Electrical Engineering

Content

Chapter One :- D.C. Machines(D.C. Motor & D.C. Generator)

Chapter Two:- Transformers

Chapter Three:- A.C. Machines

  a. 3-phase Induction Machines

  b. A.C. Synchronous Machines (Motor & Generators)

Chapter Four:- Rectifier and semiconductor Device (Converters)

Chapter Five:- Electric power supply (Distribution & Transmission)

References Book:

1. "Electrical Technology" ,Edward Hughes, Longmans.
2. "Electrical Technology", H. Cotton.
3. "Electrical Machines", Siskind.
4. "Electrical Technology",B.L.Threaja
5. "Electrical Machines and their applications", J.Hindmarsh
6. "Electrical Machines and their applications", Vincent Del Toro
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Chapter One

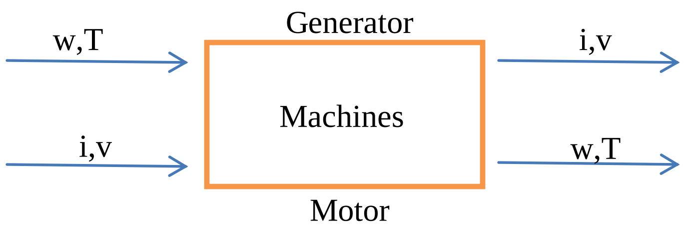
D.C Machine

1.1 Introduction

D.C. machine are called be converters mechanical energy (or power) into electrical energy(or power) (D.C. Generator) or converters electrical energy (or power) into mechanical energy (or power) (D.C. Motor) .

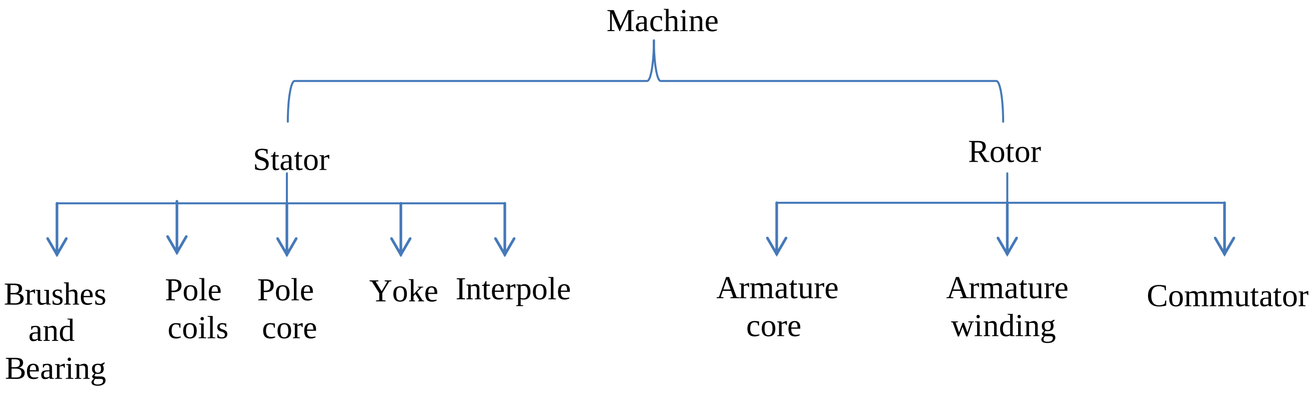
The D.C. machines are provide high starting torque as well as high accelerating and decelerating torque . It's capable of quick reversals and speed control over a rang of 4:1

These machines uses in the really tough jobs in industry , such as are found in steel mills.



1.2 Construction

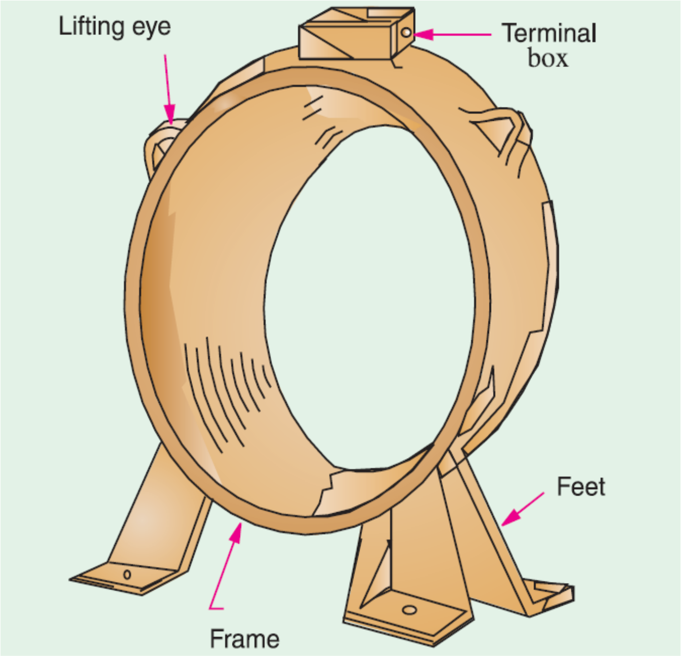
The D.C. generators and D.C. Motors have the same general construction. Any D.C. generator can be run as a D.C. motor and vise-versa. All D.C. machines have eight principles component.

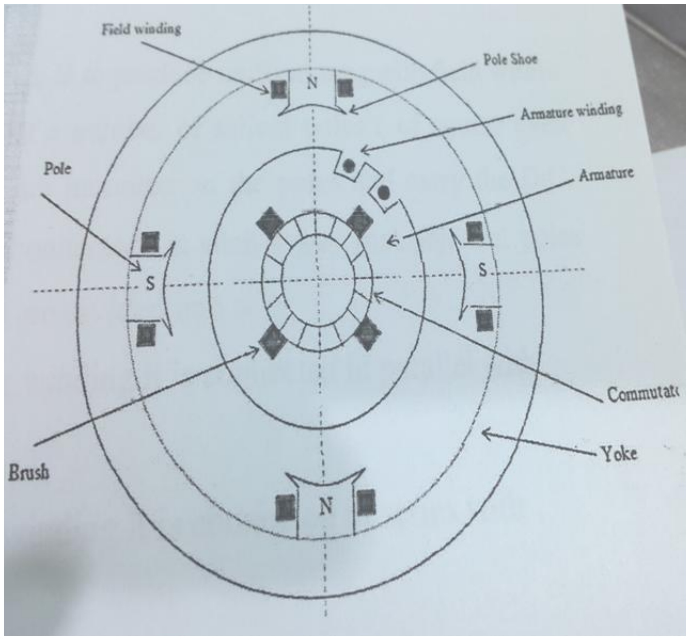


1.2.1 Yoke or Outer Frame

The yoke is usually made of solid cast steel. It serves double purpose

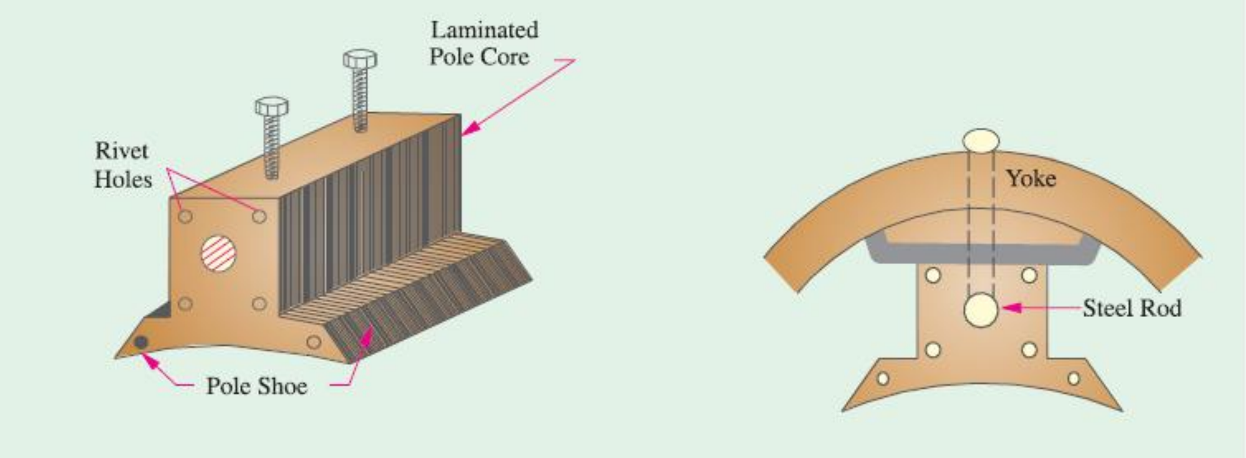
1. It provides mechanical support for the poles and acts as a protecting cover for the whole machine.
2. It carries the magnetic flux produced by the poles.





