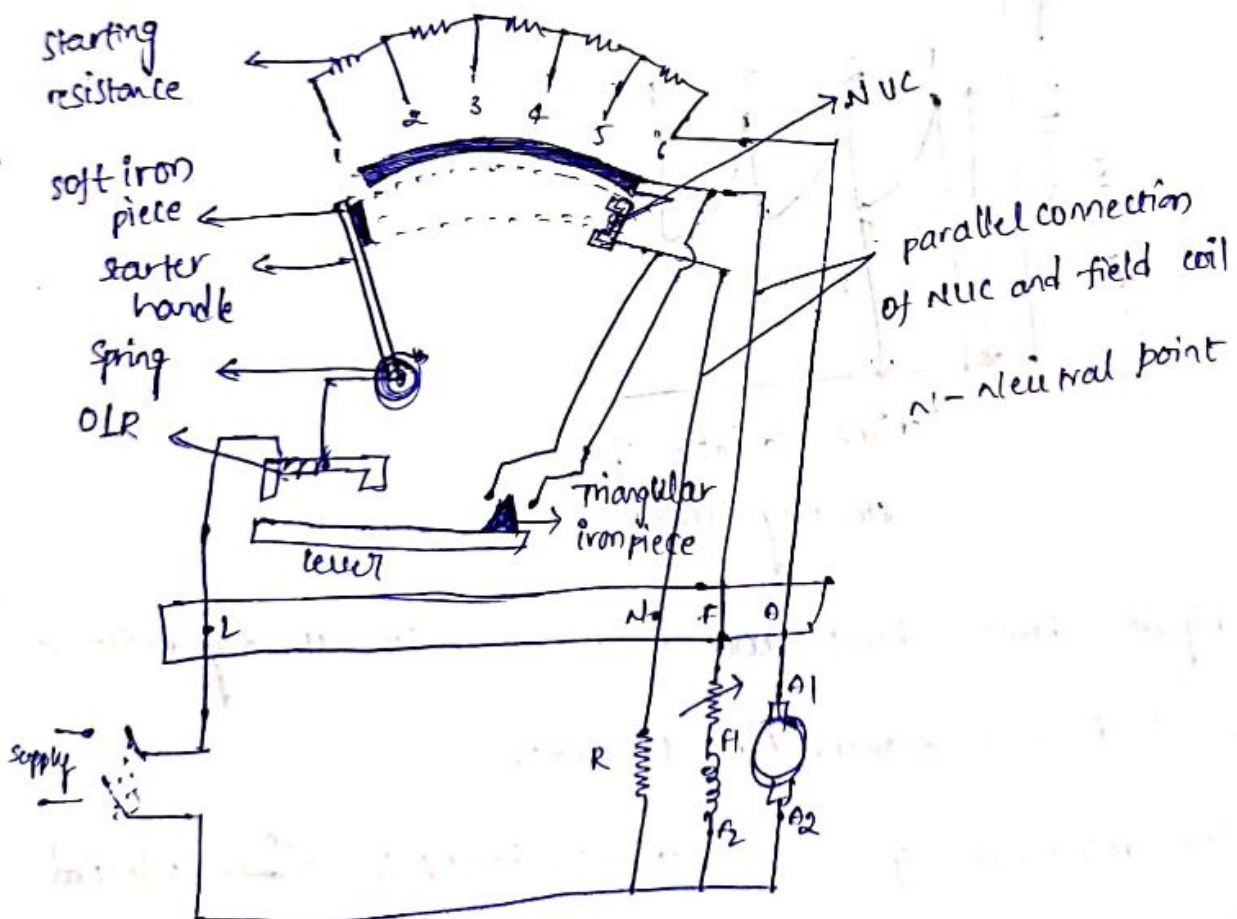
2. four point starter

Three-point starter:-

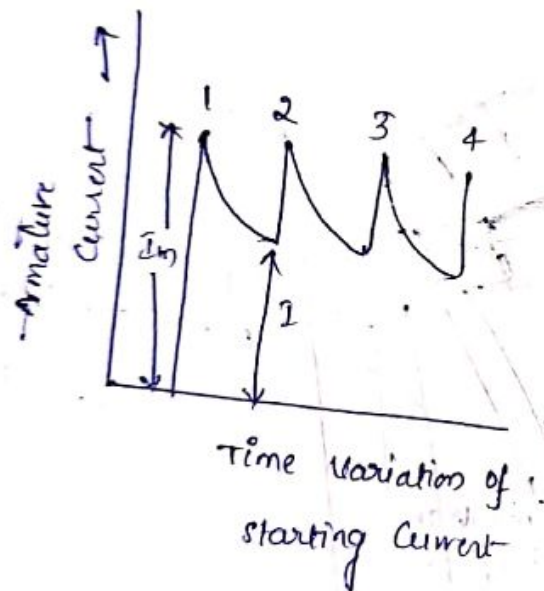
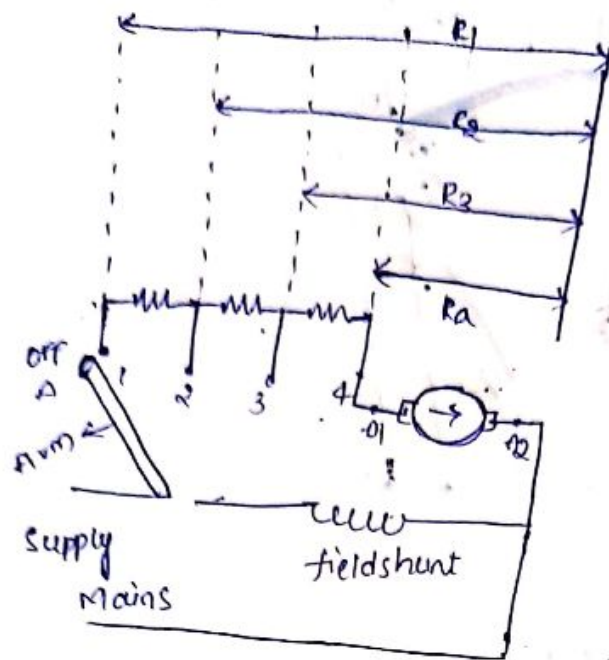




four-point starter:-



* Grading of the starting resistance:-

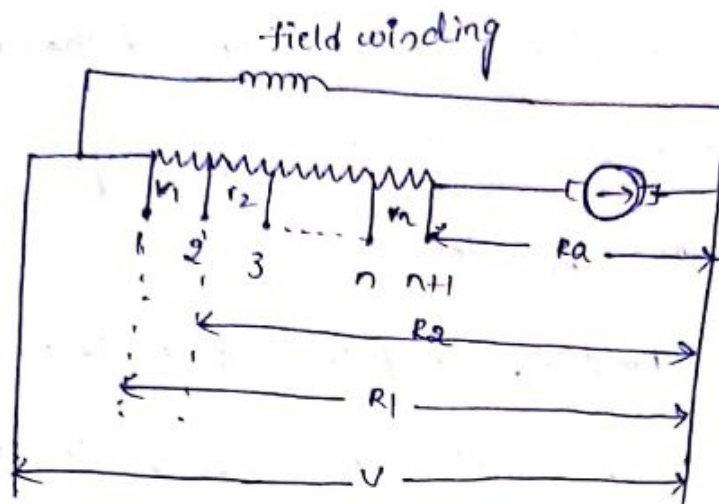


- figure shows shunt wound Motor with starting resistance divided into 3-sections b/n 4-studs.
- The resistance of these sections should be ^{so} ~~source~~ selected that current during starting remains b/n i_m and i .

I_m : Maximum value of current

i : Minimum value of current.

* Design of starter:-



- figure shows a DC-shunt motor-starter with n -resistance sections and $(n+1)$ studs.
- let R_1 is the total resistance in the armature circuit when the starter arm is on stud-1.
- R_2 -total resistance in the armature circuit when the starter arm is on stud-2. and so on...
- I_m - upper current limit
- I - lower current limit
- n - no. of sections in the starter resistance.
- V - applied voltage
- R_a - armature resistance

on stud-1 :-

when the starter arm moves to stud 1, the total resistance in the armature circuit is R_1 and the circuit current jumps to maximum value I_m given by.

$$I_m = \frac{V}{R_1} \rightarrow (1)$$

Since, $T \propto \phi I_a$, it follows that the maximum

Torque acts on the armature to accelerate it. As the armature accelerates, the induced emf increases and the armature current decreases. When the current has fallen to the predetermined value I , the starter arm is moved over to stud-2.

