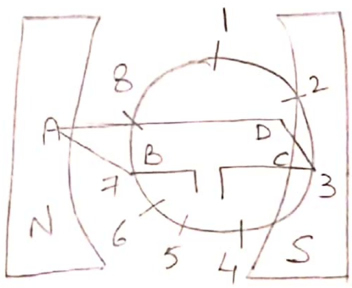
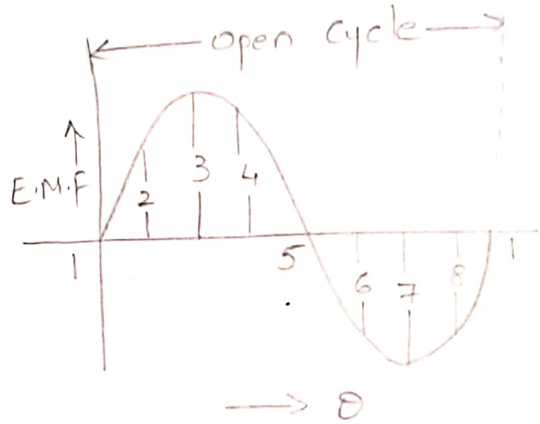
UNIT – I
(DC MACHINES)

→ An electric generator is a machine that converts mechanical energy into electrical energy.

→ An electric generator is based on the principle that whenever magnetic flux is cut by a conductor, an emf is induced which will cause a current to flow if the conductor circuit is closed.

Simple Loop Generator





Consider a single turn loop (or coil) ABCD rotating clockwise in a uniform magnetic field with a constant speed. As the coil rotates, magnetic flux linking the coil sides AB and CD changes continuously. Hence the e.m.f induced in these coil sides also changes.

(i) When the coil is in position 1, the generated e.m.f is zero because the coil sides (AB and CD) are cutting no magnetic flux.

(ii) When the coil is in position 2, the coil sides are moving at an angle to the magnetic flux and, therefore, a low e.m.f is generated.

(iii) when the loop is in position 3, the coil sides ~~are~~ are are at right angle to the magnetic flux and therefore, cutting the flux at maximum rate.

(iv) At position 4, the generated e.m.f is less because the coil sides are cutting the magnetic flux at an angle.

(v) At position 5, no magnetic lines are cut and hence, induced e.m.f is zero.

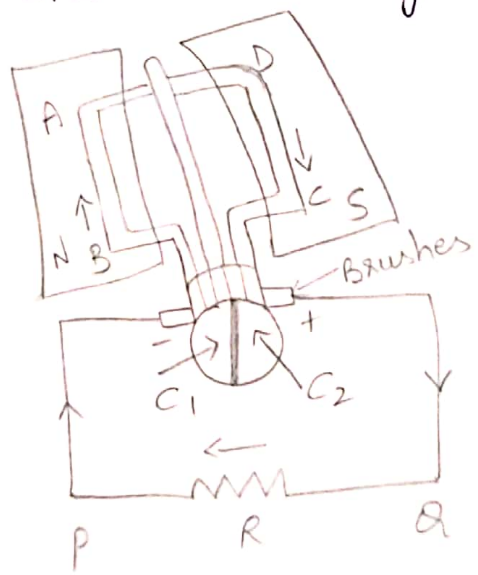
(vi) At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f is reversed.

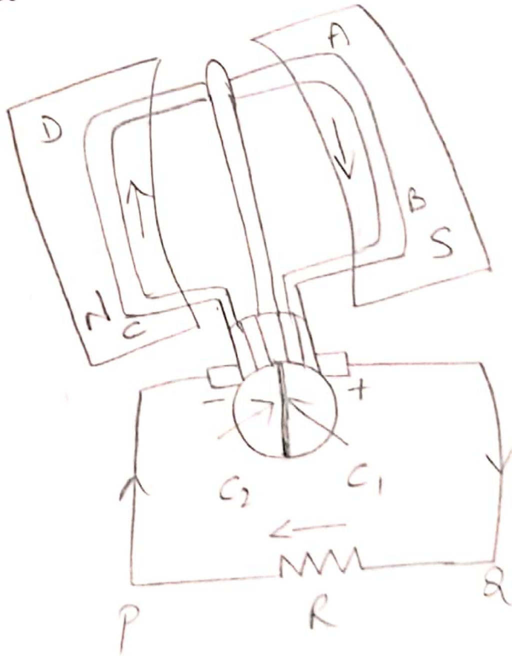
(vii) At position 7, maximum e.m.f and at positon 8, low e.m.f is generated and zero when at position 1.

This cycle repeats with each revolution of the coil.

Function of Commutator

The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator



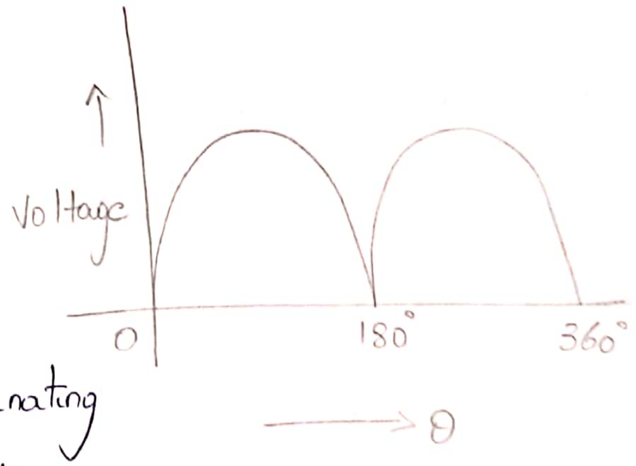


∴ Commutator Consists of a Cylindrical metal ring cut into two halves or Segments C_1 and C_2 separated by a thin sheet of mica. The ends of Coil sides AB and CD are connected to the segments C_1 and C_2. Two stationary Carbon brushes rest on the Commutator and leads Current to the external load.

(1) The Coil sides AB and CD are under N-pole and S-pole. C_1 connects the coil side AB to point P of the load Resistance R and C_2 connects the Coil side CD to point Q. The direction of current is from Q to P.

(ii) After half a revolution of the coil the coil side AB is under S-pole and coil side CD under N-pole. The currents in the coil sides now flow in the reverse direction but the segments C_1 and C_2 have also moved through 180°. The direction of current is again from Q to P.

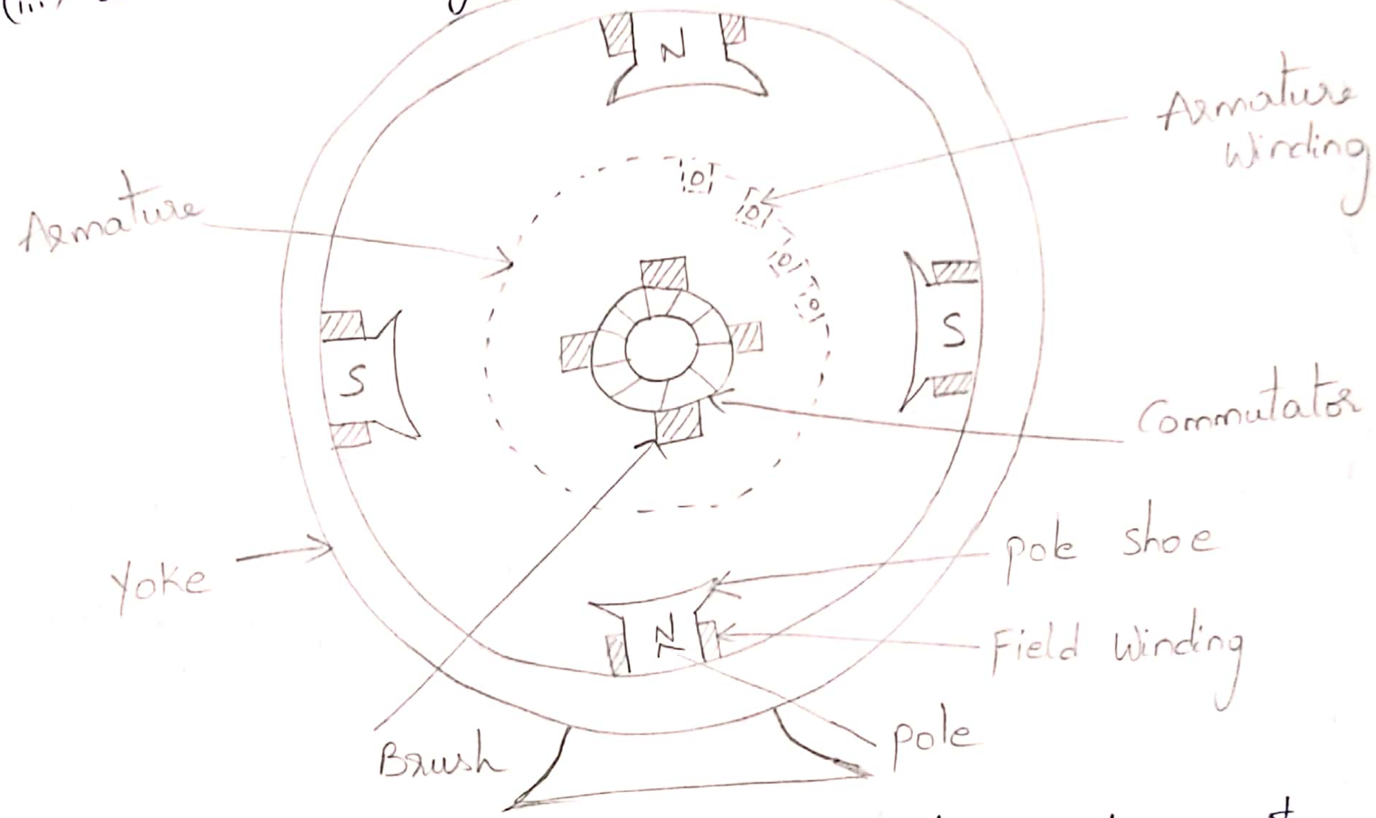
Thus the alternating voltage generated in the coil will appear as direct voltage across the brushes. By the use of Commutator we converted the generated alternating voltage into pulsating direct voltage.



A pulsating direct voltage produced by a single loop is not suitable for many commercial uses. By using a large number of coils connected in series steady direct voltage will be obtained. This arrangement is known as armature winding.

Construction of DC Generator

The d.c generators and d.c motors have the same general Construction. Any d.c generator can be run as d.c motor and Vice-Versa. All d.c machines have five principal Components (i) field system (ii) armature Core (iii) armature winding (iv) Commutator (v) brushes.



(i) Field System – The function of the field system is to produce uniform magnetic field within which the armature rotates. It consists of a number of salient poles bolted to the inside of circular frame (generally called yoke). The yoke is usually made of solid cast steel whereas the pole pieces are composed of stacked laminations. Field Coils are mounted on the poles and carry the d.c. exciting current. The field coils are connected in such a way that adjacent poles have opposite polarity.

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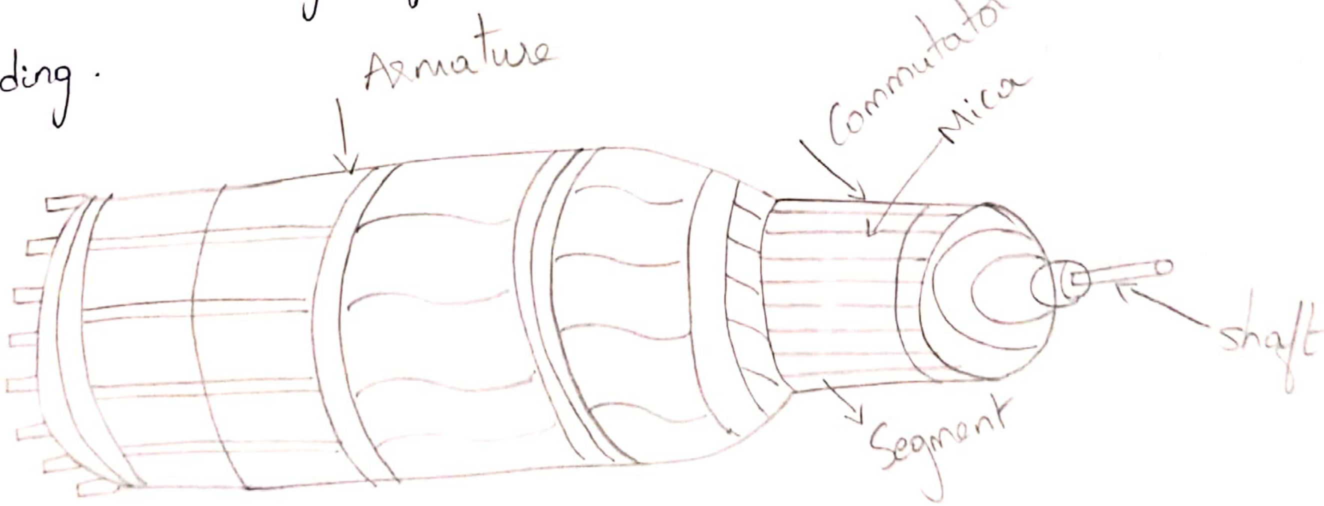
(ii) Armature Core – The armature core is keyed to the machine shaft and rotates b/w the field poles. It consists of slotted soft-iron laminations (about 0.4 to 0.6mm thick) that are stacked to form a cylindrical core. The laminations are individually coated with a thin insulating film so that they do not come in electrical contact with each other. The purpose of laminating the core is to reduce the eddy current loss.

(iii) Armature Winding – The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding. This is the winding in which "working" e.m.f is induced. The armature conductors are connected in series-parallel; the conductors being connected in series so as to increase the voltage and in parallel paths so as to increase the current. The armature winding of a d.c. machine is a closed-circuit winding.