1.2.2 Pole Core and Pole Shoes

The field magnets consist of pole core and pole shoes. The complete pole cores and pole shoes are built of thin lamination of steel and thickness of laminations varies from 1mm to 0.25mm. In small machine used of perment magnetic.



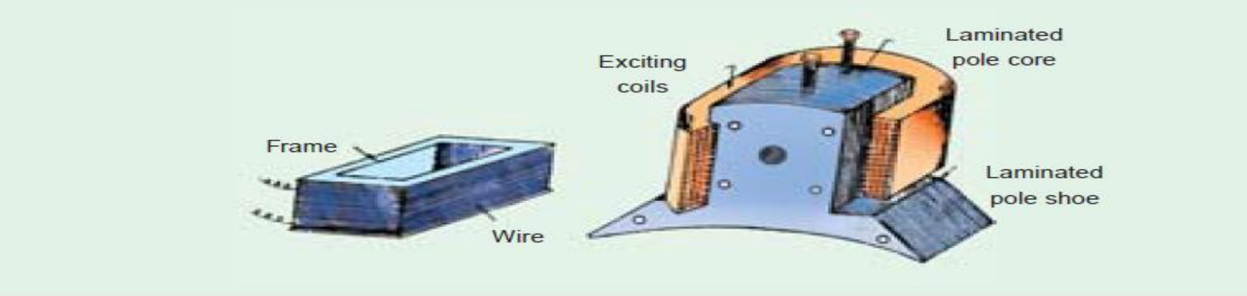
1.2.3 Pole Coils

The function of the field system is to produce uniform magnetic field within which armature rotates. It consists of a number of salient poles (of course even number). The pole (or field) coils are mounted on the poles and carry the D.C. exciting current. The poles coils are connected in such a way that adjacent poles have opposite polarity. The filed coils are divided into :-

1. Shunt coils :- the thin wire and large winding it is connected in parallel with armature.

2. Series coils:- the thick wire and few winding it is connected in series with armature.

The pole coils are put into place over the core.



1.2.4 Brushes and Bearing

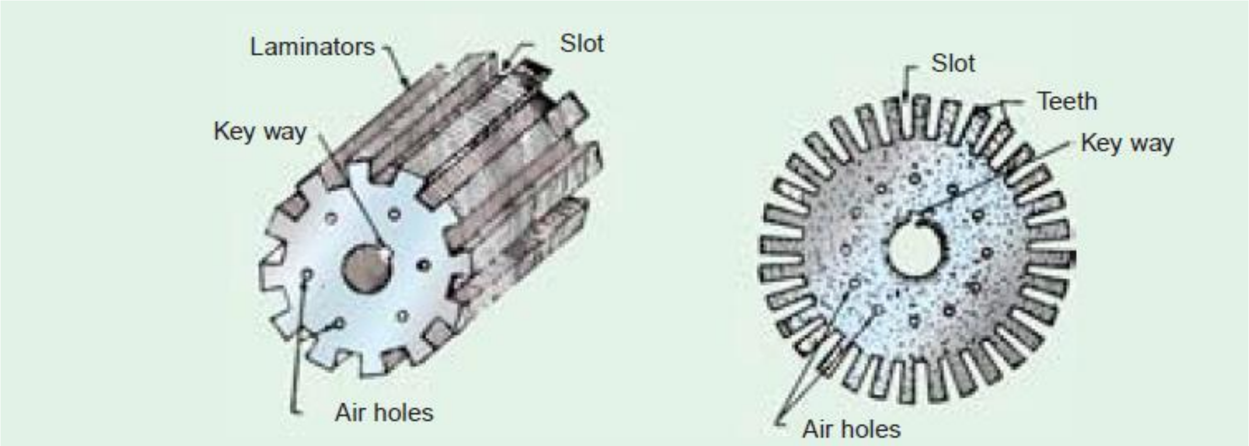
The brushes ,whose function is to collect the current from commutator or to ensure electrical connections between the rotating commutator and stationary external circuit, are usually made of carbon.

Ball-bearing are frequently employed because their reliability but roller-bearing are preferable for heavy duties.

1.2.5 Armature Core

It houses the armature conductors or coils. It is cylindrical or drum shaped and is built up of usually circular sheet steel discs or laminations (about 0.4 to 0.6 mm thick) approximately 0.5mm thick.

The purpose of using laminations is to reduce the loss due to eddy currents. Thinner the laminations , greater is the resistance offered to the induced e.m.f., smaller the current and hence less the I^2R loss in the core.



1.2.6 Armature Winding

Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots in a suitable manner which are lined with tough insulating material. The armature winding of a D.C. machine is closed circuit winding.

The armature windings wound by two type :-

1. Lap winding
2. Wave winding

and wound by single layer or double layer.

1.2.7 Commutator

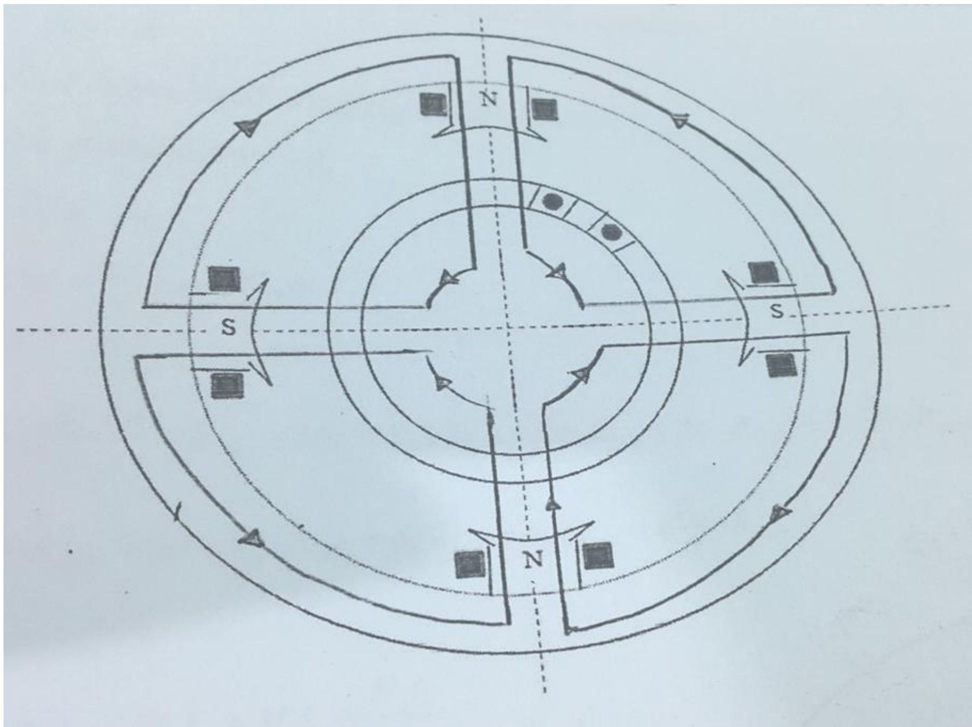
A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes. The commutator is made of copper segments insulated from each other by mica sheet. It is of cylindrical segments of high conductivity. The function of the these segments are insulated from each other by thin layer of mica and insulation from shaft by insulated cylindrical of mica. Each commutator segment is connected to the armature by means of a copper lug or strip.

1.2.8 Inter Poles

These are small and used to improve the commutation process.

1.3 Magnetic Circuit

The m.m.f. developed by the field coils produces a magnetic flux that pass through the pole pieces, the air gap, the armature, and the frame as shown in Fig. below. Practical D.C. machine have air gaps ranging o.5 mm to 1.5 mm.