Let the value of back emf be E_b at the instant of starter arm leaves the stud 1. Then I is given as

$$I = \frac{V - E_b}{R_1} \rightarrow (2)$$

on stud-2 :-

As the starter arm moves to stud-2, sufficient resistance is cut out and current rises to maximum value I_m once again given by I_m

$$I_m = \frac{V - E_b}{R_2} \rightarrow (3)$$

The acceleration continues and the back emf increases and the armature current decreases. When the current has fallen to the predetermined value I , the starter arm is moved over to stud-3. Let E_{b2} be the value of back emf and the instant the starter arm leaves the stud-2, then

$$I = \frac{V - E_{b2}}{R_2} \rightarrow (4)$$

on stud-3:-

As the starter arm moves to stud-3,

$$I_m = \frac{V - E_{b2}}{R_3} \rightarrow (5)$$

As the starter arm leaves stud-3

$$I = \frac{V - E_{b2}}{R_3} \rightarrow (6)$$

on n^{th} stud:-

As the starter arm leaves n^{th} stud

$$I_m = \frac{V - E_{bn}}{R_n}$$

on $(n+1)^{\text{th}}$ stud:-

When the starter arm moves over to $(n+1)^{\text{th}}$ stud, all the external resistance is cut out leaving only the armature resistance R_a then

$$I_m = \frac{V - E_{bn}}{R_a}, \quad I = \frac{V - E_b}{R_a}$$

dividing (2)/(3)

$$\frac{I}{I_m} = \frac{U-Eb}{R_1} \times \frac{R_2}{U-Eb}$$

$$\frac{I}{I_m} = \frac{R_2}{R_1}$$

dividing (4)/(5)

$$\frac{I}{I_m} = \frac{R_3}{R_2}$$

by continuously doing these divisions we have finally

$$\frac{I}{I_m} = \frac{R_n}{R_1}$$

let $\frac{I}{I_m} = k$ then $\frac{R_2}{R_1} = \frac{R_3}{R_2} = \dots = \frac{R_n}{R_1} = k$

If we multiply these n-equal ratios together then

$$\frac{R_2}{R_1} \times \frac{R_3}{R_2} \times \frac{R_4}{R_3} \times \dots \times \frac{R_n}{R_1} = k^n$$

$$\frac{R_n}{R_1} = k^n$$

$$k = \left[\frac{R_n}{R_1} \right]^{1/n}$$

The value of resistance elements can be obtained as

$$R_2 = R_1 \times k$$

$$R_3 = R_2 \times k$$

$$r_1 = R_1 - R_2 = (1-k)R_1$$

$$r_2 = R_2 - R_3 = (1-k)R_2 = R_1 k (1-k)$$

Knowing the values of n, Φ, R_a the above values can be obtained.

* A 2-pole lap wound dc shunt motor with 360 conductor operates at a constant flux level of 50 mwb. The motor armature has a resistance of 0.12Ω and is designed to operate at 240V, taking a current of 60 amp at full load. i) determine the value of external resistance to be inserted in the armature circuit so that armature current does not exceed twice its full load value at starting.

ii) The external resistance is completely cut out when the motor reaches its final speed, with the armature current at full load value, calculate the motor speed under these conditions.

Sol:-

$$P = 2$$

$$V = 240V$$

$$Z = 360$$

$$I_a = 60 \text{ Amp}$$

$$\Phi = 50 \times 10^{-3} \text{ wb}$$

$$R_a = 0.12 \Omega$$

$$i) I_{\max} = 60 \times 2 = 120$$

$$120 \text{ A} = \frac{V}{R_{\text{ext}} + R_a}$$

$$120 = \frac{240}{R_{\text{ext}} + 0.12}$$

$$ii) \quad E_b = \frac{\phi Z N}{60} [P/A]$$

$$N = \frac{E_b \times 60 \times A}{\phi \times Z \times P}$$

$$E_b = V - I_a R_a$$

$$= 240 - 60 \times 0.12$$

$$= 232.8$$

$$= 77.6 \text{ rpm}$$

* A 200-volts shunt motor having armature resistance of 0.4Ω and shunt field resistance of 100Ω drives a load at 500 rpm taking 27 amp. it is desired to run the motor at 700 rpm. Assuming the load torque to be constant, find the value of resistance to be used as field regulator. Neglect saturation effect.