(iv) Commutator – A Commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes. The Commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine. Depending upon the manner in which the armature conductors are connected to the Commutator segments, there are two types of armature windings
(a) lap winding (b) wave winding.

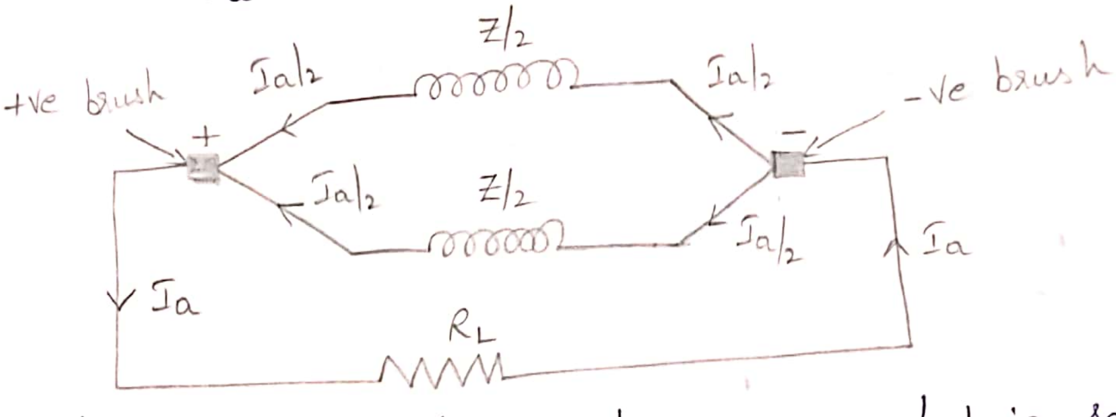
(v) Brushes – The purpose of brushes is to ensure electrical connections between the rotating Commutator and stationary external load circuit. The brushes are made of Carbon and rest on the Commutator. The brush pressure is adjusted by means of adjustable springs. If the brush pressure is very large, the friction produces heating of the Commutator and the brushes. On the other hand, if it is too weak, the imperfect contact with the Commutator may produce sparking.

Types of Armature Windings

There are two types of d.c armature windings

(i) Wave Winding – The armature coils are connected in series through commutator segments in such a way that the armature winding is divided into two parallel paths irrespective of the number of poles of the machine. if there are Z armature conductors, then $Z/2$ conductors will be in series in each parallel path. Each parallel path will carry a current $I_a/2$ where I_a is the total armature current.

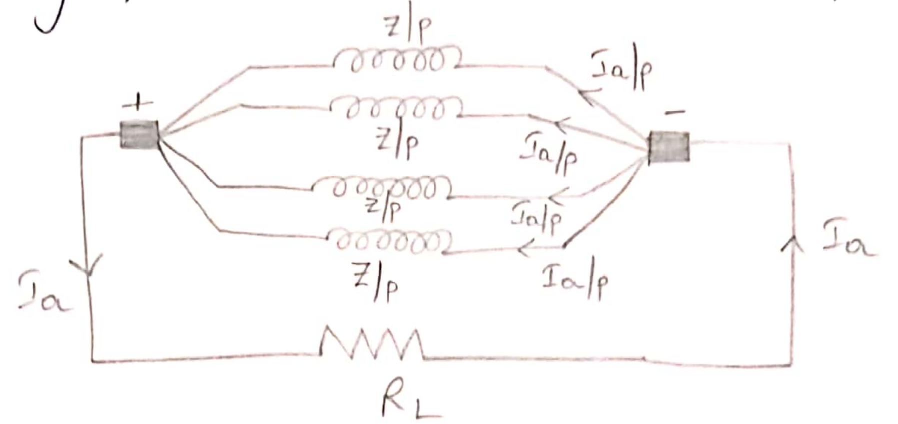
$$I_a = 2 \times \text{Current/parallel path}.$$



(ii) Lap Winding – The armature coils are connected in series through commutator segments in such a way that the armature winding is divided into as many parallel paths as the number of poles of the machine. If there are Z conductors and 'p' poles then there will be 'p' parallel paths, each containing Z/p conductors in series. Each parallel path will carry a current of I_a/p where I_a is the total armature current.

$$I_a = P \times \text{Current/parallel path}.$$

Assuming $P = 4$ so we have 4 parallel paths.



E.M.F. Equation of a D.C. Generator

Let, ϕ = magnetic flux/pole in Wb

Z = total number of armature conductors

P = number of poles

A = number of parallel paths

= 2 (for wave winding)

= P (for lap winding)

N = Speed of armature in r.p.m.

E_g = e.m.f of the generator

= e.m.f/ parallel path.

Magnetic flux cut by one conductor in one revolution of the armature, $d\phi = P.\phi$ webers.

Time taken to complete one revolution.

$$dt = \frac{60}{N} \text{ second}$$

$$\text{e.m.f generated/conductor} = \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ Volts}$$

e.m.f of generator, E_g = e.m.f/parallel path

$$= \left(\frac{\text{e.m.f}}{\text{Conductor}}\right) \times \text{no of conductors in series per } \parallel^{le} \text{ path}$$

$$= \frac{PN\phi}{60} \times \frac{Z}{A} = \frac{PZN\phi}{60A}$$

$\boxed{E_g = \frac{PZN\phi}{60A}}$ where $A = 2$ for wave, $A = P$ for lap winding

Prob ①

An 8-pole, lap-wound armature rotated at 350 r.p.m is required to generate 260V. The useful magnetic flux per pole is 0.05Wb. If the armature has 120 slots, calculate the number of conductors per slot.

Sol:-

$$E_g = \frac{PZN\phi}{60A}$$

$A = P = 8$, $E_g = 260V$, $N = 350$ r.p.m, $\phi = 0.05$ Wb

$$260 = \frac{8 \times Z \times 350 \times 0.05}{60 \times 8}$$

$$\therefore Z = \frac{260 \times 60 \times 8}{8 \times 350 \times 0.05} = 890$$

$\therefore$ No of Conductors / slot $= \frac{890}{120} = 7.14 = 8$ (b'coz value should be even)

Prob ②

The armature of a 6-pole, 600r.p.m lap-wound generator has 90 slots. If each coil has 4 turns, calculate the flux per pole required to generate an e.m.f of 288 volts

Sol:- Each turn has two active conductors and 90 coils are required to fill 90 slots.

$$Z = 90 \times 4 \times 2 = 720$$

$$E_g = \frac{PZN\phi}{60A}$$

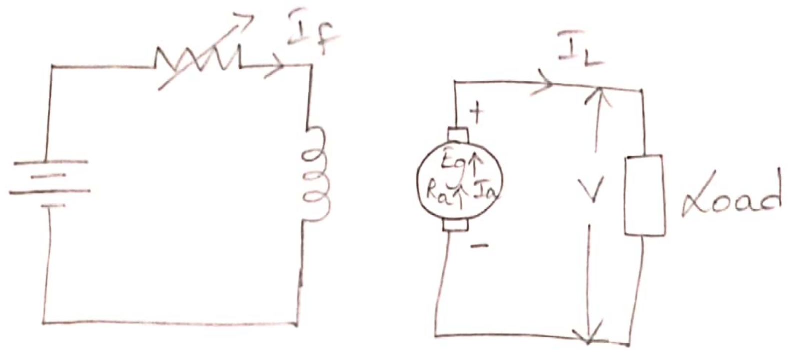
$$288 = \frac{6 \times 720 \times 600 \times \phi}{60 \times 6}$$

$$\therefore \phi = \frac{288 \times 60 \times 6}{720 \times 6 \times 600} = 0.04 \text{ wb}.$$

Types of D.C. Generators

(i) Separately Excited D.C. Generators

A d.c generator whose field magnet winding is supplied current from an independent external d.c. source (e.g. a battery) is called a separately excited generator.



($R_a \rightarrow$ Armature resistance)

Armature current, $I_a = I_L$

Terminal Voltage, $V = E_g - I_a R_a$

Electric power developed $= E_g I_a$

Power delivered to load $= E_g I_a - I_a^2 R_a = I_a(E_g - I_a R_a) = V I_a$ (or) $V I_L$

(ii) Self-Excited D.C. Generators

A d.c. generator whose field magnet winding is supplied current from the output of the generator itself is called a self excited generator. There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature.

(a) Series generator – In a series-wound generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as load.

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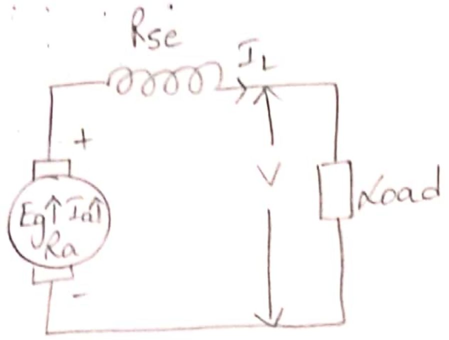


Armature Current, $I_a = I_{se} = I_L = I$

Terminal Voltage, $V = E_g - I(R_a + R_{se})$

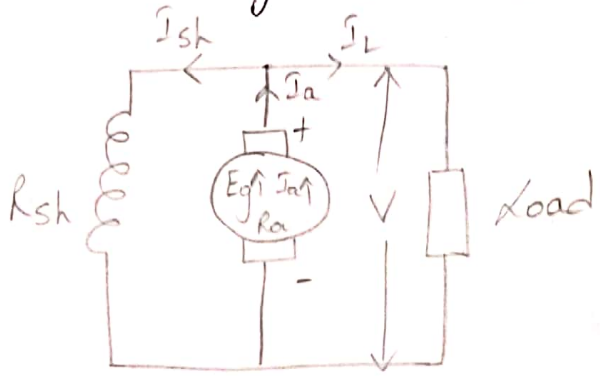
Power developed in armature $= E_g I_a$

power delivered to load $= E_g I_a - I_a^2 (R_a + R_{se})$

$= I_a [E_g - I_a (R_a + R_{se})]$

$= V I_a$ & $V I_L$

(b) <u>Shunt generator</u> – In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it.



Shunt field Current, $I_{sh} = V/R_{sh}$

Armature Current, $I_a = I_L + I_{sh}$

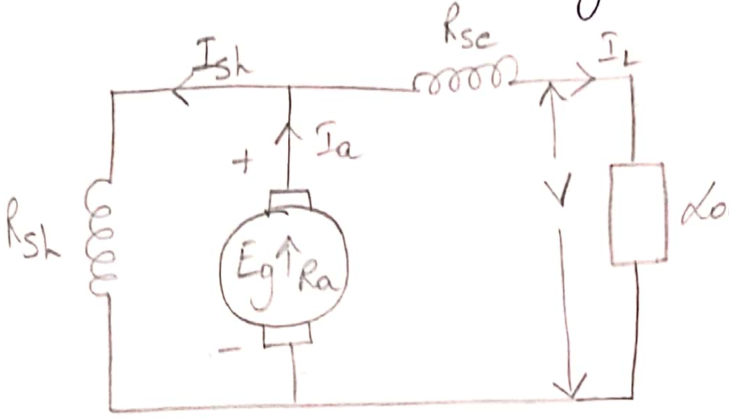
Terminal Voltage, $V = E_g - I_a R_a$

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$

(c) <u>Compound generator</u> – In a compound-wound generator, there are two sets of field windings on each pole – one is in series and the other in parallel with the armature. There are two types of compound generators.

(1) Short shunt – in which only shunt field winding is in parallel with the armature winding.



Series field Current, $I_{se} = I_L$

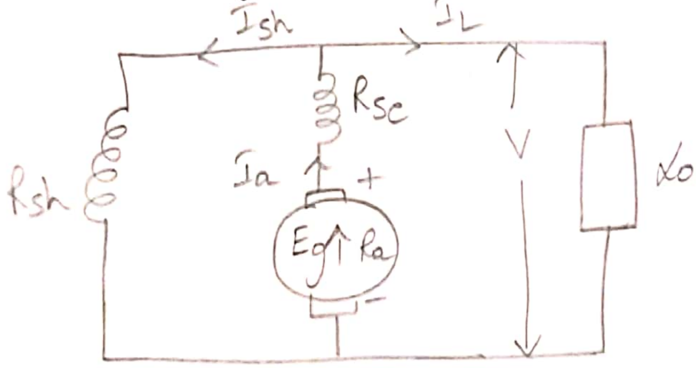
Shunt field Current, $I_{sh} = \dfrac{V + I_{se} R_{se}}{R_{sh}}$

Terminal Voltage, $V = E_g - I_a R_a - I_{se} R_{se}$

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$

(2) Long shunt – in which shunt field winding is in parallel with both series field and armature winding



Series field Current, $I_{se} = I_a = I_L + I_{sh}$

Shunt field Current, $I_{sh} = \dfrac{V}{R_{sh}}$

Terminal Voltage, $V = E_g - I_a (R_a + R_{se})$

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$

Prob (1) A 100KW, 240V shunt generator has a field resistance of 55Ω and armature resistance of 0.067Ω. Find the full-load generated Voltage.

Sol:-

$$V = E_g - I_a R_a$$

$$E_g = V + I_a R_a$$

$$V = 240V, \quad I_a = I_L + I_{sh}$$

$$P = V I_L \Rightarrow I_L = \frac{P}{V} = \frac{100\times10^3}{240} = 416.7A$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{55} = 4.36A$$

$$\therefore I_a = 416.7 + 4.36 = 421.1A$$

$$E_g = V + I_a R_a$$
$$= 240 + (421.1)(0.067)$$
$$= 268.2V$$

Prob (2) A Compound generator is to supply a load of 250 lamps, each rated at 100W, 250V. The armature, series and shunt windings have resistances of 0.06Ω, 0.04Ω and 50Ω respectively. Determine the generated e.m.f when the machine is connected in (i) Long shunt (ii) short shunt. Take drop per brush as 1V.