Magnetic flux density = $B = \frac{\phi}{A}$ (wb/m^2 or Tesla)

Where:-

ϕ = flux magnetic or flux line (wb)

A= cross-section area perpendicular of flux line (m^2)

Magnetic flux intensity = $H = \frac{B}{\mu} = \frac{B}{\mu_o \mu_r}$ (A/m)

Where :- $\mu = \mu_o \mu_r$ =Permeability

μ_o = air Permeability=$4\pi\times10^{-7}$

μ_r =Relative Permeability

The magnetic motive force (m.m.f) = $F = Hl = \frac{B}{\mu_o \mu_r} l = \frac{\phi}{A} . \frac{1}{\mu_o \mu_r} l = \phi R$ (AT)

Where:-

$$R = \frac{l}{A \mu_0 \mu_r} = \text{Magnetic Reluctance}$$

$$F = Hl = \phi R$$

The last equation has s similarly with electric equation

$$V = I.R$$

The main flux from field winding divided into:-

1. linkage or useful flux $= \phi_m$

2. leakage flux $= \phi_l$

$$F = NI = \sum Hl = \sum \phi R$$

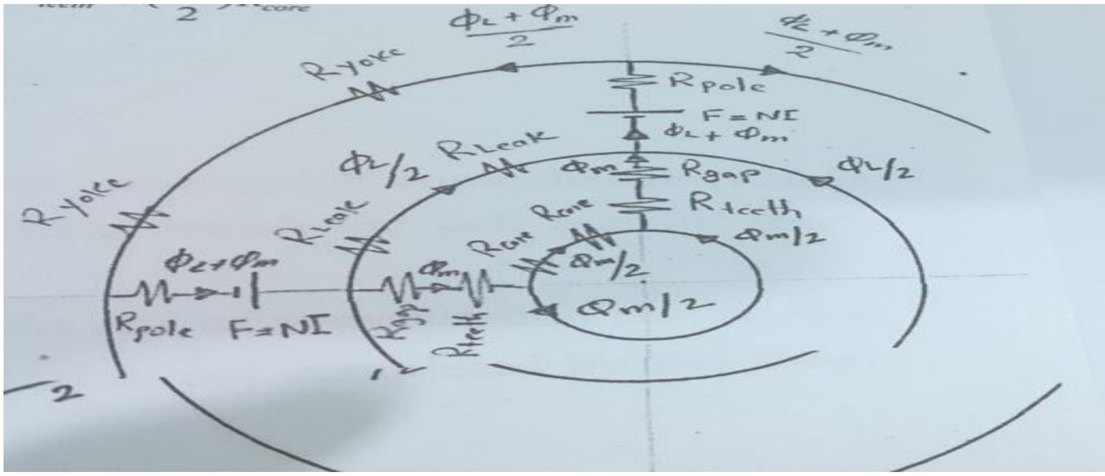
From figure below

$$2F = 2NI = 2(\frac{\phi_l + \phi_m}{2}) R_{yoke} + 2(\phi_l + \phi_m) R_{pole} + 2\phi_m R_{gap} + 2\phi_m R_{teeth} + 2(\frac{\phi_m}{2}) R_{core}$$

$$F = (\frac{\phi_l + \phi_m}{2}) R_{yoke} + (\phi_l + \phi_m) R_{pole} + \phi_m R_{gap} + \phi_m R_{teeth} + (\frac{\phi_m}{2}) R_{core}$$

or

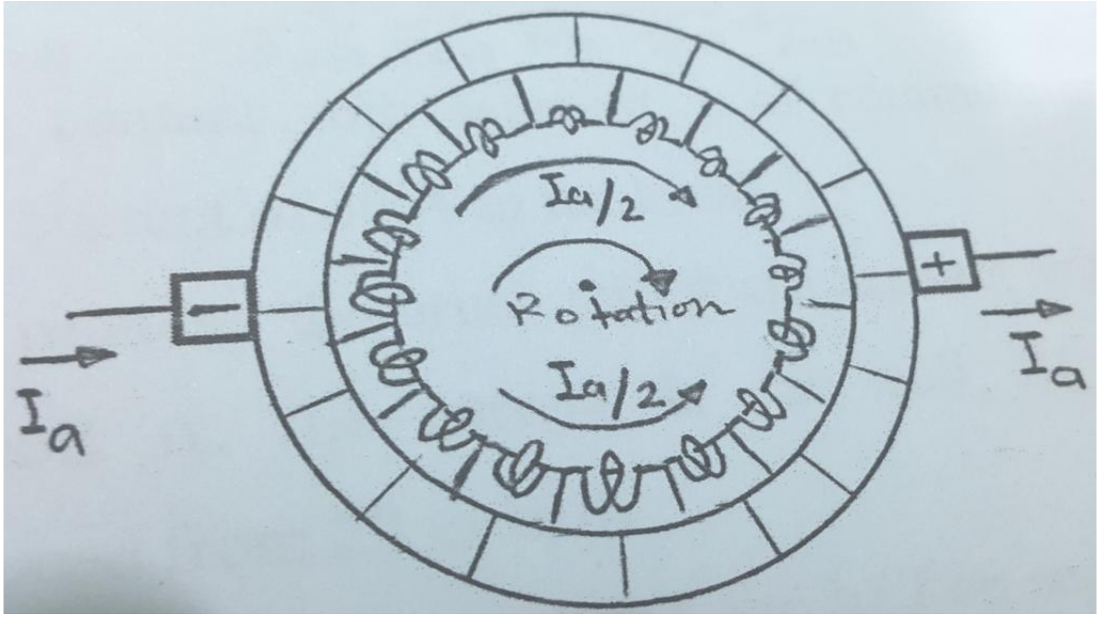
$$F = \frac{H_y l_y}{2} + H_p l_p + H_g l_g + H_t l_t + \frac{H_c l_c}{2}$$



1.4 Commutation

It is the process of changing the A.C. current in the armature conductor to D.C. current at the external terminals. The A.C. flow in one direction when armature conductors are under N-pole and in the opposite direction when they are under S-pole. This reversal of current take place along magnetic neutral axis or brush axis when the coil reaches the neutral zone, it is short –circuited by the brush. The current in the short circuited coil will changing from say +I to –I during the short-circuited period (commutation period) or Tc.

Fig. below shows the schematic diagram of 2-pole machine. There are two parallel paths between the brushes. Therefore, each coil of the winding carries one half ($I_a/2$ in this case) of the total current (I_a). The current in a coil will reverse as the coil passes a brushes. This reversal of current as the coil passes a brushes is call commutation.

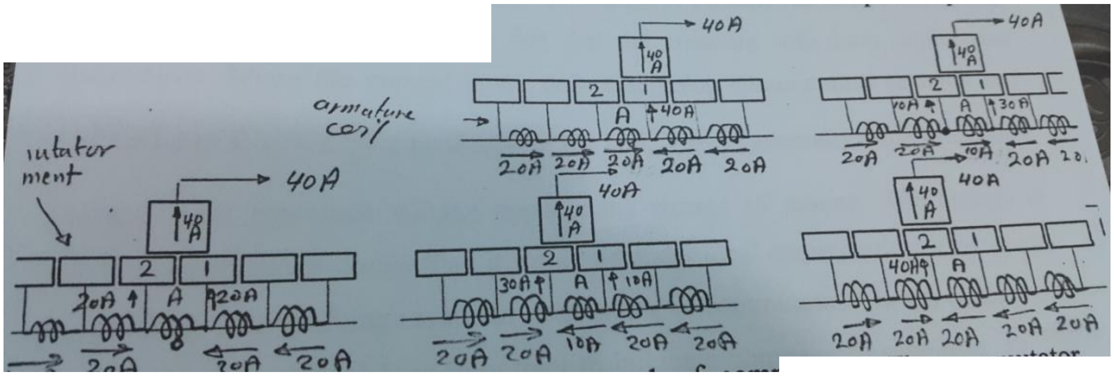


when commutation take place, the coil undergoing commutation is short circuited by the brush. The brief period during which the coil remains short circuited is known as commutation period T_c.

If the current reversal is completed by the end of commutation period, it is called ideal commutation. If the current reversal is not completed by that time, ten sparking occurs between the brush and commutator which results in progressive damage to both.