$$\text{sol: } V = 200 \text{ V} \quad I_L = 27 \text{ Amp}$$

$$R_a = 0.4 \Omega$$

$$N_1 = 500$$

$$R_{sh} = R_f = 100 \Omega$$

$$N_2 = 700$$

Initial conditions:-

$$I_{sh1} = \frac{V}{R_{sh}} = \frac{200}{100} = 2 \text{ amp}$$

$$I_{a1} = I_L - I_{sh1} = 27 - 2 = 25 \text{ Amp}$$

$$E_{b1} = V - I_{a1} R_a = 200 - 25 \times 0.4$$

$$= 190 \text{ V}$$

$$N_2 = 700 \text{ rpm}$$

$$E_{b2} = V - I_{a2} R_a$$

$$\phi \propto I_a \text{ (Torque constant)}$$

$$\phi_1 I_{a1} \propto I_{a2} \phi_2$$

$$\phi \propto I_{sh}$$

$$I_{sh1} I_{a1} \propto I_{a2} I_{sh2}$$

$$I_{sh2} = \frac{I_{sh1} I_{a1}}{I_{a2}}$$

$$= \frac{2 \times 25}{I_{a2}} = \frac{50}{I_{a2}}$$

WKT

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

$$N_1 \propto \frac{E_{b1}}{\phi_1}, N_2 \propto \frac{E_{b2}}{\phi_2}$$

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

$$\frac{500}{700} = \frac{190 \times \frac{50}{I_{a2}}}{2 \times (200 - I_{a2} \cdot 0.4)} \quad [\phi \propto I_{sh}]$$

$$5 \times (2 \times (200 - I_{a2} \cdot 0.4)) = 7 (190 \times \frac{50}{I_{a2}})$$

$$2000 - 4I_{a2} = \frac{66500}{I_{a2}}$$

$$2000 I_{a2} - 4I_{a2}^2 = 66500$$

$$I_{a2}^2 - 500I_{a2} + 16625 = 0$$

$$I_{a1} = 464.18 \text{ Amp}$$

$$I_{a2} = 35.81 \text{ Amp}$$

let consider $I_{a2} = 35.81 \text{ Amp}$

No motor has the current 464 Amp

$$I_{sh2} = \frac{50}{I_{a2}} = \frac{50}{35.81} = 1.39 \text{ Amp}$$

$$R_{sh2} = \frac{V}{I_{sh2}} = \frac{200}{1.39} = 143.88 \Omega$$

field rheostatic resistance = $143.88 - 100$

$$= 43.88 \Omega$$

* A starter is required for a 250V shunt motor. the maximum current limit is to be 67amp and the minimum is $3/4^{\text{th}}$ of this value. Armature resistance is 0.5Ω . find the no. of sections of the starter and the resistance of each element.