Sol:- (i)

$$V = E_g - I_a R_a - I_{se} R_{se} - \text{total brush drop}$$

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

$$P = V I_L \Rightarrow I_L = \frac{P}{V}$$

$$= \frac{250\times100}{250} = 100A$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{50} = 5A$$

$$\therefore I_a = I_L + I_{sh} = 100+5 = 105A$$

We have two brushes so,

Total brush drop $= 2\times1 = 2V$.

$$E_g = V + I_a R_a + I_{se} R_{se} + \text{Total brush drop}$$

$$= 250 + 105\times0.06 + 105\times0.04 + 2$$

$$= 262.5V$$

(ii) $V = E_g - I_a R_a - I_{se} R_{se}$

$$E_g = V + I_a R_a + I_{se} R_{se} + \text{Total brush drop}$$

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

$$I_L = 100A = I_{se}$$

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

$$= \frac{250 + 100\times0.04}{50} = 5.08A.$$

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

$$= 100 + 5.08 = 105.08A$$

$$\therefore E_g = 250 + 105.08\times0.06 + 100\times0.04 + 2$$

$$= 262.3V$$

Prob 3

A 4-pole lap wound d.c. shunt generator has a useful flux per pole of 0.07 Wb. The armature winding consists of 220 turns, each of 0.004 Ω resistance. Calculate the terminal Voltage when running at 900 r.p.m. if the armature current is 50A.

Sol:-

$$E_g = \frac{PZN\phi}{60A}$$

$Z = 220 \times 2 = 440$ (∵ each turn has 2 conductors).

$N = 900$ r.p.m, $\phi = 0.07$ Wb, $P = 4$, $A = P = 4$

$$\therefore E_g = \frac{4 \times 440 \times 900 \times 0.07}{60 \times 4} = 462V$$

no of turns per parallel path $= \frac{Z}{P} = \frac{220}{4} = 55$

Resistance per parallel path $= 0.004 \times 55 = 0.22\Omega$

Resistance for 4 parallel paths, $R_a = \frac{0.22}{4} = 0.055\Omega$.

$$E_g = V + I_a R_a$$

$$462 = V + 50 \times 0.055$$

$$= 459.25V$$

Prob 4 A 30KW, 300V d.c. shunt generator has armature and field resistances of 0.05Ω and 100Ω respectively. Calculate the total power developed by the armature

Sol:- $I_L = \frac{P}{V} = \frac{30 \times 10^3}{300} = 100A$, $I_{sh} = \frac{V}{R_{sh}} = \frac{300}{100} = 3A$

$I_a = I_L + I_{sh} = 100 + 3 = 103A$

$E_g = V + I_a R_a = 300 + 103 \times 0.05 = 305.15V$

Power by armature $= E_g I_a = 305.15 \times 103$

$= 31.43KW$

Losses in a D.C. Machine

The losses in d.c. machine (generator or motor) appear as heat and thus raise the temperature of the machine. They also lower the efficiency of the machine.

- Losses in a d.c. machine
  - Copper Losses
    - Armature Cu loss
    - Shunt field Cu loss
    - Series field Cu loss
  - Iron Losses
    - Hysteresis loss
    - Eddy Current loss
  - Mechanical losses
    - Friction
    - Windage.

1. Copper Losses — These losses occur due to currents in the various windings of the machine.

(i) Armature Copper loss $= I_a^2 R_a$

(ii) Shunt field Copper loss $= I_{sh}^2 R_{sh}$

(iii) Series field Copper loss $= I_{se}^2 R_{se}$.

2. Iron or Core losses — These losses occur in the armature of a d.c. machine and are due to the rotation of armature in the magnetic field of the poles.

(i) Hysteresis loss, $P_h = \eta B_{max}^{1.6} f V$ watts

B_{max} = Maximum magnetic flux density in armature

f = frequency of magnetic reversals

$= \frac{NP}{120}$

V = Volume of armature in m^3

η = Steinmetz hysteresis coefficient

(ii) Eddy Current Loss, $P_e = K_e B_{max}^2 f^2 t^2 V$ Watts

K_e = Constant
B_{max} = Maximum magnetic flux density
f = frequency
t = Thickness of lamination
V = Volume of Core in m^3

3. Mechanical Losses – These losses are due to friction and windage.

(i) friction loss e.g. bearing friction, brush friction
(ii) Windage loss i.e. air friction of rotating armature.

→ Iron losses and mechanical losses together are called stray losses.

Constant and Variable losses

The losses in a d.c. generator or d.c. motor may be sub-divided into

(i) Constant losses – Those losses in a d.c. generator which remain constant at all loads are known as constant losses.

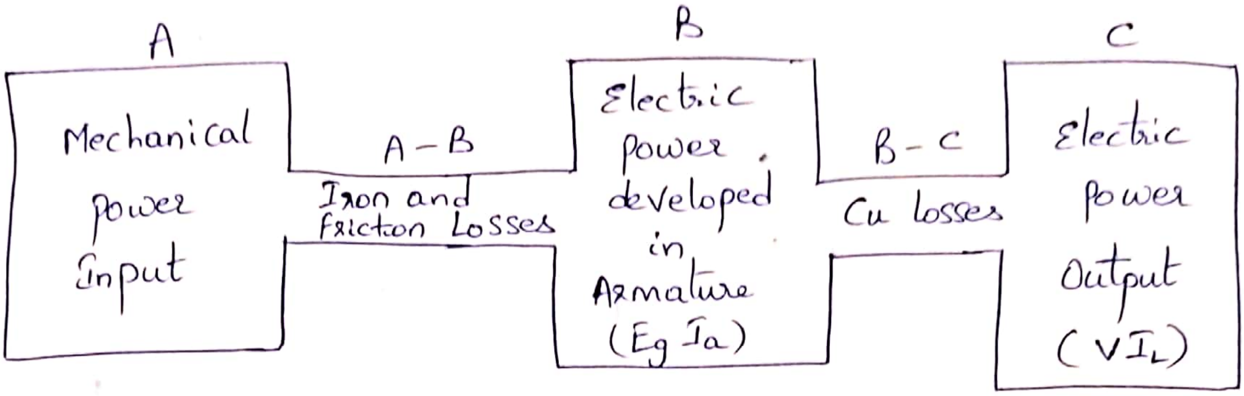
The constant losses in a d.c. generator are:
(a) iron losses (b) mechanical losses (c) shunt losses.

(ii) Variable losses – Those losses in a d.c generator which vary with load are called variable losses. The variable losses in a d.c. generator are:

(a) Copper loss in armature winding ($I_a^2 R_a$)
(b) Copper loss in series field winding ($I_{se}^2 R_{se}$)

Total Losses = Constant losses + Variable losses

Power stages (D.C. generator)



(i) Mechanical efficiency

$$\eta_m = \frac{B}{A} = \frac{E_g I_a}{\text{Mechanical power input}}$$

(ii) electrical efficiency

$$\eta_e = \frac{C}{B} = \frac{V I_L}{E_g I_a}$$

(iii) Commercial or overall efficiency

$$\eta_c = \frac{C}{A} = \frac{V I_L}{\text{Mechanical power input}}$$

$$\eta_c = \eta_m \times \eta_e$$

Commercial efficiency, $\eta_c = \frac{C}{A}$

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

$$= \frac{\text{Input} - \text{Losses}}{\text{Input}}.$$

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Condition for Maximum Efficiency

The efficiency of a d.c. generator is not constant but varies with load. Consider a shunt generator delivering a load current I_L at a terminal voltage V.

Generator output = $V I_L$

Generator input = output + losses

= $V I_L$ + Variable losses + Constant losses

$= V I_L + I_a^2 R_a + W_c$

$= V I_L + (I_L + I_{sh})^2 R_a + W_c$

I_{sh} is small compared to I_L so can be neglected

$\therefore$ Generator input $= V I_L + I_L^2 R_a + W_c$

$$\eta = \frac{\text{output}}{\text{input}} = \frac{V I_L}{V I_L + I_L^2 R_a + W_c}$$

$$= \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{W_c}{V I_L}\right)}$$

The efficiency will be max when the denominator is minimum

$$\frac{d}{d I_L}\left(\frac{I_L R_a}{V} + \frac{W_c}{V I_L}\right) = 0$$

$$\frac{R_a}{V} - \frac{W_c}{V I_L^2} = 0$$

$$\frac{R_a}{V} = \frac{W_c}{V I_L^2} \Rightarrow I_L^2 R_a = W_c$$

Variable loss = Constant loss

The load current corresponding to maximum efficiency is

$$\boxed{I_L = \sqrt{\frac{W_c}{R_a}}}$$

Prob ① The shunt generator delivers full load current of 200A at 240V. The shunt field resistance is 60Ω and full-load efficiency is 90%. The stray losses are 800W. Find (i) armature resistance (ii) current at which maximum efficiency occurs.

Sol:- (i) Armature Cu Loss $= I_a^2 R_a$

$I_a = I_L + I_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{60} = 4A$; $I_L = 200A$

$\therefore I_a = 200 + 4 = 204A$.

Armature Cu Loss = Total Losses − Constant Losses.

(∵ Total Losses = Variable losses + Constant losses)

Generator output $= VI_L = 240 \times 200 = 48000W$

" input $= \frac{output}{\eta} = \frac{48000}{0.9} = 53333W$

Total Losses $= i/p - o/p = 53333 - 48000 = 5333W$

Constant losses = stray Losses + shunt Cu Loss

$= 800 + I_{sh}^2 R_{sh}$

$= 800 + (4)^2(60) = 1760W$

$\therefore$ Armature Cu Loss $= 5333 - 1760 = 3573W$.

$I_a^2 R_a = 3573$

$R_a = \frac{3573}{I_a^2} = \frac{3573}{(204)^2} = 0.0858\Omega$

(ii) For max. efficiency,

Variable losses = Constant losses

$I_L^2 R_a = 1760$

$I_L = \sqrt{\frac{1760}{0.0858}} = 143.22A$

Prob (2)

A 75 KW shunt generator is operated at 230 V. The stray losses are 1810 W and shunt field circuit draws 5.35 A. The armature circuit has a resistance of 0.035 Ω and brush drop is 2.2 V. Calculate (i) total losses (ii) input of prime mover (iii) efficiency at rated load.

Sol:- (i) Load current, $I_L = \frac{P}{V} = \frac{75 \times 10^3}{230} = 326.1\,A$

Armature current, $I_a = I_L + I_{sh}$

$= 326.1 + 5.35$

$= 331.5\,A$

Armature Cu loss $= I_a^2 R_a = (331.5)^2 \times (0.035)$

$= 3846\,W$

Shunt Cu loss $= I_{sh}^2 R_{sh} = V I_{sh} = 230 \times 5.35$

$= 1230\,W$

Brush power loss $=$ Brush drop $\times I_a$

$= 2.2 \times 331.5 = 729\,W$

∴ Total losses = stray losses + Armature Cu loss + shunt Cu loss + Brush power loss

$= 1810 + 3846 + 1230 + 729 = 7615\,W$

(ii) Output power $= 75\,KW$

Input of prime mover $=$ o/p + Losses

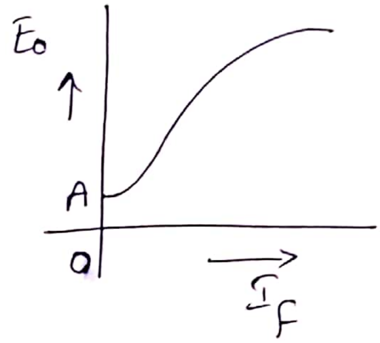
$= 75 \times 10^3 + 7615 = 82615\,W$

(iii) $\eta = \frac{o/p}{i/p} = \frac{75 \times 10^3}{82615} \times 100 = 90.8\,\%$

D.C. Generator Characteristics

(i) Open Circuit Characteristic (O.C.C) — This curve shows the relation between the generated e.m.f at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve.

Points to be noted :



When the field current is zero, there is some generated e.m.f OA. This is due to the residual magnetism in the field poles.

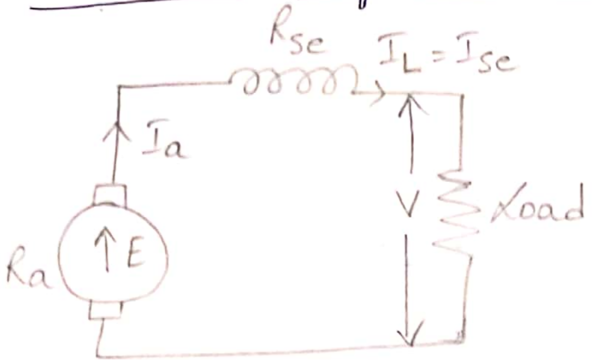
As I_f is increased from zero in steps the corresponding values of E_0 also increases.