Ideal commutation

Let us discuss the phenomenon of ideal commutation (i.e., coil has no inductance) in one coil in armature winding shown above. We consider the coil A. The brush width is equal to the width of one commutator segment and one mica insulation. Suppose the armature current is 40 A. Since there are two parallel paths each coil carries a current of 20 A.



(i) The brush is in contact with segment 1 of commutator. The commutator segment 1 conduct a current of 40 A to te brush.

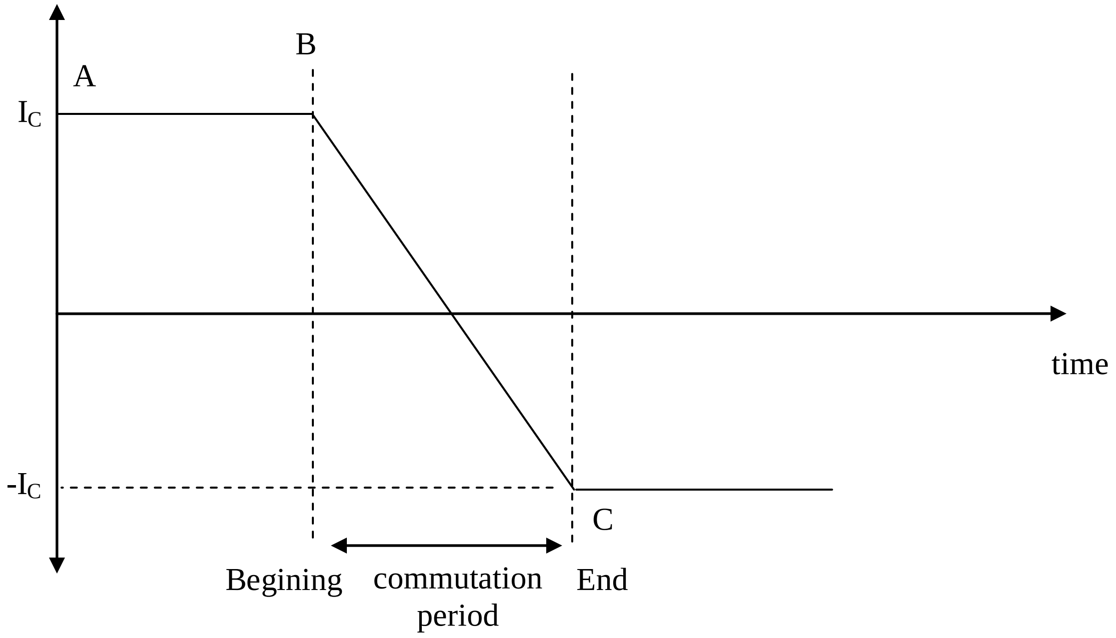
(ii) As the armature rotates, the brush will make contact with segment 2 and this short-circuits the coil A. the current in the coil A (the coil undergoing commutation) is reduced from 20 to 10 A.

(iii) the brush is one-half on segment 2 and one-half on segment 1. The brush again conducts a current of 40 A, the resistance of the two parallel paths are equal. The current in coil A is zero.

(iv) the current in coil A is 10 A but in the reverse direction.

(v) the current in coil A is 20 A but in the reverse direction.

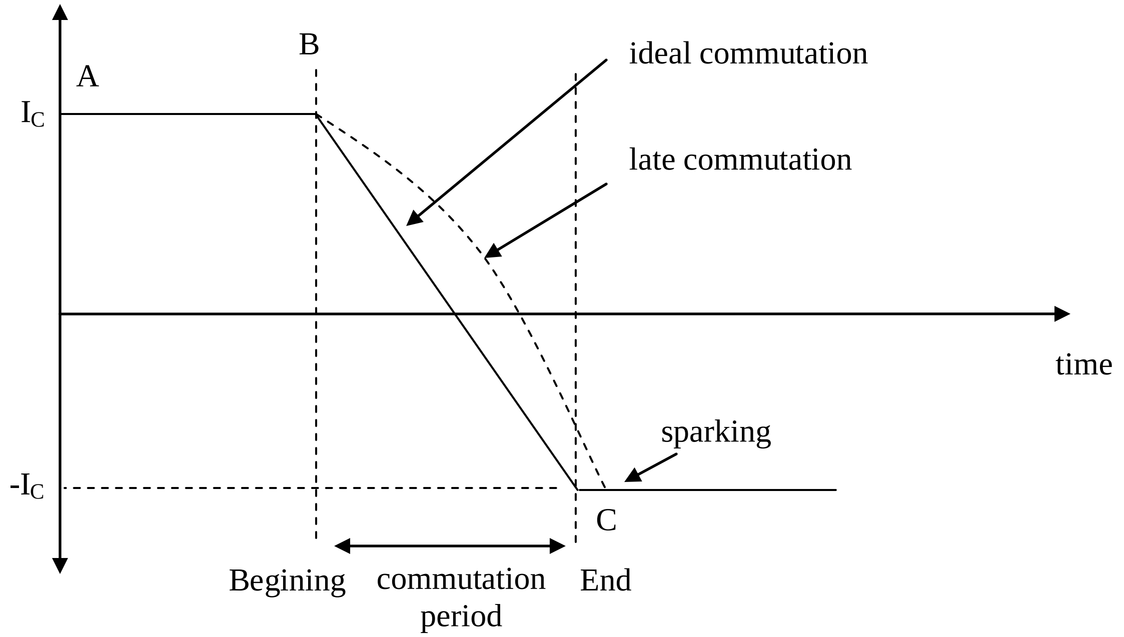
The below shows the current time graph for the coil A undergoing commutation.

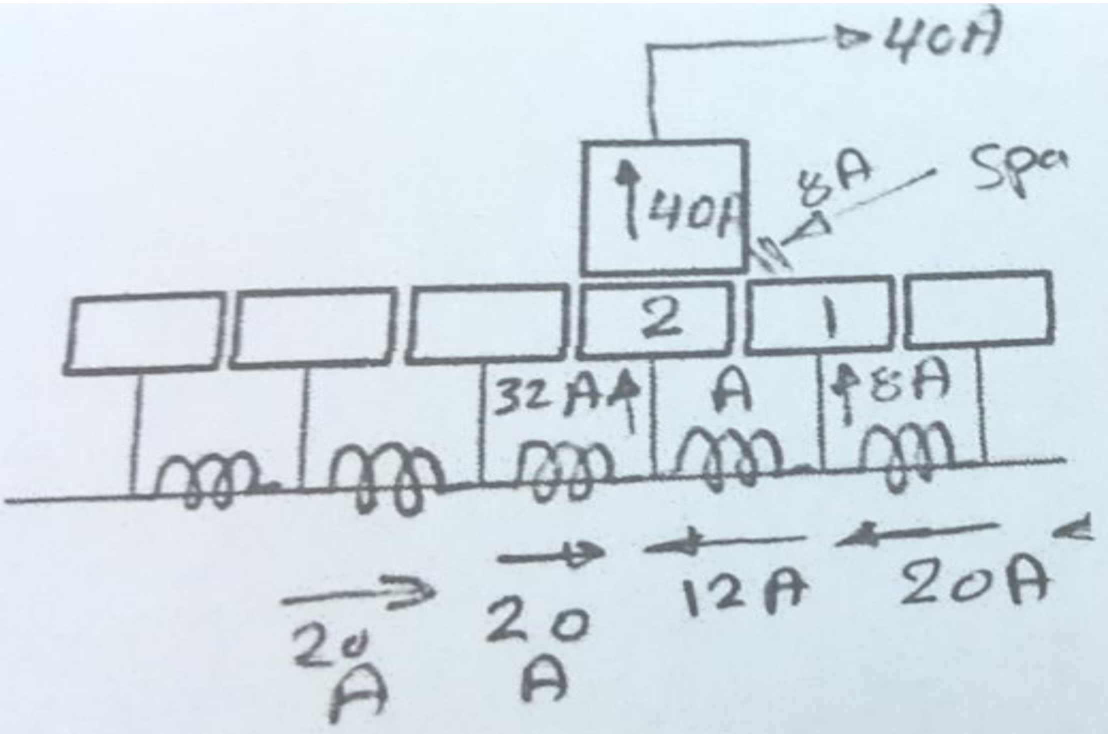


Practical difficulties

The ideal commutation (i.e., straight line change of current) can not be attained in practice. This mainly due to the fact that the armature coils have appreciable inductance. when the current in the undergoing commutation changes, self-induced e.m.f. $e_r = L\frac{di}{dt}$ is product in the coil. This is generally called reactance voltage.This reactance voltage opposes the change of current. The change of current occurs more slowly than it would be under ideal commutation. This results in sparking. The sparking results in overheating of commutator-brush contact and causing damage to both. It is important to induce a compensating voltage (e_c) in the coil circuit which will tend to cancel e_r. This can be achieved by:-

1. Brush shifting
2. Using interpoles , $e_r \rangle e_c$ late commutation , $e_r = e_c$ ideal , $e_r \langle e_c$ early commutation


B
A
I_C
ideal commutation
late commutation
time
sparking
$-I_C$
C
Begining
commutation period
End


40A
40A
8A
Spa
2
1
32 A A
A
8A
20 A
20 A
12A
20A

1.5 E.M.F. Equation

The conductor in magnetic field (B) and moving with speed (v) yield e.m.f. , thus .