solⁿ $V = 250V$, $I_{L \text{ max}} = 67A$, $K = 3/4$

$$I_{min} = 67 \times 3/4, R_a = 0.5\Omega$$

$$e^n = R_a / R_1 \quad K = \left(\frac{R_a}{R_1} \right)^{1/n}$$

$$= \left(\frac{I_1 R_a}{I_1 R_1} \right)^{1/n}$$

$$k = \left(\frac{R_1 R_9}{U} \right)^{1/n}$$

$$\left(\frac{3}{4} \right)^n = \frac{67 \times 0.5}{250}$$

$$\left(\frac{3}{4} \right)^n = 0.134$$

$$(0.75)^n = 0.134$$

$$n \log 0.75 = \log 0.134$$

$$n = \frac{-2.009}{-0.287}$$

$$n = 7$$

$$\frac{R_9}{R_1} = k^n$$

$$R_1 = \frac{R_9}{k^n} = \frac{0.5}{\left(\frac{3}{4} \right)^7}$$

$$= \frac{0.5}{0.133} = 3.785 \Omega$$

$$\frac{R_2}{R_1} = k \Rightarrow R_2 = R_1 k = 2.838 \Omega$$

$$\frac{R_3}{R_2} = k \Rightarrow R_3 = R_2 k = 2.129 \Omega$$

$$\frac{R_4}{R_3} = k \Rightarrow R_4 = R_3 \times k = 1.596 \Omega$$

$$\frac{R_5}{R_4} = k \Rightarrow R_5 = R_4 \times k = 1.197 \Omega$$

$$\frac{R_6}{R_5} = k \Rightarrow R_6 = R_5 \times k = 0.898 \Omega$$

$$\frac{R_7}{R_6} = k \Rightarrow R_7 k = R_6 k \Rightarrow 0.673 \Omega$$

$$\frac{R_8}{R_7} = k \Rightarrow R_8 = R_7 k \Rightarrow 0.504 \Omega$$

$$r_1 = R_1 - R_2 = 0.947 \Omega$$

$$r_2 = R_2 - R_3 = 0.709 \Omega$$

$$R_3 = R_3 - R_4 = 0.533 \Omega$$

$$r_4 = R_4 - R_5 = 0.399 \Omega$$

$$r_5 = R_5 - R_6 = 0.299 \Omega$$

$$r_6 = R_6 - R_7 = 0.224 \Omega$$

* A 220V shunt motor has an Armature resistance of 0.4Ω .
the armature current at starting must not exceed 40amp.

If the no. of sections is 6. calculate the values of the
resistor steps to be use in this starter.

sol:-

$$V = 220V$$

$$R_a = 0.4 \Omega$$

$$I_1 = I_a = 40 \text{ amp}$$

$$n = 6$$

$$k = R_a / R_1$$

$$k = \left(\frac{R_a}{R_1} \right)^{1/n}$$

$$= \left(\frac{I_1 R_a}{I_1 R_1} \right)^{1/n}$$

$$k = \left(\frac{8 R_a}{V} \right)^{1/4}$$

$$= \left(\frac{40 \times 0.4}{220} \right)^{1/4}$$

$$= \cancel{0.6186} \\ = 0.646$$

$$\frac{R_a}{R_1} = k^n$$

$$R_1 = \frac{R_a}{k^n} = \frac{0.4}{(0.646)^6}$$

0.928

$$= \cancel{0.6186} = 0.567$$

$$\frac{R_2}{R_1} = k \Rightarrow R_2 = k R_1 = 0.567 \times 0.928$$

3.610

$$\frac{R_3}{R_2} = k \Rightarrow R_3 = k R_2 = 0.567 \times 3.610$$

2.325

$$\frac{R_4}{R_3} = k \Rightarrow R_4 = k R_3 = 0.567 \times 2.325$$

1.497

$$\frac{R_5}{R_4} = k \Rightarrow R_5 = k R_4 = 0.567 \times 1.497$$

0.964

$$\frac{R_6}{R_5} = k \Rightarrow R_6 = k R_5 = 0.567 \times 0.964$$

0.621

$$\frac{R_7}{R_6} = k \Rightarrow R_7 = k R_6 = 0.567 \times 0.621$$

0.399

$$r_1 = R_1 - R_2 = 1.997$$

$$r_2 = R_2 - R_3 = 1.285$$

$$r_3 = R_3 - R_4 = 0.825$$

$$r_4 = R_4 - R_5 = 0.533$$

$$r_5 = R_5 - R_6 = 0.343$$

$$r_6 = R_6 - R_7 = 0.222$$

* Testing of DC Machine :-

Losses in a DC Machine :-

The losses in a DC machine may be divided into 2-classes

- i) constant losses — [core losses
Mechanical losses
- ii) Variable losses
↓
copper losses

Copper losses :- these losses occur due to current in the various windings of the machine. There are 3-types of losses.

- i) - Armature copper loss
- ii) shunt copper loss
- iii) series field copper loss

Hysteresis loss:-

Hysteresis losses occur in the dc-machine in the armature since any given ~~part~~^{part} of the armature is subjected to magnetic field reversals as it passes under successive poles. It is given by "Steinmetz" formula.

$$P_h = \eta B_{\max}^{1.6} f v \text{ watts.}$$

where

$B_{\max}$ = maximum flux density in armature

f = frequency of magnetic reversals

v = volume of armature in m^3

η = Steinmetz coefficient

- In order to reduce the hysteresis loss, core is made of such materials which have a low value of Steinmetz coefficient. Ex: silicon-steel

Eddy Current Loss:-

In addition to the voltages induced in the armature conductors, there are also voltages induced in the armature core. These voltages produce circulating currents in the armature core. These are called eddy currents and power loss due to their flow is called Eddy current loss.

- To reduce the eddy current loss laminations are used.

$$\therefore P_e = k_e B_{\max}^2 f^2 t^2 V \text{ watts}$$

where

k_e = constant depending upon the electrical resistance of the core.