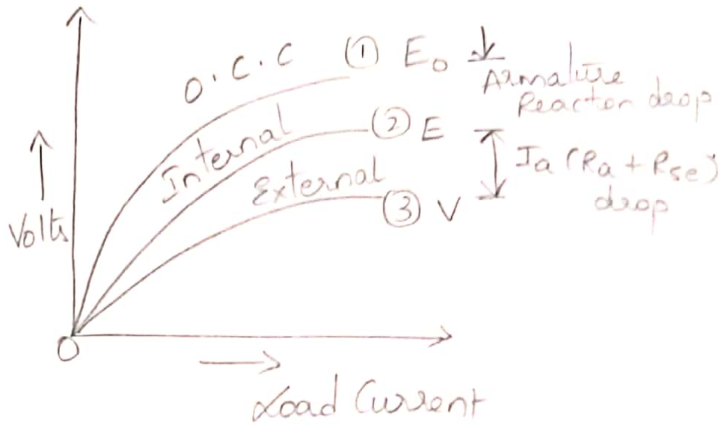
(ii) Internal or Total Characteristic (E/I_a) — This curve shows the relation between the generated e.m.f on load (E) and the armature current (I_a). The e.m.f. E will be less than E_0 due to the effects of armature reaction. Therefore, this curve lie below the open circuit characteristic.

Armature Reaction : Current flowing through armature conductors also creates a magnetic flux (called armature flux) distorts and weakens the magnetic flux coming from the poles (called main flux). The action of armature flux on the main flux is known as armature reaction.

(iii) External characteristic (V/I_L) — This curve shows the relation between the terminal voltage (V) and load current (I_L). The 'V' will be less than 'E' due to voltage drop in the armature circuit.

Characteristics of Series Generator





(Series generator so load current is same as exciting current b'coz same current flows)

(i) O.C.C – Curve 1 shows the open circuit characteristic of a series generator. As we increase the current in steps from zero voltage (E_0) also increases.

(ii) Internal characteristic – Curve 2 shows the total & internal characteristic of a series generator. It gives the relation between the generated e.m.f 'E' on load and armature current. Due to armature reaction, the flux in the machine will be less than the flux at no load. Hence, e.m.f 'E' generated under load conditions will be less than the e.m.f E_0 generated under no load conditions. Therefore internal characteristic curve lie below O.C.C. curve

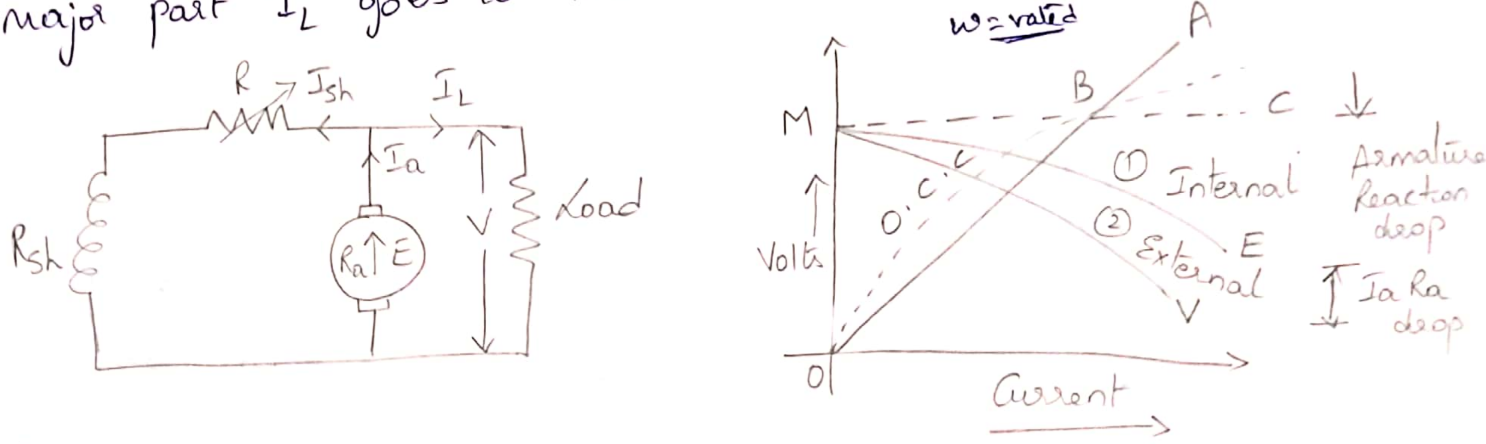
(iii) External characteristic – Curve 3 shows the external characteristic of a series generator. It gives the relation between terminal voltage V and load current I_L.

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

Since there is a drop of $I_a (R_a + R_{se})$ external characteristic curve will lie below internal characteristic curve.

Characteristics of a Shunt Generator

The armature current I_a splits up into two parts; a small fraction I_{sh} flows through shunt field winding while the major part I_L goes to the external load.



(i) O.C.C – The O.C.C of a shunt generator is similar to that of a series generator. The line OA represents the shunt field circuit resistance.

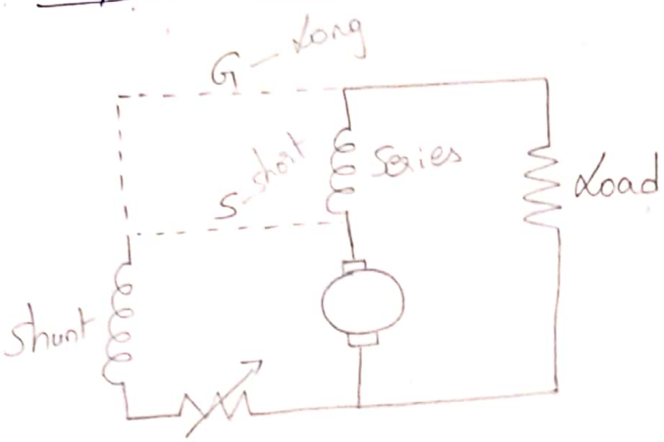
(ii) Internal characteristic – When the generator is loaded, flux per pole is reduced due to armature reaction. Therefore, e.m.f E generated on load is less than the emf generated at no load. As a result, the internal characteristic (E/I_a) drops down slightly.

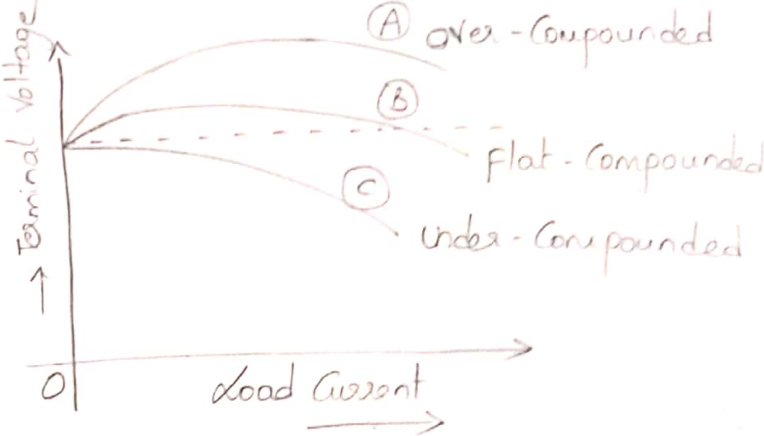
(iii) External Characteristic – Curve 2 shows the external characteristic of a shunt generator. It gives the relation between terminal Voltage V and load Current I_L.

$$V = E - I_a R_a$$
$$= E - (I_L + I_{sh}) R_a$$

Since there is a drop of $I_a R_a$ external characteristic will lie below the internal characteristic.

Compound Generator characteristics





The degree of Compounding depends upon the increase in series excitation with the increase in load Current.

(i) If series winding turns are so adjusted that with the increase in load Current, the terminal voltage increases, it is Called over-Compounded generator.

(ii) If series winding turns are so adjusted that with the increase in load Current, the terminal Voltage substantially remains Constant, it is Called flat - Compounded generator.

(iii) If series field winding has lesser number of turns than that for a flat-Compounded machine, the terminal Voltage falls with increase in load Current such a machine is Called under-Compounded generator.

D.C. Motor Principle

→ A machine that converts d.c. power (electrical) into mechanical power is known as a d.c. motor

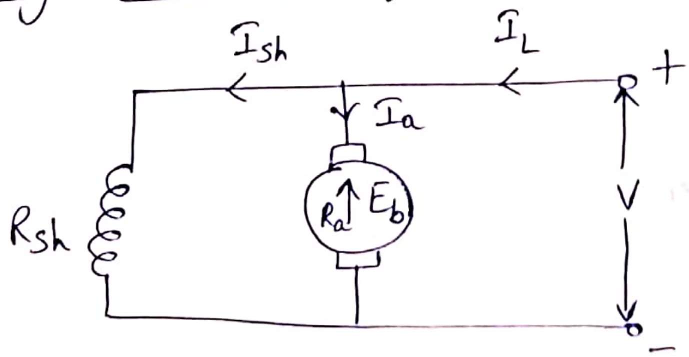
→ Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of this force is given by Fleming's left hand rule.

$$F = BIL \text{ newtons}.$$

→ the construction of d.c. motor is same as d.c. generator.

→ When the armature of a d.c. motor rotates, the armature conductors move through the magnetic field and hence e.m.f is induced in them. The induced e.m.f acts in opposite direction to the applied voltage 'V' which is known as back or counter e.m.f E_b $\left[E_b = \frac{PZN\phi}{60A} \right]$

Voltage Equation of D.C. Motor



Let,

V = applied voltage

E_b = back e.m.f

R_a = armature resistance

I_a = armature current

Since back e.m.f E_b acts in opposite to the applied voltage V, the net voltage across the armature circuit is $V - E_b$. The armature current I_a is

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

$$\boxed{V = E_b + I_a R_a}$$ → Voltage equation of d.c. motor

Power Equation

Multiplying Voltage Equation by I_a we get,

$$\boxed{V I_a = E_b I_a + I_a^2 R_a}$$ → power equation of the d.c. motor

$V I_a$ = electric power supplied to armature (armature input)

$E_b I_a$ = power developed by armature (armature output)

$I_a^2 R_a$ = electric power wasted in armature (armature Cu loss)

Condition for maximum power

The mechanical power developed by the motor is $P_m = E_b I_a$

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

For max power, $\frac{dP_m}{dI_a} = 0$

$$\therefore \frac{dP_m}{dI_a} = V - 2 I_a R_a = 0$$

$$I_a R_a = \frac{V}{2}$$

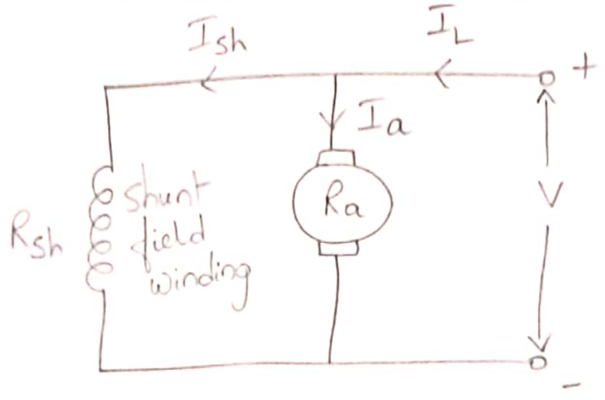
$$V = E_b + I_a R_a$$

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

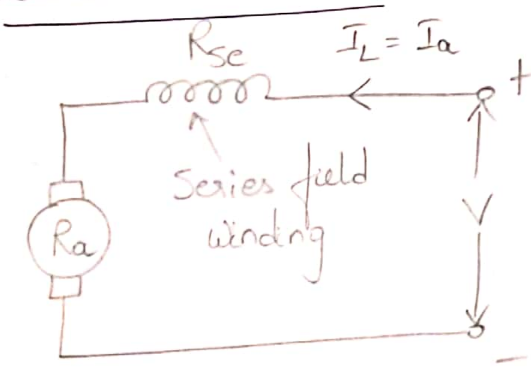
$$\boxed{\therefore E_b = \frac{V}{2}}$$ → Condition for max power

Types of D.C. Motors

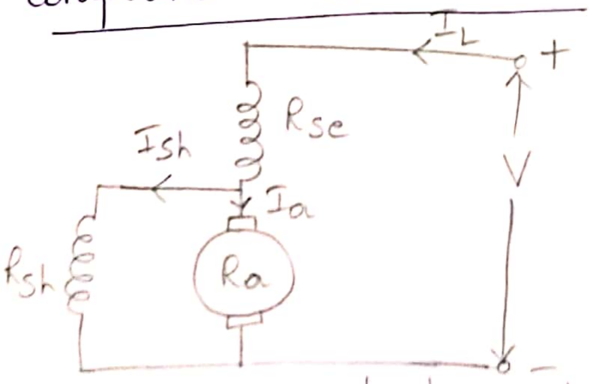
(i) **Shunt - Wound Motor** — The field winding is connected in parallel with the armature. The current through the shunt field winding is not the same as the armature current. Shunt field windings are designed to produce the necessary m.m.f by means of a relatively large number of turns of wire having high resistance.



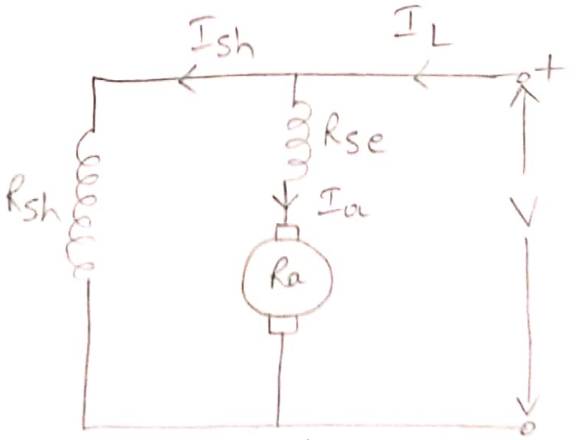
(ii) **Series-Wound Motor** — The field winding is connected in series with the armature. Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with few turns than shunt field windings for the same m.m.f. Therefore, a series field winding has small number of turns of thick wire with low resistance.