The e.m.f. per conductor $= Blv$

Where

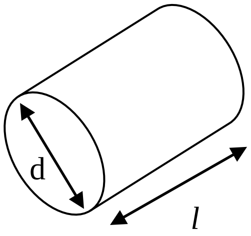
B = flux density (wb/m^2 or Tesla)

l =length of the conductor (core length)

v = speed (m/sec) = πdn

$d =$ armature diameter (m)

$n =$ armature speed (r.p.s.)



For D.C. machine ⇒ Total e.m.f. $= E = B_{av} l v Z_s$

Where

$Z_s = \frac{Z}{2a} =$ no. of armature conductors connected is series

$Z =$ total no. of conductors

$2a =$ no. of parallel paths

$$\mathbf{B_{av} = \frac{\textit{Flux per pole x number of pole}}{\textit{cylinderical area of armature surface}} = \frac{\phi}{\pi d \frac{l}{2p}} = \frac{2p\phi}{\pi d}}$$

Where

$2p =$ no. of poles

$\phi =$ air gap flux per pole

$$E = \frac{2p\phi}{\pi d l} . l \pi d n \frac{Z}{2a} \quad \text{volt}$$

$$E = \frac{2p}{2a} \phi n Z$$

Where

$$N = \frac{n(r.p.m)}{60}$$

There are two types of armature winding according to the shape of connection

1. Lap winding
2. Wave winding

For lap winding $2a = 2p$ and equal to no. of brushes, also used for high current.

For wave winding $2a = 2$ and equal to no. of brushes, also used for high voltage.

Example:- A four-pole wave-connected armature has 51 slots with 12 conductors per slot and is driven at 900 r/min. If the useful flux per pole is 25 mWb, calculate the value of the generated e.m.f.

Total no. of conductors = Z = 51 × 12 = 612; for wave connected 2a = 2; p = 2;

n = 900 r/min;

N=n/60 =900/60=15 r.p.s ;

; Φ = 0.025 Wb.

$$E = \frac{2p}{2a}\phi nZ$$

$$E = \frac{2\times 2}{2}\times 612\times 15\times 25\times 10^{-3}$$

$$E = 459V$$

Example:- A 4-pole wave-connected D.C. armature has a bore diameter of 71.12 cm . It has 520 conductors and the ratio of pole arc /pole pitch is 0.63. If the armature is running at 720 r.p.m. and the flux density in air-gap is 1.6Wb/m^2. Calculate the e.m.f. generated in the armature. Effective length of the armature conductor is 20.32cm.

Z = 520; for wave connected 2a = 2; 2p = 4; pole arc/pole pitch=0.63

n = 720 r/min ;N=n/60=720/60=12 r.p.s ; Φ = ? Wb.

$$E = \frac{2p}{2a}\phi n Z$$

Pole pitch $= \frac{\pi d}{2p} = \frac{\pi \times 71.12}{4}$

Pole arc $= 0.63 \times \frac{\pi \times 71.12}{4} = 35.2cm$

Axial length =20.32cm

Area of pole face = arc × axial length

= 35.2 × 20.32

= 715.3 cm2

= 715.3×10^{-4} m^2

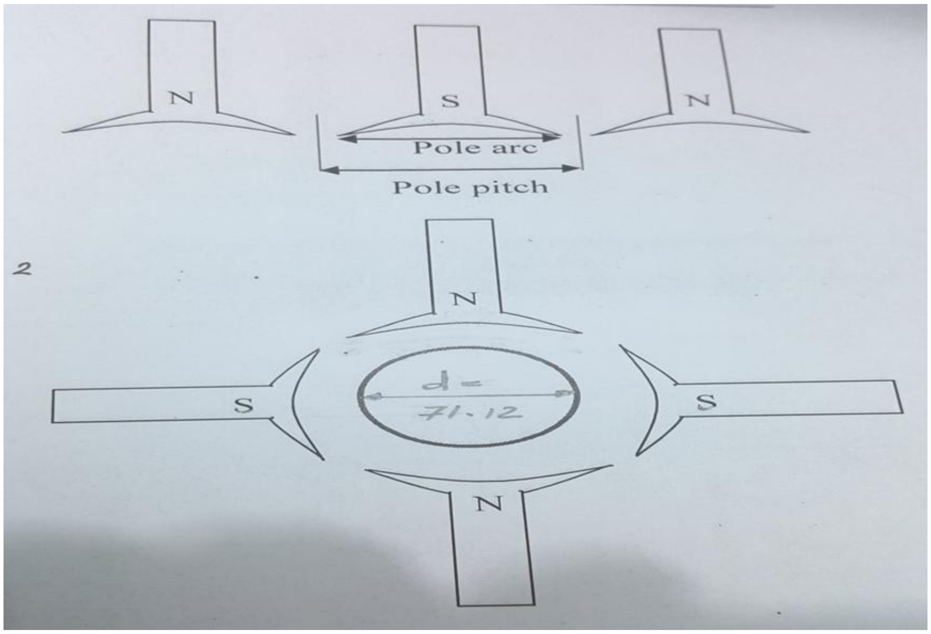
Φ= pole area × flux density

$=1.6\times715.3\times10^{-4}$

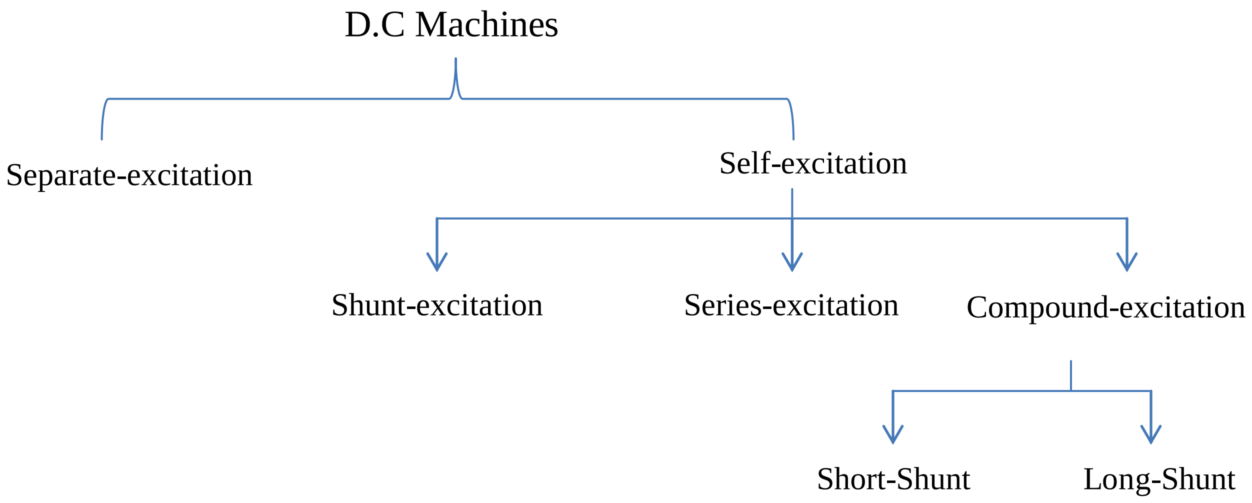
= 0.1145 wb

$$E = \frac{2p}{2a}\phi n Z$$

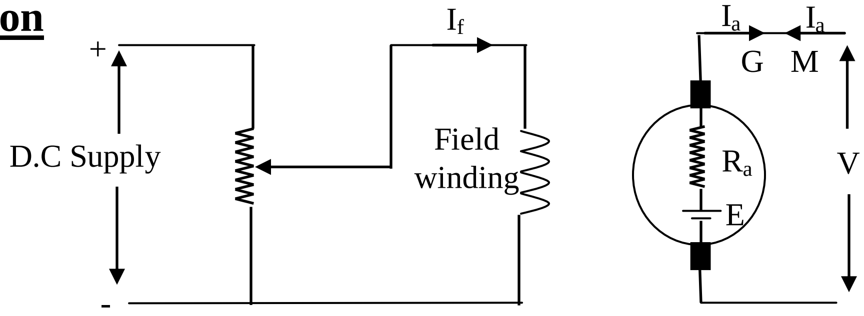
$$\boldsymbol{E = \frac{4}{2}\times 520\times\frac{720}{60}\times 0.1145 = 1428V}$$