$B_{\max}$ = Max. flux density

f = frequency of magnetic reversals

t = thickness of the lamination

V = volume of the core

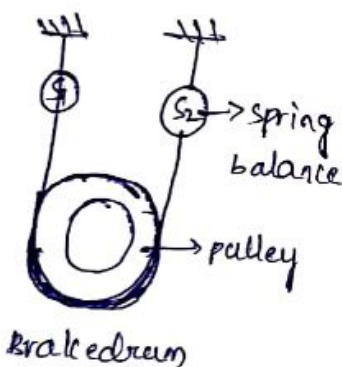
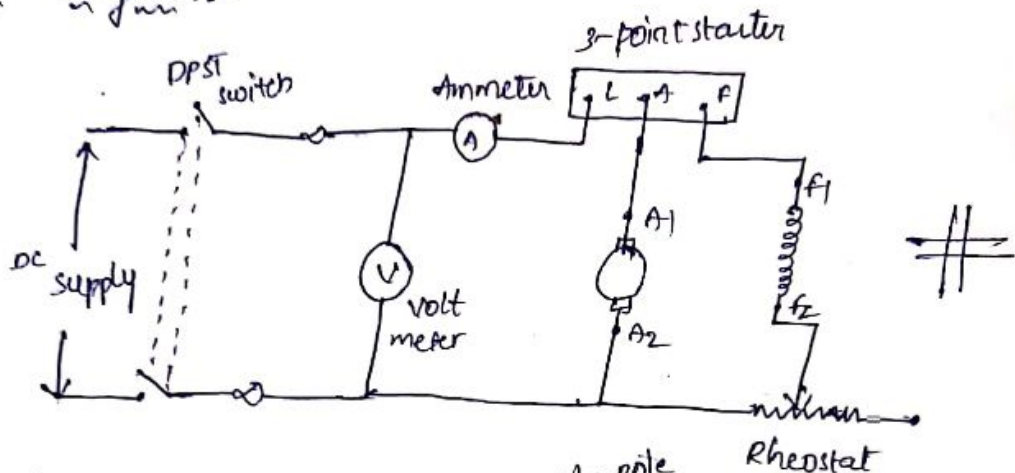
* Testing of a D.C. Machine:-

Direct Testing:-

(direct load testing)

Brake Test → by using Brake drum Testing we are doing direct testing in a shunt motor.

Circuit diagram:-



DPST- double pole single throw

$r \times \pi \times \omega$ = radius of circumference of circle of brake drum

$$\phi = \frac{2\pi NT}{60}$$

T = torque

$$\phi = \frac{V \times I_L}{10^8} \text{ (volt} \times \text{ampere)}$$

voltmeter (V)	ammeter (amp)	S ₁	S ₂	S ₁ & S ₂	Speed (rpm)	$T = (S_1 - S_2) \times \frac{r \times \pi \times \omega}{9.81 \times r}$	ϕ	A/P	$\eta = \frac{P_o}{P_i}$

Advantages:-

- The method gives the correct value of efficiency of the machine.
- The Temperature rise and commutation conditions can be checked on the spot at full load.

Disadvantages:-

1. This method requires the application of load on the machine.
2. For machines of large rating, the loads of required size may not be available.
3. Even if it is possible to provide such loads, large power will be dissipated, making it an expensive method.

Indirect testing:-

(not applying load directly but indirectly)

we are applying]