(iii) **Compound - Wound Motor** —



Short - Shunt Connection



Long - Shunt Connection

Compound-wound motor has two field windings, one connected in parallel with the armature and the other in series with it. When the shunt field winding is directly connected across the armature terminals it is called short-shunt connection. When the shunt field winding is so connected that it shunts the series combination of armature and series field, it is called long-shunt connection.

Prob ① The counter e.m.f of a shunt motor is 227V, the field resistance is 160Ω and field current is 1.5A. If the line current is 39.5A, find the armature resistance. Also find the armature current when the motor is stationary.

Sol:

$$V = I_{sh} R_{sh} = 1.5 \times 160 = 240V$$

$$I_a = I_L - I_{sh} = 39.5 - 1.5 = 38A$$

$$V = E_b + I_a R_a$$

$$R_a = \frac{V - E_b}{I_a} = \frac{240 - 227}{38}$$

$$= 0.342\Omega$$

At start-up, motor is stationary so $E_b = 0$

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

$$= \frac{240}{0.342} = 701.5A$$

Prob ② A 20KW, 250V d.c. shunt generator has armature and field resistances of 0.1Ω and 125Ω respectively. Calculate the total armature power developed when running (i) as a generator delivering 20KW output (ii) as a motor taking 20KW input.

Sol:- (i) As a generator,

$P = 20\times10^{3}\ W,\quad V = 250V,\quad R_a = 0.1\Omega,\quad R_{sh} = 125\Omega$

$$I_L = \frac{P}{V} = \frac{20\times10^{3}}{250} = 80A$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2A$$

$$I_a = I_L + I_{sh} = 80+2 = 82A$$

$$E_g = V + I_a R_a$$
$$= 250 + (82)(0.1) = 258.2V$$

$\therefore$ power developed in armature $= E_g I_a = (258.2)(82)$
$= 21.17KW$

(ii) As a motor,

$$I_L = 80A$$

$$I_{sh} = 2A$$

$$I_a = I_L - I_{sh} = 80-2 = 78A$$

$$E_b = V - I_a R_a$$
$$= 250 - (78)(0.1) = 242.2V$$

Power developed in armature $= E_b I_a$
$= (242.2)(78)$
$= 18.9KW$

Prob (3)

Find the useful flux per pole on no-load of 250V, 6-pole shunt motor having wave-connected armature winding with 110 turns. The armature resistance is 0.2Ω. The armature current is 13.3 A at the no-load speed of 908 r.p.m.

Sol:

$$E_b = V - I_a R_a$$

$$= 250 - (13.3)(0.2)$$

$$= 247.34V$$

$$E_b = \frac{PZN\phi}{60A} \Rightarrow \phi = \frac{E_b \times 60A}{PZN}$$

$$= \frac{247.34 \times 60 \times 2}{6 \times 220 \times 908}$$

$$= 24.8 \times 10^{-3} \text{ Wb}$$

$$= 24.8 \text{ mWb}.$$

$E_b = 247.34V$

$A = 2$

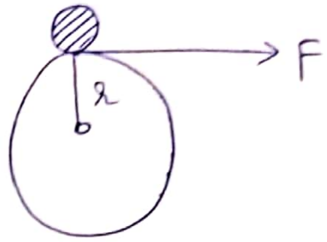
$P = 6$

$Z = 110 \times 2 = 220$

$N = 908$ r.p.m

Armature Torque of D.C. Motor

Torque is measured by the product of force (F) and radius (r).



$$T = F \times r$$

In a d.c. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature. Therefore, each conductor exerts a force, tending to rotate the armature. The sum of the torques due to all armature conductors is known as gross or armature torque (T_a).

Let,

r = average radius of armature in m

L = effective length of each conductor in m

Z = total number of armature conductors

A = number of parallel paths.

i = current in each conductor $= I_a/A$

B = average flux density in Wb/m^2

ϕ = flux per pole in Wb

P = number of poles.

Force on each conductor, $F = BiL$ newtons

Torque due to one conductor $= F \times r$ newton-metre

Total armature torque, $T_a = ZFr$ newton-metre

$= ZBiLr$

Now, $i = \dfrac{I_a}{A}$

$B = \dfrac{\phi}{a}$ where 'a' is cross sectional area of flux path at radius 'r'

$$\therefore a = \frac{2\pi r L}{P}$$

$$T_a = Z B i L r$$

$$= Z \times \frac{\phi}{\frac{2\pi r L}{P}} \times \frac{I_a}{A} \times L \times r$$

$$= \frac{Z \phi I_a P}{2\pi A} \text{ N-m}$$

$$= 0.159\, Z \phi I_a \left(\frac{P}{A}\right) \text{Nm}$$

Since Z, P and A are fixed for a given machine

$$T_a \propto \phi I_a.$$

(i) For a shunt motor, ϕ is practically constant.

$$\therefore T_a \propto I_a$$

(ii) For a series motor, ϕ is directly proportional to I_a

$$\therefore T_a \propto I_a^2.$$

<u>Alternative expression for Ta</u>

We have, $E_b = \dfrac{PZN\phi}{60A} \Rightarrow \dfrac{PZ\phi}{A} = \dfrac{60 \times E_b}{N}$

$$\therefore T_a = 0.159 \left(\frac{60 \times E_b}{N}\right) I_a$$

$$= 9.55 \times \frac{E_b I_a}{N} \text{ N-m}.$$

Prob ① An armature of a 6-pole machine 75cm in diameter has 664 Conductors each having an effective length of 30cm and carrying a current of 100A. If 70% of total conductors lie simultaneously in the field of average flux density 0.85 wb/m². Find (i) armature torque (ii) horse power output at 250 r.p.m.

Sol:- (i) $T_a = ZBil\,r$ N-m

$r = \frac{d}{2} = \frac{75}{2} = 37.5$

$$= 664 \times \frac{70}{100} \times 0.85 \times 100 \times \frac{30}{100} \times \frac{37.5}{100}$$

$$= 4445.4 \text{ N-m}$$

(ii) power output $= \frac{2\pi N T_a}{60 \times 746}$ H.P

$$= \frac{2 \times 3.14 \times 250 \times 4445.4}{60 \times 746} = 156 \text{ H.P}$$

Prob ② A d.c. motor takes an armature current of 110A at 480V The armature circuit resistance is 0.2Ω. The machine has 6 poles and the armature is lap-connected with 864 conductors The flux per pole is 0.05Wb. Find (i) the speed and (ii) the gross torque developed by the motor.

Sol:- (i) $E_b = V - I_a R_a = 480 - (110)(0.2) = 458$ Volts

$$E_b = \frac{PZN\phi}{60A} \Rightarrow N = \frac{E_b \times 60 \times A}{P \times Z \times \phi} = \frac{458 \times 60 \times 6}{6 \times 864 \times 0.05}$$

$$= 636 \text{ r.p.m}$$

(ii) Gross torque

$$T_a = 9.55 \times \frac{E_b I_a}{N} = \frac{9.55 \times \cancel{636}\,458 \times 110}{636} = 756.4 \text{ N-m}$$

(or)

$$T_a = 0.159\,\phi Z I_a \left(\frac{P}{A}\right) = 0.159 \times 0.05 \times 864 \times 110 \times \left(\frac{6}{6}\right)$$

$$= 755.5 \text{ N-m}$$

Speed of a D.C. Motor

$$E_b = V - I_a R_a$$

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

$$\frac{PZN\phi}{60A} = V - I_a R_a$$

$$N = \frac{V - I_a R_a}{\phi} \; \frac{60A}{PZ}$$

$$N = \frac{K(V - I_a R_a)}{\phi} \quad \text{where } K = \frac{60A}{PZ}$$

But $V - I_a R_a = E_b$

$$\therefore N = K\frac{E_b}{\phi} \Rightarrow N \propto \frac{E_b}{\phi}$$

In a d.c. motor, speed is directly proportional to back e.m.f E_b and inversely proportional to flux per pole ϕ.

Speed Relations

Let initial values be N_1, ϕ_1 and E_{b1} and the corresponding final values are N_2, ϕ_2 and E_{b2}, then,

$$N_1 \propto \frac{E_{b1}}{\phi_1} \quad \text{and} \quad N_2 \propto \frac{E_{b2}}{\phi_2}$$

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

(i) for a shunt motor, flux practically remains constant so $\phi_1 = \phi_2$

$$\therefore \frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}$$

(ii) For a series motor, $\phi \propto I_a$

$$\therefore \frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{I_{a2}}{I_{a1}}$$

where I_{a1} = initial armature current

I_{a2} = final armature current.

Speed Regulation

The speed regulation of a motor is the change in speed from full-load to no load and is expressed as a percentage of the speed at full-load i.e.

$$\% \text{ speed regulation} = \frac{\text{N.L. Speed} - \text{F.L. Speed}}{\text{F.L. Speed}} \times 100$$

$$= \frac{N_0 - N}{N} \times 100$$

where $N_0 \rightarrow$ No-load Speed

$N \rightarrow$ Full load Speed.

Prob① A d.c. Shunt generator delivers an output of 100kW at 500V when running at 800 r.p.m. The armature and field resistances are 0.1Ω and 100Ω respectively. Calculate the speed of the same machine when running as a shunt motor and taking 100kW input at 500V. Allow 1 volt per brush for contact drop

Sol:- As a Generator,

$$I_{a_1} = I_L + I_{sh}$$

$$I_L = \frac{P}{V} = \frac{100\times10^3}{500} = 200A$$

$$= 200 + 5$$

$$= 205A.$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{500}{100} = 5A$$

$$E_1 = V_1 + I_{a_1} R_a + \text{Brush drop}$$

$$= 500 + (205)(0.1) + 2\times1$$

$$= 522.5V$$

$$N_1 = 800 \text{ r.p.m}.$$

As a Motor,

$$I_{a_2} = I_L - I_{sh}$$

$$= 200 - 5 = 195A$$

$$E_2 = V - I_{a_2} R_a - \text{Brush drop}$$

$$= 500 - (195)(0.1) - 2\times1$$

$$= 478.5V$$

For a shunt m/c,

$$\frac{N_2}{N_1} = \frac{E_2}{E_1}$$

$$N_2 = \left(\frac{E_2}{E_1}\right) N_1$$

$$= \frac{478.5}{522.5} \times 800 = 732.6 \text{ r.p.m}$$

prob② A 200V series motor takes a current of 100A and runs at 1000 r.p.m. The total resistance of the motor is 0.1Ω and the field is unsaturated. Calculate

(i) the percentage change in torque and speed if the load is so changed that motor current is 50A.

(ii) the motor current and speed if the torque is halved.

Sol: (i) $T \propto \phi I_a$, $\phi \propto I_a$ $\qquad I_{a_1} = 100A$

$T_1 \propto I_{a_1}^2$ & $T_2 \propto I_{a_2}^2$ $\qquad I_{a_2} = 50A$

$$\therefore T_2 = T_1\left(\frac{I_{a_2}}{I_{a_1}}\right)^2 = T_1\left(\frac{50}{100}\right)^2 = 0.25\,T_1$$

$$\%\text{ change in torque} = \frac{T_1 - T_2}{T_1} \times 100 = \frac{T_1 - 0.25T_1}{T_1} \times 100 = 75\%$$

$$E_{b1} = V - I_{a_1}(R_a + R_{se}) = 200 - (100)(0.1) = 190V$$

$$E_{b2} = V - I_{a_2}(R_a + R_{se}) = 200 - (50)(0.1) = 195V$$

for series motor, $$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a_1}}{I_{a_2}}$$

$$= \left(\frac{195}{190}\right) \times \left(\frac{100}{50}\right) = 2.052$$

$$\therefore N_2 = 2.052 \times N_1 = 2.052 \times 1000 = 2052\text{ r.p.m}$$

(ii) $$\frac{T_2}{T_1} = \left(\frac{I_{a_2}}{I_{a_1}}\right)^2 \Rightarrow I_{a_2} = I_{a_1}\sqrt{\frac{T_2}{T_1}}$$

$$= 100\sqrt{\frac{1}{2}} = 70.7A$$

($\because$ torque halved)

$$E_{b2} = V - I_{a_2}(R_a + R_{se})$$

$$= 200 - (70.7)(0.1) = 192.93V$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a_1}}{I_{a_2}} = \frac{192.93}{190} \times \frac{100}{70.7} = 1.436$$

$$N_2 = 1.436 \times N_1 = 1.436 \times 1000 = 1436\text{ r.p.m.}$$

Losses in a D.C Motor

The losses occuring in a d.c motor are the same as in a d.c. generator. These are : (i) Copper losses (ii) Mechanical losses (iii) iron losses.

Efficiency of a D.C. Motor

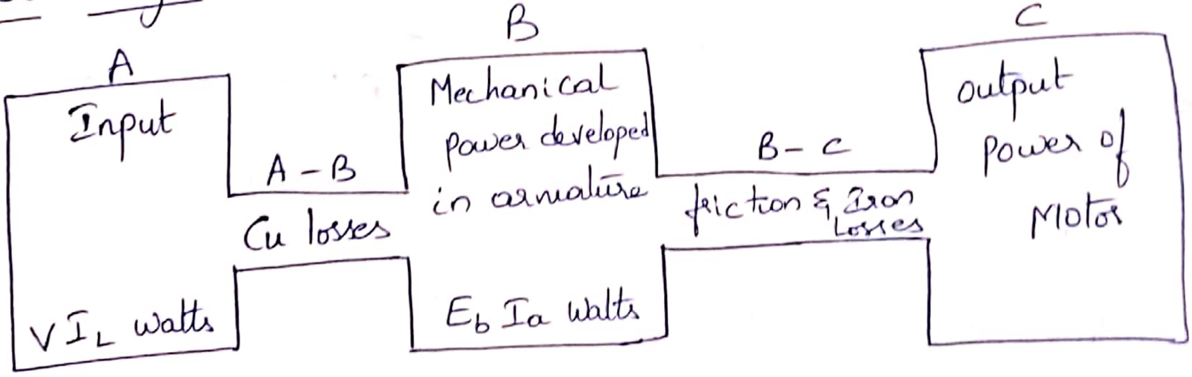
$$\eta = \frac{\text{output}}{\text{Input}} \times 100$$

$$= \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

The efficiency of a d.c. motor will be maximum when:

Variable losses = Constant losses.