1.6 Type of D.C Machines



1.6.1 Separate_ Excitation



$$I_a = I_l$$

$$E = V \overset{G}{\underset{M}{\pm}} R_a I_a$$

Where

E = e.m.f. induced in armature conductors $= \frac{2p}{2a}\phi nZ$

I_a = armature current

V= *terminal voltage*

Ra = *armature Resistance*

1.6.2 Self-Excitation

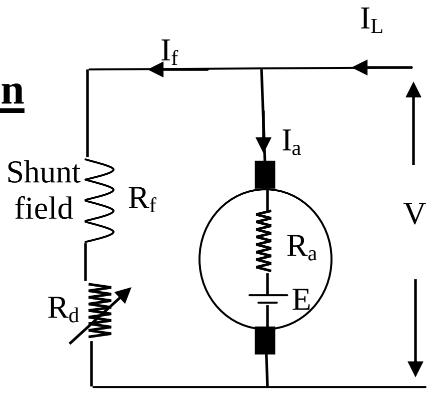
1.6.2.1 Shunt _Excitation

For motor $I_L = I_a + I_f$

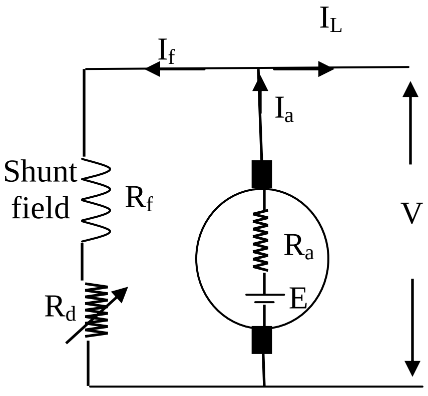
For Generator $I_a = I_L + I_f$

$$E = V \overset{G}{\underset{M}{\pm}} R_a I_a$$

$$\phi \propto I_f$$



Motor



Generato

R_f = Shunt resistance

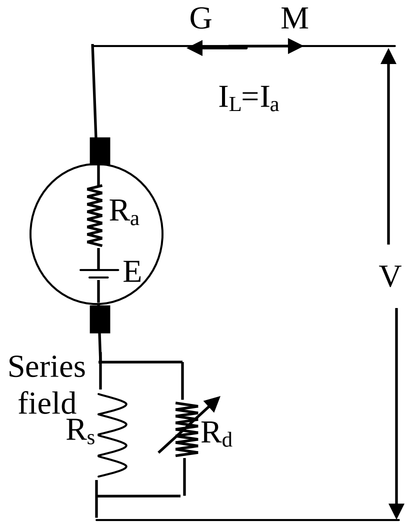
R_d = Divider resistance

Resistance of the shunt field (R_f) is high and no. of turns are high and used of small conductors diameter.

1.6.2.2 Series _Excitation

$I_a = I_L$

$$E = V \underset{M}{\overset{G}{\pm}} (R_a + R_s) I_a$$

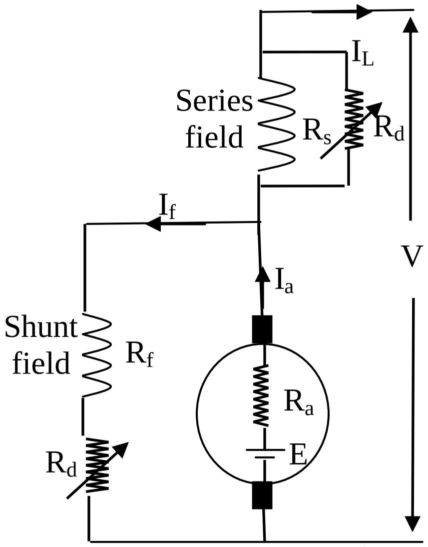


R_s = Series resistance

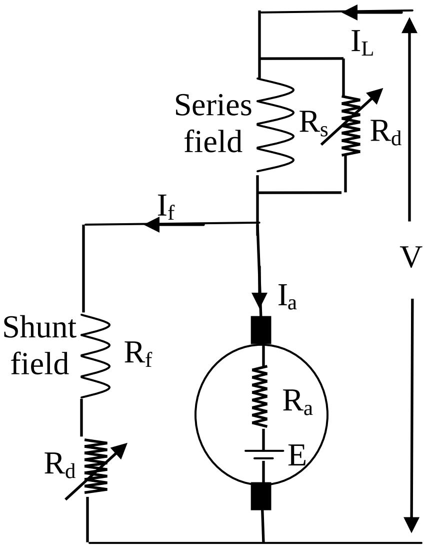
Resistance of the series field (R_s) is small and no. of turns are small and used of large conductors diameter.

1.6.2.3 Compound _Excitation

1.6.2.3.1 Short Shunt (Short Compound)



G



M

For motor $I_L = I_a + I_f$

For Generator $I_a = I_L + I_f$

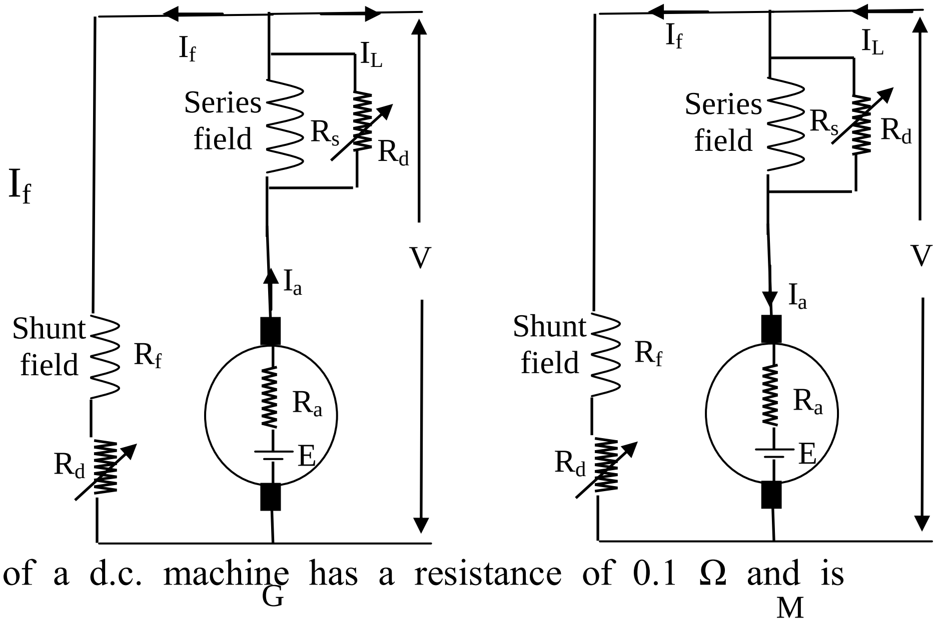
$$E = V \overset{G}{\underset{M}{\pm}} R_a I_a \overset{G}{\underset{M}{\pm}} I_L R_s$$

1.6.2.3.2 Long Shunt (Long Compound)

For motor $I_L = I_a + I_f$

For Generator $I_a = I_L + I_f$

$$E = V \overset{G}{\underset{M}{\pm}} (R_a + R_s) I_a$$



Example:- The armature of a d.c. machine has a resistance of 0.1 Ω and is connected to a 250 V supply. Calculate the generated e.m.f. when it is running

(a) as a generator giving 80 A.