- Swinburn's test:-

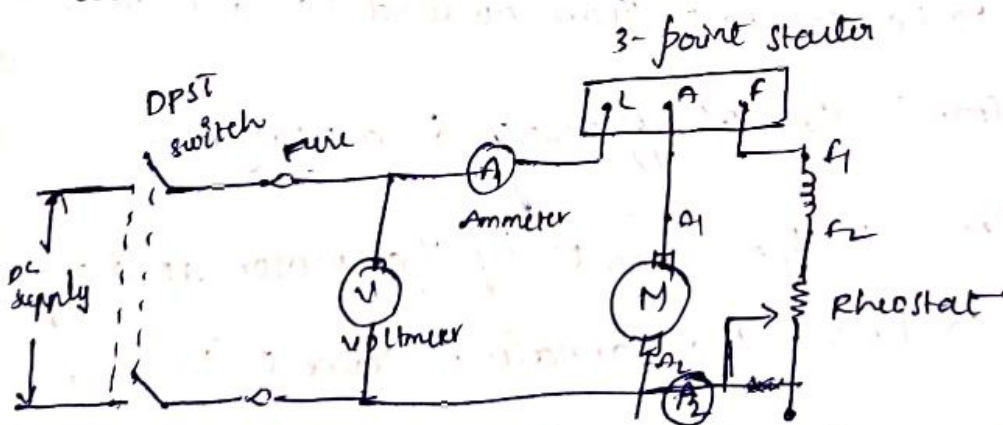
- Hopkinson's test

- Separation of losses test

- Retardation test

- field test

* Swinburn's test into load test / pre-determined test:-



Voltmeter (V)	Line current (A _L) (I _L)	field current (A _F) (I _F)

Calculation of constant losses:-

- If I_0 is the no-load line current taken by the motor, I_f is the field current and V is line voltage, then the armature current on no-load I_{a0} .

$$I_{a0} = I_0 - I_f$$

- The Armature copper loss on no load = $I_{a0}^2 R_a$

Since the test is only no load test, the input to the motor on no-load will give the sum of the no-load Armature copper loss and the constant losses

$$\text{no load input} = I_{a0}^2 R_a + \text{constant losses}$$

$$\text{constant losses} = VI_0 - I_{a0}^2 R_a$$

- The constant losses that are obtained consists of iron loss, shunt field loss and mechanical loss are assumed to be constant from no load to full load.

→ predetermination of efficiency in a motor:-

Let I be the current by the motor at any assumed load. then the armature current $I_a = I - I_f$

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

$$\text{total losses due to load } W_L = W_c + I_a^2 R_a$$

Input to the motor $P_i = V_1 I$

output of the motor $P_o = \text{Input} - \text{losses}$

$$= V_1 I - W_L$$

$$= V_1 I - (W_L + I_a^2 R_a)$$

$$\text{Efficiency } \eta = \frac{\text{output}}{\text{input}}$$

$$= \frac{V_1 I - (W_L + I_a^2 R_a)}{V_1 I}$$

- for different values of I can be assumed and at each line current, the efficiency can be computed as indicated above.

Determination of efficiency as a Generator:-

If the machine runs as a Generator, it will supply load current. let ' I ' be the load current then the armature current is $I_a = I + I_f$

Armature copper loss on load $= I_a^2 R_a$

total loss under load $W_L = W_L + I_a^2 R_a$

output of the machine when working as a Generator

$$P_o = V_1 I$$

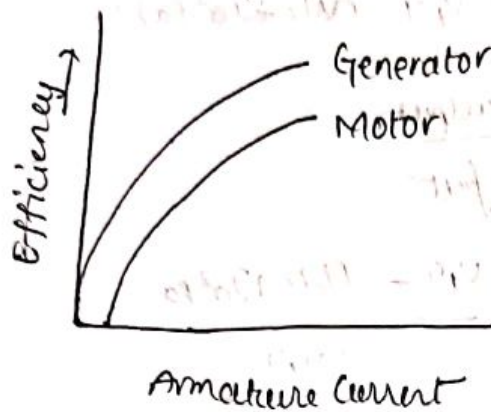
Input to the Generator = output + losses

$$P_i = V_1 I + W_L$$

$$= V_1 I + W_L + I_a^2 R_a$$

$$\text{Efficiency } \eta = \frac{O/P}{I/n}$$

$$= \frac{V_1 I}{V_1 I + W_c + I_a^2 R_a}$$



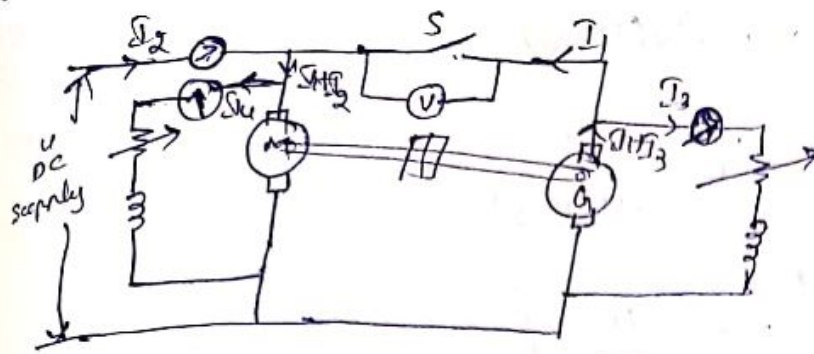
Advantages:-

- The power required to carry out the test is small because it is a no load Test. Therefore this method is quite economical.
- The efficiency can be determined at any load because constant losses are known.
- It is ~~very~~ convenient.