Power stages



overall efficiency, $\eta_c = \frac{C}{A}$

electrical efficiency, $\eta_e = \frac{B}{A}$

Mechanical efficiency, $\eta_m = \frac{C}{B}$

Prob ①

A 220V shunt motor takes a total current of 80A and runs at 800 r.p.m. Shunt field resistance and armature resistance are 50Ω and 0.1Ω respectively. If iron and friction losses amount to 1600W. Find (i) Copper losses (ii) armature torque (iii) shaft torque (iv) efficiency.

Sol:- Shunt field current, $I_{sh} = \frac{220}{50} = 4.4A$ $\left(I_{sh} = \frac{V}{R_{sh}}\right)$

Armature current, $I_a = 80 - 4.4 = 75.6A$ $(I_a = I_L - I_{sh})$

Back e.m.f, $E_b = V - I_a R_a$

$= 220 - (75.6)(0.1)$

$= 212.44V$

(i) Input power $= V I_L = (220)(80) = 17600\,W$

power developed in armature $= E_b I_a$

$= (212.44)(75.6) = 16060\,W$

$\therefore$ Copper losses $= 17600 - 16060 = 1540W$ (A-B from power stages)

(ii) Armature torque, $T_a = 9.55 \times \frac{E_b I_a}{N}$

$= \frac{9.55 \times 212.44 \times 75.6}{800} = 192\,N\text{-}m$

(iii) Output power $= 16060 - 1600 = 14460\,W$ $\left[\begin{aligned} o/p &= i/p - \text{losses} \\ &= 17600 - 1540 - 1600 \end{aligned}\right]$

shaft ~~power~~ torque, $T_{sh} = 9.55 \times \frac{\text{output}}{N}$

$= 9.55 \times \frac{14460}{800} = 172.6\,N\text{-}m$

(iv) Efficiency $= \frac{o/p}{i/p} \times 100 = \frac{14460}{17600} \times 100 = 82.1\%$

Scanned by CamScanner

Prob (2) A d.c. shunt machine when run as a motor on no-load takes 440W and runs at 1000 r.p.m. The field current and armature resistance are 1A and 0.5Ω respectively. Calculate the efficiency of the machine when (i) running as a generator delivering 40A at 220V and (ii) as a motor taking 40A from a 220V supply.

Sol:- Under no-load,

Total motor input = Total no-load losses = 440W

$I_{sh} = 1A$, $I_{LO} = \frac{P}{V} = \frac{440}{220} = 2A$

$\therefore I_{ao} = I_{LO} - I_{sh} = 2-1 = 1A$

Armature Cu loss $= I_{ao}^2 R_a = (1)^2(0.5) = 0.5W$

Field Cu loss $= I_{sh}^2 R_{sh} = V \times I_{sh} = (220)(1) = 220W$

$\therefore$ Iron and friction loss $= 440 - 220 - 0.5$
$= 219.5W$

Iron and friction losses will be assumed Constant.

(i) As a generator,

$I_L = 40A$, $I_a = I_L + I_{sh}$
$= 40+1 = 41A$

Armature Cu loss $= I_a^2 R_a = (41)^2(0.5) = 840.5W$

Field Cu loss $= I_{sh}^2 R_{sh} = V I_{sh} = (220)(1) = 220W$

Iron and friction losses = 219.5W ($\because$ Considered Constant)

Total losses = $840.5 + 220 + 219.5 = 1280W$

Output of generator = $VI_L = (220)(40) = 8800W$

Efficiency = $\frac{o/p}{o/p + losses} \times 100 = \frac{8800}{8800+1280} \times 100 = 87.3\%$

(ii) As a motor,

$I_L = 40A$, $I_a = I_L - I_{sh} = 40 - 1 = 39A$

Armature Cu loss = $I_a^2 R_a = (39)^2(0.5) = 760.5W$

Field Cu loss = $(220)(1) = 220W$

Iron and friction losses = $219.5W$

Total losses = $760.5 + 220 + 219.5 = 1200W$

Motor input = $VI_L = (220)(40) = 8800W$

Efficiency = $\frac{i/p - losses}{i/p} \times 100 = \frac{8800 - 1200}{8800} \times 100$

$= 86.4\%$

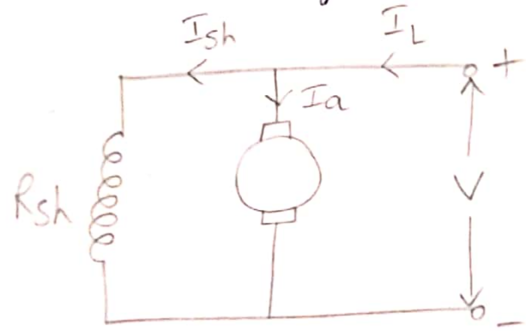
D.C. Motor Characteristics

(i) Torque and Armature Current Characteristics (T_a/I_a) – It is the curve between armature torque T_a and armature current I_a of a d.c. motor. It is also known as electrical characteristic of the motor.

(ii) Speed and armature Current Characteristic (N/I_a) – It is the curve between speed N and armature current I_a of a d.c. motor.

(iii) Speed and torque characteristic (N/T_a) – It is the curve between speed N and armature torque T_a of a d.c. motor. It is also known as mechanical characteristic.

Characteristics of Shunt Motors

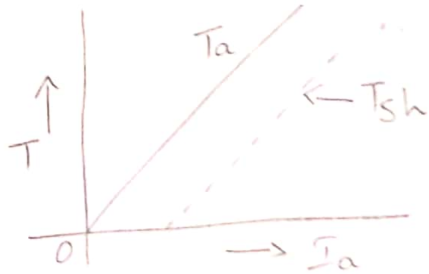


(i) T_a/I_a Characteristic

In a d.c. motor,

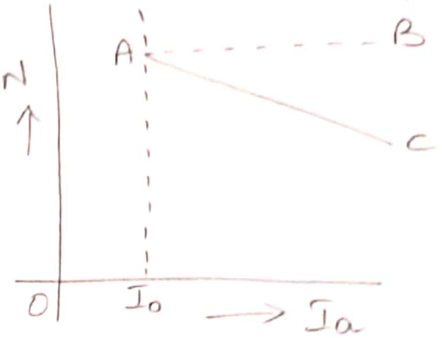
$$T_a \propto \phi I_a$$

ϕ is constant, $\therefore T_a \propto I_a$



Hence T_a/I_a characteristic is a straight line passing through origin.

(ii) N / I_a characteristic

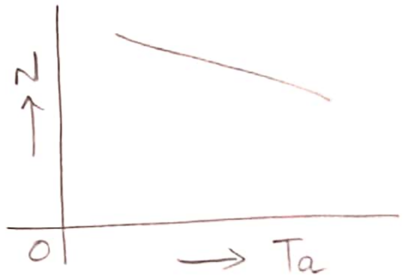


$$N \propto \frac{E_b}{\phi}$$

ϕ & E_b in a shunt motor are almost constant. Therefore, speed of a shunt motor will remain constant.

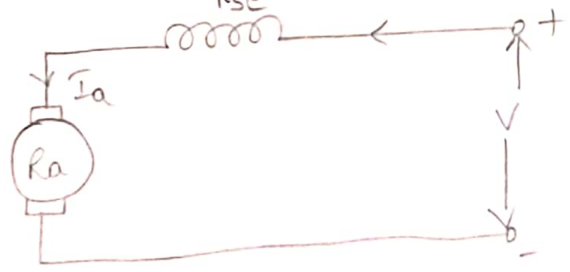
When load is increased, E_b and ϕ decreases due to the armature resistance drop and armature reaction so that the speed of the motor decreases slightly with load.

(iii) N / T_a characteristic

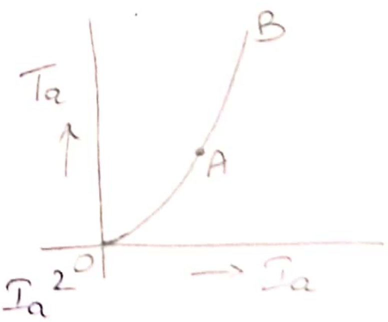


As the load torque increases the speed decreases.

Characteristics of Series Motors



(i) T_a / I_a characteristic



We know that,

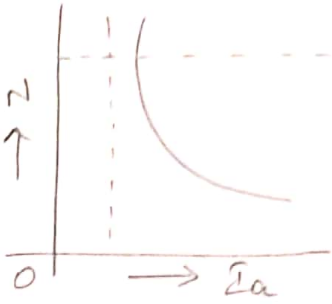
$$T_a \propto \phi I_a$$

upto magnetic saturation, $\phi \propto I_a$ so $T_a \propto I_a^2$

After magnetic saturation, ϕ is constant so $T_a \propto I_a$

(ii) N/I_a Characteristic

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



When I_a increases, E_b decreases due to $I_a(R_a+R_{se})$ drop while the flux increases. $I_a(R_a+R_{se})$ drop is small and can be neglected.

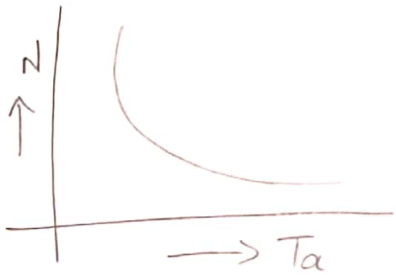
$$\therefore N \propto \frac{1}{\phi}$$

$$\propto \frac{1}{I_a} \text{ upto magnetic saturation}$$

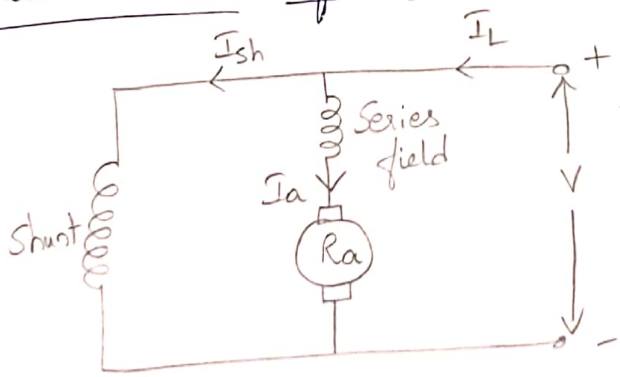
So, N/I_a curve shows hyperbolic path.

(iii) N/T_a Characteristic

Series motor develops high torque at low speed and vice-versa.

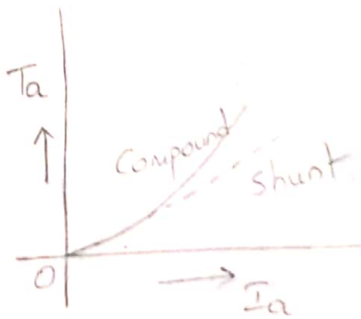


Characteristics of Cumulative Compound Motors



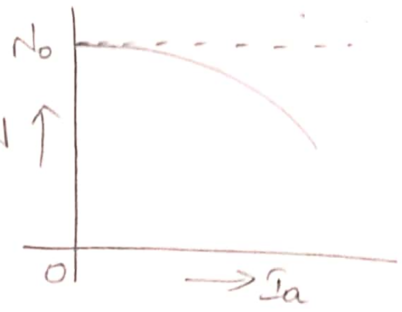
(i) T_a/I_a Characteristic

As the load increases, the series field increases but shunt field remains constant. So, total flux is increased and hence the armature torque.



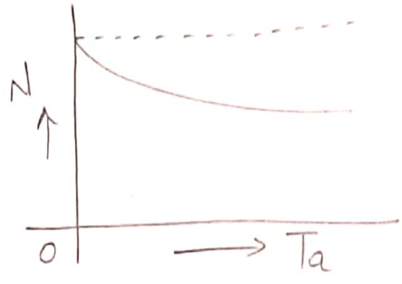
(ii) N/I_a characteristic

As load increases, the flux per pole also increases. Hence the speed $(N \propto \frac{1}{\phi})$ of the motor falls.



(iii) N/T_a Characteristic

For a given armature current, the torque of a cumulative compound motor is more than that of a shunt motor but less than that of a series motor.



Speed Control of DC Motors

The speed of a d.c. motor is given by

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

$$N = \frac{K(V - I_a R)}{\phi}$$

where $R = R_a$, for shunt motor

$R = R_a + R_{se}$, for series motor

Two methods of controlling the speed of a d.c. motor

(i) By varying ϕ, this is known as flux control method.

(ii) By varying the resistance in the armature circuit, this is known as armature control method.