(b) as a motor taking 60 A.

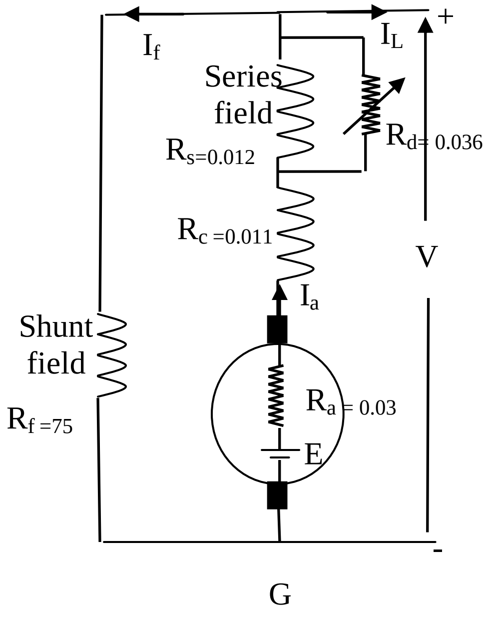
(a) $R_a = 0.1\Omega$ $V = 250v$ $I_a = 80A$ $E = V + R_a I_a$

Generated e.m.f. = 250 + 8 = 258 V

(b) $R_a = 0.1\Omega$ $V = 250v$ $I_a = 60A$ $E = V - R_a I_a$

Generated e.m.f. = 250 − 6 = 244 V

Example:- The following information is given for a 300 kw , 600 v , long-shunt compound generator shunt field resistance (75Ω) , armature resistance including brush resistance (0.03Ω) commutating resistance (0.011Ω), series field resistance (0.012Ω) , divider resistance of series winding (0.036Ω) when the machine is delivering full load , calculate the voltage and power generated by the armature ?



I_L=300000/600 =500A

I_f = 600/75 = 8A

$I_a = I_F + I_L$

Ia = 500 + 8 =508A

$E = V+I_a\ (R_a + R_c + R_s//R_d)$

E = 600+508 (0.03 + 0.011 + 0.012//0.036)

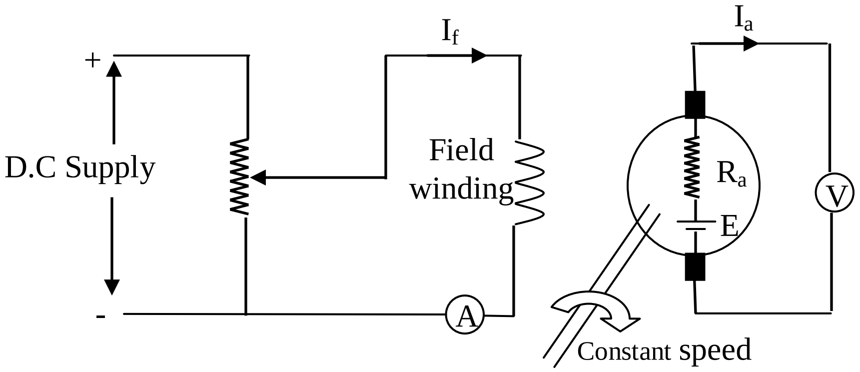
E = 625.4V

$P_{\text{armature}} = EI_a = 625.4 \times 508 = 317.7$ kw

Power developed in armature = $P_{\text{armature}} = E\ I_a$

1.7 Generator Characteristics

1.7.1 Open Circuit Characteristics (O.C.C) or Magnetization Curve



The field winding of D.C. generator (series or shunt is disconnected from the machine and separately excited from an external D.C. source as shown in Fig.

above. The generator run at fixed speed. The field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_o) read off on voltmeter connected across the armature terminals. On plotting the relation between E_o and I_f , we get the open circuit characteristics.

For open circuit

$$I_a = 0$$

$$E = V + R_a \underset{\longrightarrow 0}{I_a}$$

$$\therefore E = V$$

$$\because E = \frac{2p}{2a} \phi n Z = kn\phi$$

$$k = \frac{2p}{2a} Z$$

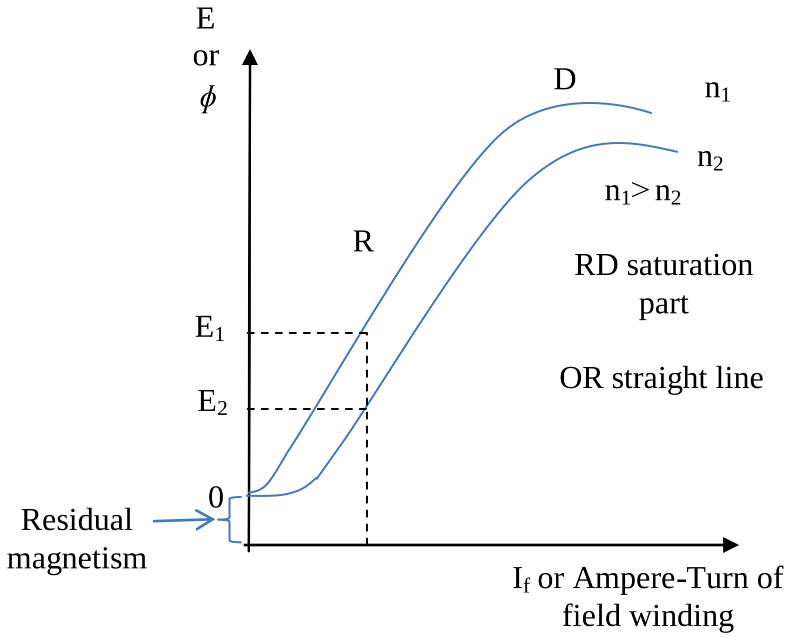
$$\frac{E_1}{E_2} = \frac{kn_1\phi_1}{kn_2\phi_2}$$

$\phi_1 = \phi_2$ (I_f constant)

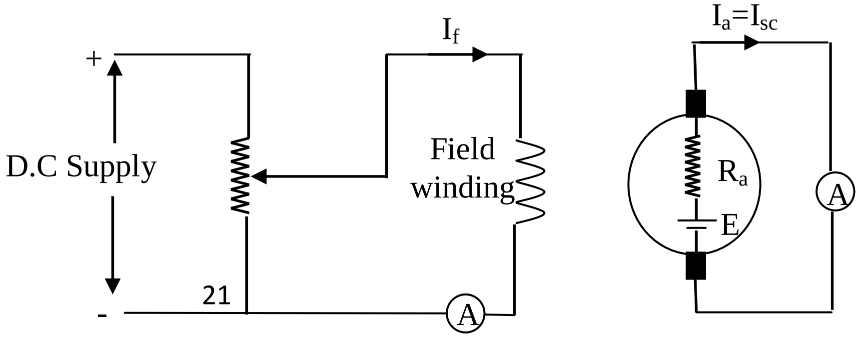
$$\frac{E_1}{E_2} = \frac{n_1}{n_2}$$

$\phi_1 \neq \phi_2$ (I_f not constant)

$$\frac{E_1}{E_2} = \frac{n_1\phi_1}{n_2\phi_2}$$



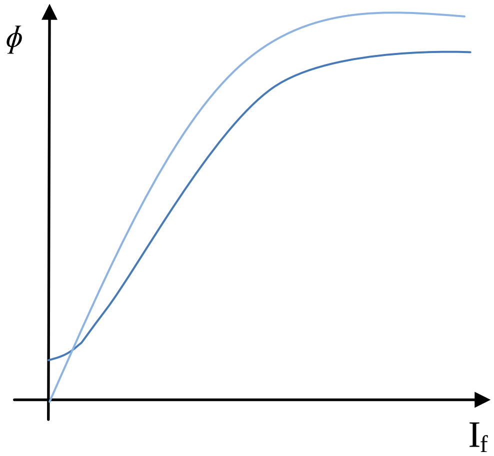
1.7.2 Short Circuit Characteristics (S.C.C)