Disadvantages:-

- It does not take into account the stray load losses that occur when the machine is loaded.
- This test does not enable us to check the performance of the machine on full load.
- This test does not give quite accurate efficiency of the machine. It is because iron losses under actual load are greater than those measured. This is mainly due to armature reaction.

Hopkinson's Test / Regenerative Test :-



Calculations:-

$V \Rightarrow$ supply voltage

$$\text{Motor input} = V(I_1 + I_2)$$

$$\text{Generator output} = V(I_3)$$

To find the efficiencies of the machines let us consider 2 cases.

1. Assuming that both the machines have the same efficiency.

2. Assuming Iron, friction and windage losses are same in both the machines.

Case-1:- both have same machines:-

$$\text{Motor output} = \eta \times \text{motor input}$$

$$= \eta \times V(I_1 + I_2)$$

$$= \text{Generator input}$$

$$\text{Generator output} = \eta \times \text{generator input}$$

$$= \eta \times \eta \times V(I_1 + I_2)$$

$$= \eta^2 \times V(I_1 + I_2)$$

But gen output $\approx UI_1$
motor

$$UI_1 \approx \eta^2 UI(I_1 + I_2)$$

$$\eta^2 = \frac{UI_1}{UI(I_1 + I_2)}$$

$$\boxed{\eta = \sqrt{\frac{I_1}{I_1 + I_2}}}$$

Conclusion: This expression gives the value of efficiency sufficiently accurate for a rough test. However if greater accuracy is required the efficiencies of the two machines should be calculated separately as indicated below.

Case 2: Assuming constant losses are same in both machines

$R_a \Rightarrow$ armature resistance of each machine

$I_3 \Rightarrow$ field current of Generator G.

$I_4 \Rightarrow$ field current of Motor M.

Armature Copper losses in generator $= (I_1 + I_3)^2 R_a$

Armature Copper loss in motor $= (I_1 + I_2 - I_4)^2 R_a$

Shunt Copper loss in Generator $= UI_3$

Shunt Copper loss in Motor $= UI_4$

Power drawn from the DC supply is $= UI_2 =$ total losses of the motor and Generator

$W_2 =$ total loss of G & M

If we subtract armature and shunt copper losses of the two machines from W_2 , we get iron, friction & windage losses of the two machines.

$$W_c = W_2 - [(I_1 + I_3)^2 R_a + (I_1 + I_2 - I_4)^2 R_a + V I_3 + V I_4]$$

Constant losses of Each Machine is $\frac{W_c}{2}$

Efficiency

for Generator:-

$$\text{output} = V I_1$$

$$\text{total losses} = \frac{W_c}{2} + (I_1 + I_3)^2 R_a + V I_3 = W_g$$

$$\eta_g = \frac{V I_1}{V I_1 + W_g}$$

for Motor)

$$\text{input} = V(I_1 + I_2)$$

$$\text{Total losses} = \frac{W_c}{2} + (I_1 + I_2 - I_4)^2 R_a + V I_4 = W_m$$

$$\eta_m = \frac{V(I_1 + I_2) - W_m}{V(I_1 + I_2)}$$

Advantages:-

1. The total power required to test the two machines is small, compare with the full load power of each machine.
2. The Machines can be Tested under full load condition's so that commutation qualities and Temperature rise can be checked.
3. It is more accurate to measure the loss directly than to measure it as the difference of the measured input and output.
4. All the measurements are electrical which are simpler and more accurate than Mechanical measurements.

Disadvantages:-

1. Two similar DC Machines are required.

Retardation Test / Running down Test:-

Case-I
If the supply to the armature is cut off but the field remains normally excited, the motor slows down gradually and finally stops. The kinetic energy of the armature is used up to overcome friction, windage and iron losses.

Case II
If the supply to the Armature as well as field excitation is cut off, the motor again slows down and finally stops. Now the kinetic energy of the armature is used to overcome only the friction and windage losses. This is expected, because in the absence of flux there will be no iron losses.