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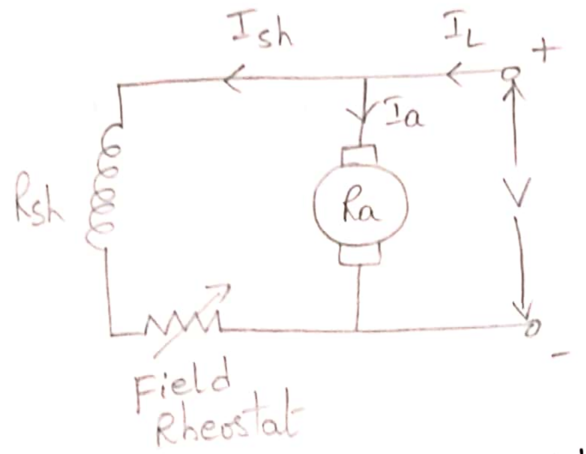
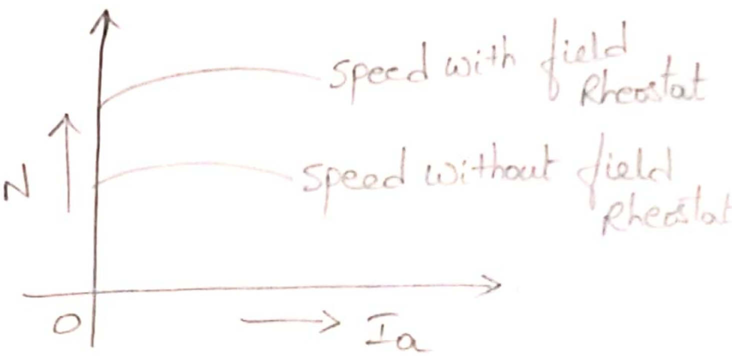
Speed Control of Shunt Motors

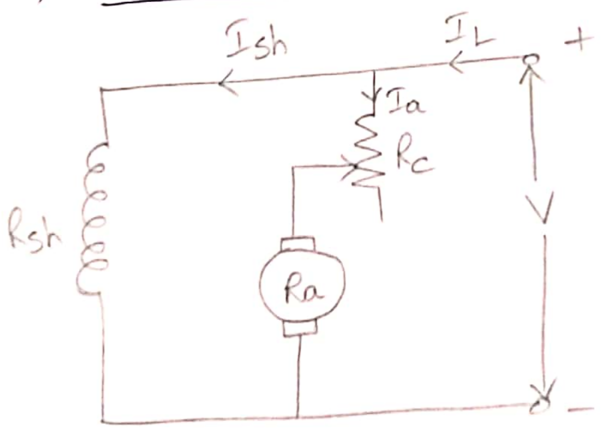
1) Flux Control method

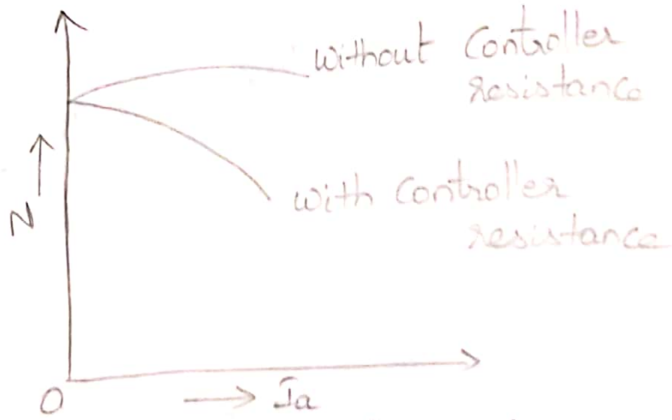




In this method, a variable resistance (known as shunt field Rheostat) is placed in series with shunt field winding. The shunt field rheostat reduces the shunt field current I_{sh} and Hence the flux ϕ. Therefore, this method can only provide speeds above the normal speed.

2) Armature Control Method





By varying the voltage available across the armature, the back e.m.f and hence the speed of the motor changes. This is done by inserting a variable resistance R_c (known as controller resistance) in series with the armature.

$$N \propto V - I_a (R_a + R_c)$$

Due to voltage drop in the controller resistance, E_b is decreased. Since $N \propto E_b$ the speed of the motor is reduced. This method can only provide speeds below normal speed.

Prob (1) A 220V d.c. shunt motor having an armature resistance of 0.25Ω carries an armature current of 50A and runs at 600 r.p.m. If the flux is reduced by 10% by field regulator, find the speed assuming load torque remains the same.

Sol:- $N_1 = 600$ r.p.m, $I_{a_1} = 50A$, $R_a = 0.25\Omega$

$$E_{b1} = V - I_{a_1} R_a$$
$$= 220 - (50)(0.25)$$
$$= 207.5V$$

$$\phi_2 = 0.9\,\phi_1, \Rightarrow \frac{\phi_2}{\phi_1} = 0.9$$

As the load torque remains same,

$$\phi_1 I_{a_1} = \phi_2 I_{a_2}$$
$$I_{a_2} = \left(\frac{\phi_1}{\phi_2}\right) I_{a_1}$$
$$= \left(\frac{1}{0.9}\right)(50) = 55.6A$$

$$E_{b2} = V - I_{a_2} R_a$$
$$= 220 - (55.6)(0.25) = 206.1V$$

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

$$\frac{N_2}{600} = \frac{206.1}{207.5} \times \frac{1}{0.9}$$

$$\therefore N_2 = 662 \text{ rpm}$$

Prob ② A shunt motor supplied at 230V runs at 900 r.p.m while taking armature current of 30A, the resistance of armature circuit being 0.4Ω. Calculate the resistance required in series with the armature circuit to reduce the speed to 500 r.p.m, assuming that the armature current is 25A.

Sol:- $N_1 = 900\,rpm$, $N_2 = 500\,rpm$, $I_{a_1} = 30\,A$, $I_{a_2} = 25A$

$R_a = 0.4\Omega$

$$E_{b1} = V - I_{a_1} R_a$$

$$= 230 - (30)(0.4) = 218\,V$$

$$E_{b2} = V - I_{a_2} R_t$$

$$= 230 - 25 R_t$$

Since excitation is unchanged, $\phi_1 = \phi_2$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{500}{900} = \frac{230 - 25 R_t}{218}$$

$$R_t = 4.356\,\Omega$$

∴ Addition series resistance required in the armature

$$R_t = R_c + R_a$$

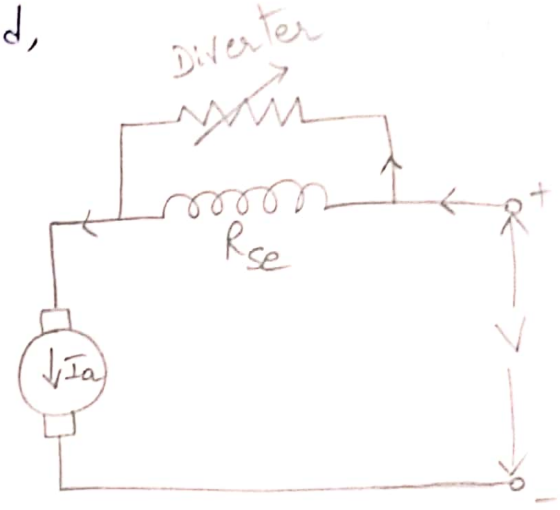
$$4.356 = R_c + 0.4$$

$$\therefore R_c = 3.956\,\Omega$$

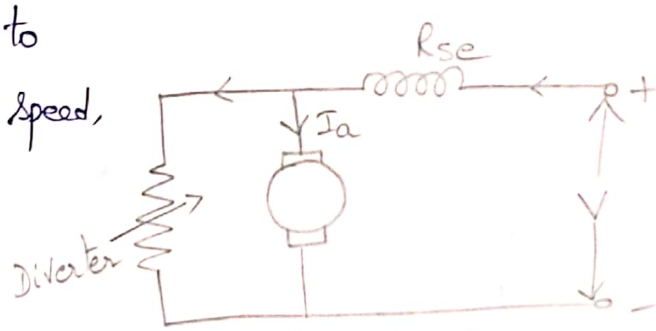
Speed Control of Dc Series Motors

1) Flux Control Method

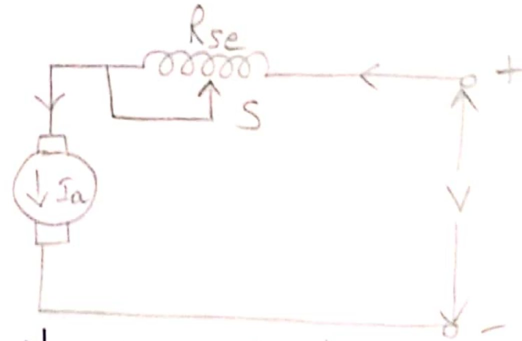
(i) Field diverters — In this method, a variable resistance (called field diverter) is connected in parallel with series field winding. Its effect is to shunt some portion of the line current from the series field winding, thus weakening the field and increasing the speed ($\because N \propto \frac{1}{\phi}$). This method can only provide speeds above the normal speed.



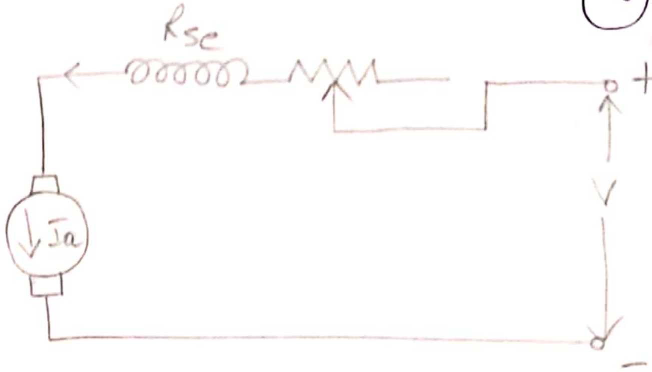
(ii) Armature diverter — In order to obtain speed below the normal speed, a variable resistance (called armature diverter) is connected in parallel with the armature. The diverter shunts some of the line current, thus reducing the armature current. If I_a is decreased, ϕ must increase ($\because T \propto \phi I_a$). Since $N \propto \frac{1}{\phi}$, speed decreases



(iii) Tapped field control — In this method, the flux is reduced by decreasing the number of turns of the series field winding and hence speed is increased. The switch 'S' can short circuit any part of the field winding, thus decreasing the flux and increasing the speed.



2) Armature Control Method –



In this method, a variable resistance is directly connected in series with the supply to the complete motor. This reduces the voltage available across the armature and hence the speed falls. By changing the value of variable resistance, any speed below the normal speed can be obtained.

Prob ① A 220V d.c. series motor runs at 900 r.p.m when taking a line current of 40A. The armature resistance and series field resistance are 0.06Ω and 0.04Ω respectively. If current taken remains the same, calculate the series resistance required to reduce the speed to 600 r.p.m.

Sol:– $R_a + R_{se} = 0.04 + 0.06 = 0.1\Omega$

$N_1 = 900$ r.p.m, $N_2 = 600$ r.p.m, $I_{a1} = I_{a2} = 40A$

$E_{b1} = V - I_{a1}(R_a + R_{se})$

$= 220 - (40)(0.1) = 216$ V

$E_{b2} = V - I_{a2}R = 220 - 40R$

$R =$ Series resistance $+ R_a + R_{se}$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{600}{900} = \frac{220 - 40R}{196} \Rightarrow R = \text{[illegible]}$$

Series resistance $= R - (R_a + R_{se}) =$ [illegible] $- 0.1 =$ [illegible]

Prob ② A 200V d.c. series motor runs at 800 r.p.m when taking a line current of 15A. The armature resistance and series field resistance are 0.6Ω and 0.4Ω respectively. Find the speed at which it will run when connected in series with a 5Ω resistance and taking the same current at the same voltage.

Sol:

$$R_a + R_{se} = 0.6 + 0.4 = 1\Omega$$

$$N_1 = 800 \text{ r.p.m}, \quad I_{a1} = I_{a2} = 15A$$

without 5Ω resistance in series,

$$E_{b1} = V - I_{a1}(R_a + R_{se})$$

$$= 200 - 15(0.6 + 0.4) = 185V$$

with 5Ω resistance in series,

$$E_{b2} = V - I_{a2}(R_a + R_{se} + 5)$$

$$= 200 - 15(0.6 + 0.4 + 5) = 110V$$

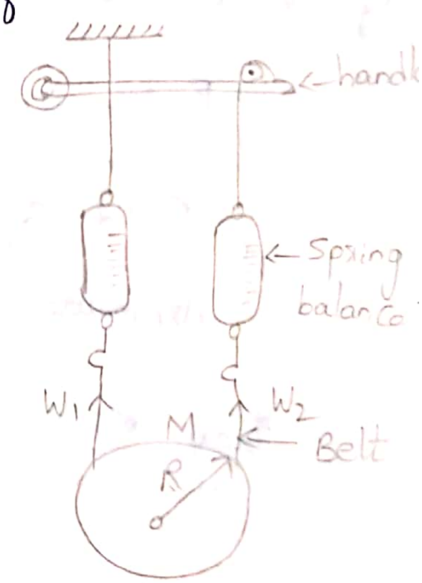
$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{N_2}{800} = \frac{110}{185}$$

$$N_2 = 476 \text{ r.p.m}.$$

Brake Test

This is a direct method of testing the motor. In this method, the motor is put on the direct load by means of a belt and pulley arrangement. By adjusting the tension of belt, the load is adjusted to give the various values of currents. The load is finally adjusted to get full load current. The power developed gets wasted against the friction between belt and shaft. Due to the braking action of belt the test is called brake test.



Let,

R = Radius of pulley in m

N = Speed in r.p.m

W_1 = Spring balance reading on tight side in kg

W_2 = " " " " slack " " "

$\therefore$ Net pull $= (W_1 - W_2)$ kg $= 9.81(W_1 - W_2)$ N

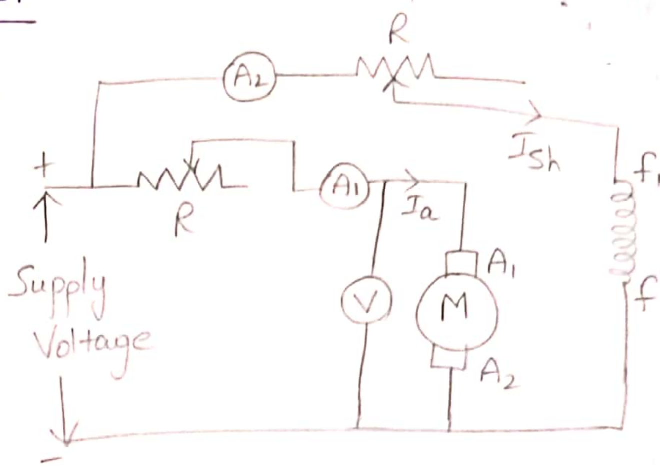
shaft torque ← T_{sh} = net pull $\times R = 9.81(W_1 - W_2)R$ N-m

$$P_{out} = T_{sh} \times \omega = 9.81(W_1 - W_2)R \times \frac{2\pi N}{60} \text{ Watts}$$

$$P_{in} = VI \text{ Watts}$$

$$\% \eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{9.81(W_1 - W_2)R \times \frac{2\pi N}{60}}{VI} \times 100$$

Swinburne's Test or No Load Test



This is indirect method of testing d.c. motors.

The no load armature Current I_a is measured by ammeter A_1 whereas the shunt Current is measured by ammeter A_2.

if 'V' is the supply Voltage then motor input at no load

Power input at no load $= V(I_a + I_{sh})$ Watts

Field Copper loss $= V \times I_{sh}$

Armature Copper loss $= I_a^2 R_a$

Stray losses = Input at no load − Field Copper losses − no load armature Copper losses

$$= V(I_a + I_{sh}) - V I_{sh} - I_a^2 R_a = W_a.$$

If α_1 = Resistance temperature Coefficient of Copper at room temp

$$R_a' = R_a(1 + \alpha_1 + 40)$$

At room temp, the shunt field winding resistance

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

$$\therefore R_{sh}' = R_{sh}(1 + \alpha_1 + 40)$$

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

New field copper loss $= I_{sh}'^2 R_{sh}$

If we want to find the efficiency of the motor at say $\frac{1}{4}$th full load. It can be calculated as

Let $I_{F.L}$ = full load current of motor

W_F = field copper loss

W = stray losses

Load current at $\frac{1}{4}$th full load $= \frac{I_{F.L}}{4}$

Motor input at $\frac{1}{4}$th full load $= V \times \frac{I_{F.L}}{4}$ watts

Armature current at $\frac{1}{4}$th full load, $I_a' = \frac{I_{F.L}}{4} - I_{sh}'$

Armature copper loss at $\frac{1}{4}$th full load $= I_a'^2 Ra$

$$= \left(\frac{I_{F.L}}{4} - I_{sh}'\right)^2 Ra$$

Motor output at $\frac{1}{4}$th full load = Motor input at $\frac{1}{4}$th load − losses

$$= \left(\frac{V I_{F.L}}{4}\right) - \left(\frac{I_{F.L}}{4} - I_{sh}'\right)^2 Ra - W_F - W$$

Efficiency at $\frac{1}{4}$th full load, $\eta = \frac{o/p}{i/p} = \frac{i/p - \text{losses}}{i/p}$

$$= \frac{\left(\frac{V I_{F.L}}{4}\right) - I_a'^2 \cdot Ra - W_F - W}{V \cdot \frac{I_{F.L}}{4}}$$

Prob ① In a brake test conducted on a d.c. shunt motor the full load readings are observed as,

Tension on tight side = 9.1 kg

" " slack " = 0.8 kg

Total Current = 10 A

Supply Voltage = 110 V

Speed = 1320 r.p.m

The radius of the pulley is 7.5 cm

Calculate its full load efficiency

Sol:- $W_1 = 9.1\,kg$, $W_2 = 0.8\,kg$, $I = 10\,A$, $V = 110\,V$, $R = 7.5\,cm$

$$T_{sh} = (W_1 - W_2)\,9.81 \times R$$

$$= (9.1 - 0.8)\,9.81 \times 0.075$$

$$= 6.1067\ N\text{-}m$$

$$P_{out} = T_{sh} \times \omega = T_{sh} \times \frac{2\pi N}{60}$$

$$= \frac{6.1067 \times 2 \times 3.184 \times 1320}{60}$$

$$= 844.133\,W$$

$$P_{in} = VI = 110 \times 10 = 1100\,W$$

$$\%\,\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{844.133}{1100} \times 100$$

$$= 76.74\%$$

Prob③ A 440V d.c. shunt motor takes a no load current of 2.5A. The resistance of the shunt field and the armature are 550Ω and 1.2Ω respectively. The full load line current is 32A. Find the full load output and the efficiency of the motor.

Sol:-
$I = 2.5A$

no load input $= VI = 440 \times 2.5 = 1100\,W$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{440}{550} = 0.8\,A$$

$$I_a = I_L - I_{sh} = 2.5 - 0.8 = 1.7\,A$$

No load armature Cu loss $= I_a^2 R_a = (1.7)^2 (1.2) = 3.468\,W$

Constant losses = no load input − no load armature Cu loss

$= 1100 - 3.468 = 1096.532\,W$

Full load line current, $I = 32A$

$$I_a = I_L - I_{sh} = 32 - 0.8 = 31.2\,A$$

Full load armature Cu loss $= I_a^2 R_a = (31.2)^2 (1.2) = 1168.128\,W$

Total losses = Full load armature Cu loss + Constant losses

$= 1168.128 + 1096.532 = 2264.66\,W$

full load motor input $= VI = 440 \times 32 = 14080\,W$

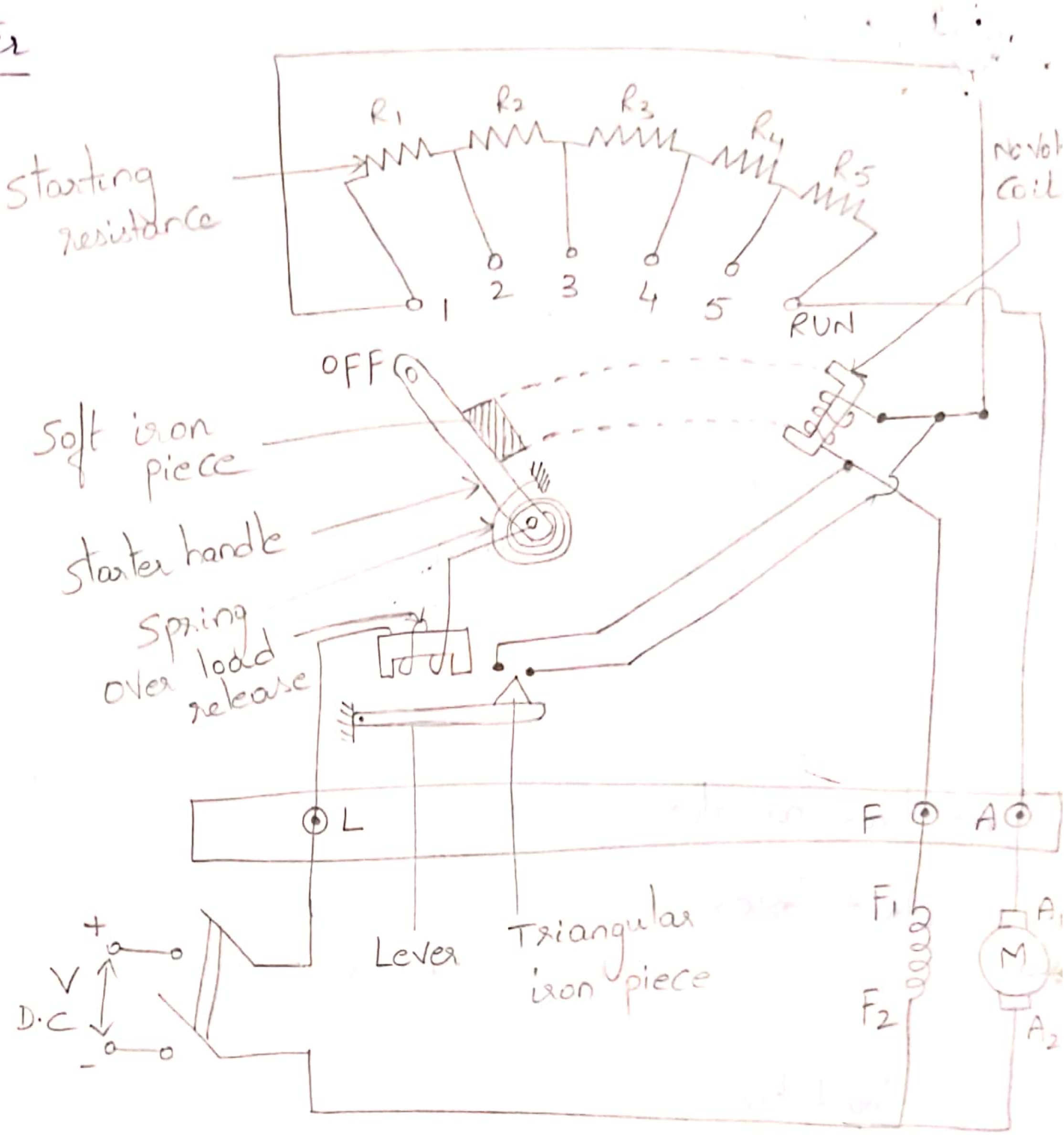
Full load motor output = Input − losses

$= 14080 - 2264.66 = 11815.34\,W$

% Efficiency at full load $= \dfrac{\text{Full load o/p}}{\text{full load i/p}} \times 100$

$$= \frac{11815.34}{14080} \times 100 = 83.91\%$$

3-point Starter



The starter is basically a Variable resistance, divided into number of sections. The contact points of these sections are called studs. There are three main points of this starter

L → line terminal to be connected to positive of supply

A → To be connected to the armature winding

F → To be connected to the field winding.

The starting resistance is entirely in series with the armature. The OLR (over load release) and NVC (no volt coil) are the two protecting devices of the starter.

...ation :— Initially the handle is in the OFF position. The d.c. supply to the motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding gets supply through the parallel path provided to starting resistance, through NVC. While entire starting resistance comes in series with the armature and armature current which is high at start, gets limited. As the handle is moved further, it goes on making contact with studs 2, 3, 4, etc, cutting out the starting resistance gradually from the armature circuit. Finally when the starter handle is in 'RUN' positon, the entire starting resistance gets removed from the armature circuit and motor starts operating with normal speed.

Applications of DC Generators

1) Separately excited generators — As a separate supply is required to excite field, the use is restricted to some special applications like electro-plating, electro-refining of materials etc.

2) Shunt generators — Commonly used in battery charging and ordinary lighting purposes.

3) Series generators — Commonly used as boosters on d.c feeders, as a constant current generators for welding generator and arc lamps.

4) Cummulatively Compound Generators — used for domestic lighting purposes and to transmit energy over long distance.

5) Differential Compound Generators — The use of this type of generators is very rare and it is used for special application like electric arc welding

Applications of D.C Motors

1) Shunt Motors — used in (i) Blowers and fans
(ii) Centrifugal and reciprocating pumps
(iii) Lathe machines
(iv) Machine tools
(v) Milling machines
(vi) Drilling machines.

2) Series Motors — used in (i) Cranes
(ii) Hoists, Elevators
(iii) Trolleys
(iv) Conveyors
(v) electric locomotives

3) Cummulative Compound Motors — used in (i) Rolling mills
(ii) Punches
(iii) Shears
(iv) Heavy planers
(v) Elevators

4) Differential Compound Motors — ~~used~~ not suitable for any practical application.

X ——— X ——— X ——— X

Need of Electrical Machines – To generate energy (electrical and mechanical)

Electrical Energy	Coupling Field	Mechanical Energy

→ Electrical machines converts electrical energy to mechanical energy which is a motor and machine which converts mechanical energy to electrical energy is a generator.

→ Electrical energy to mechanical energy and mechanical energy to electrical energy cannot be converted ~~different~~ directly. Inorder to do this we require an intermediate called Coupling field.

→ Coupling field – it stores energy

Coupling field: electric field, magnetic field

Energy stored in electric field is less than the energy stored in magnetic field. So, in electrical machines we will go with magnetic field because it can store more energy

→ Electric charge –

electrons (–ve charge) $= -1.6 \times 10^{-19}$ C

protons (+ve charge) $= 1.6 \times 10^{-19}$ C

→ Electric Current – flow of electric charge (or electrons)

Direction of current is opposite to flow of electrons

→ Electric field – The field or space around a charged particle where its force can be experienced by another charged particle

→ Magnetic field – It is created by moving electric charges

Classification of Electrical Machine

- Ac Machine
  - Synchronous machine
  - Induction machine
    - Single phase
      - Shaded pole
      - Split phase
      - Capacitor start
      - Capacitor start Capacitor run
    - Three phase
- DC Machine
  - Brushed
    - Self excited
      - Series
      - Shunt
      - Compound
        - Cummulative Compound
        - Differential Compound
          - long shunt
          - Short shunt
    - Separately excited
  - Brushless
    - Inrunner
    - outrunner

Four-point Starter

In a four-point starter, the no-volt release coil is connected directly across the supply line through a protective resistance R. The only difference between a three-point starter and a four-point starter is the manner in which no-volt release coil is connected. However, the working of the two starters is the same. It may be noted that the three-point starter also provides protection against an open-field circuit. This protection is not provided by the four-point starter.