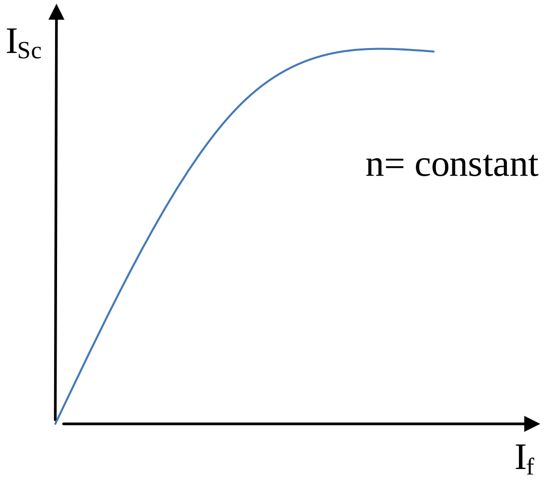


$$E = \underset{\to 0}{V} + R_a I_a$$

$$I_a = I_{sc} = \frac{E}{R_a}$$

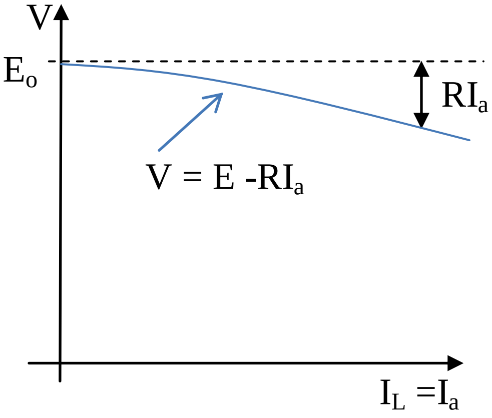
$$\therefore I_{sc} = \frac{E}{R_a} = \frac{kn\phi}{R_a}$$

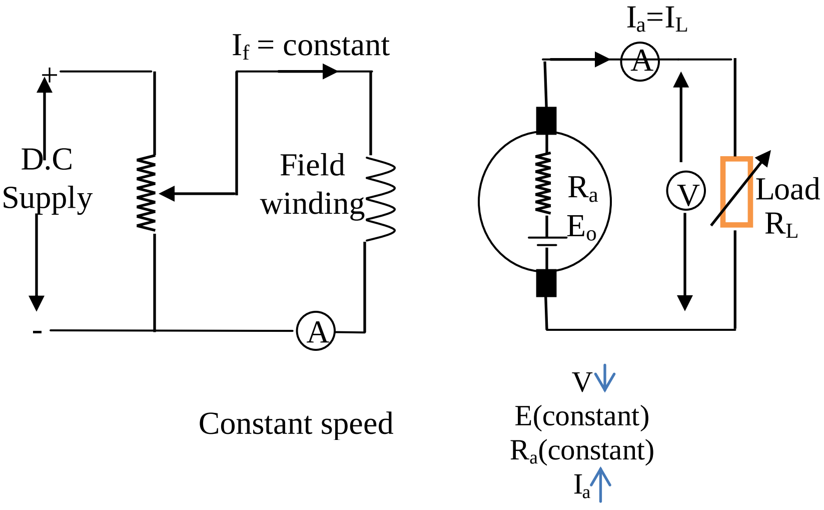




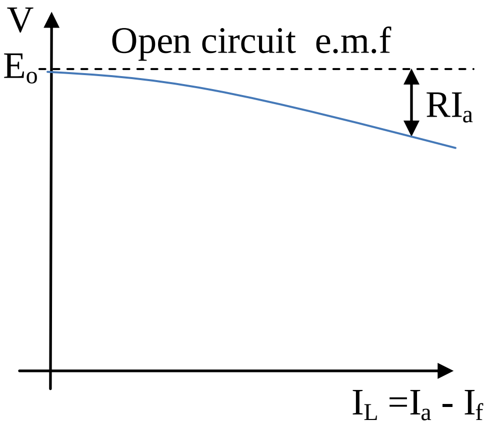
1.7.3 Load or External Characteristics

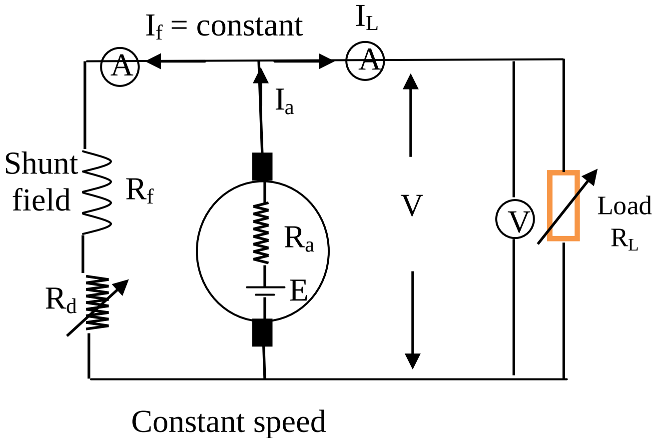
1.7.3.1 Separately Excitation



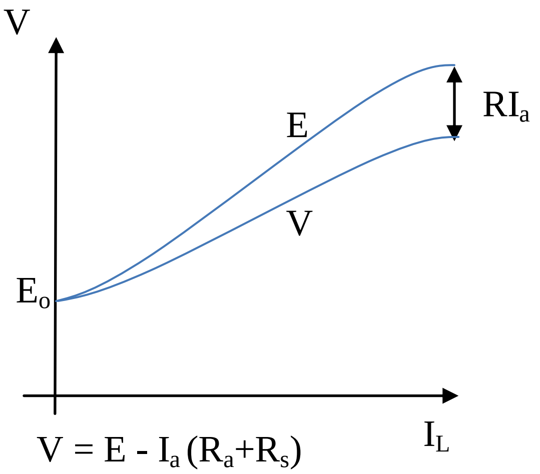


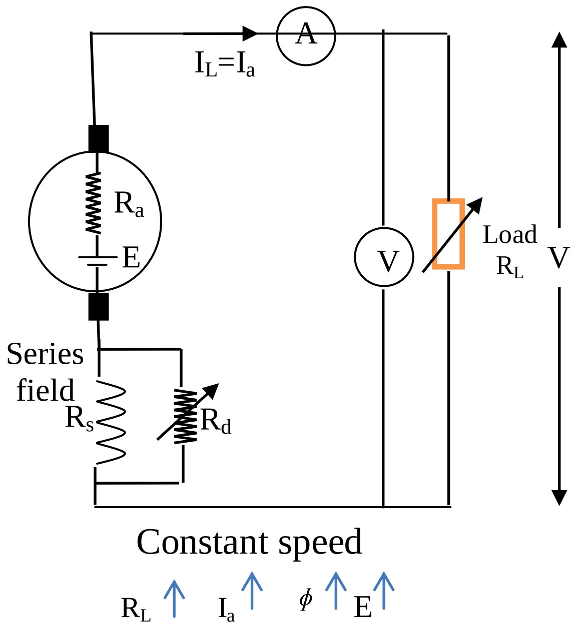
1.7.3.2 Shunt Excitation



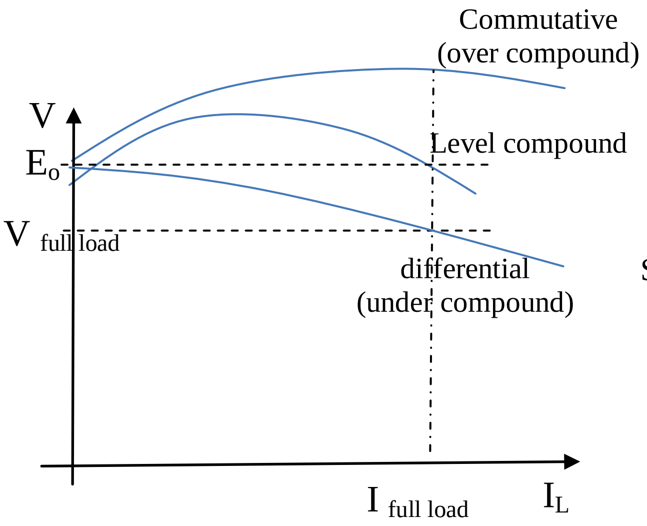


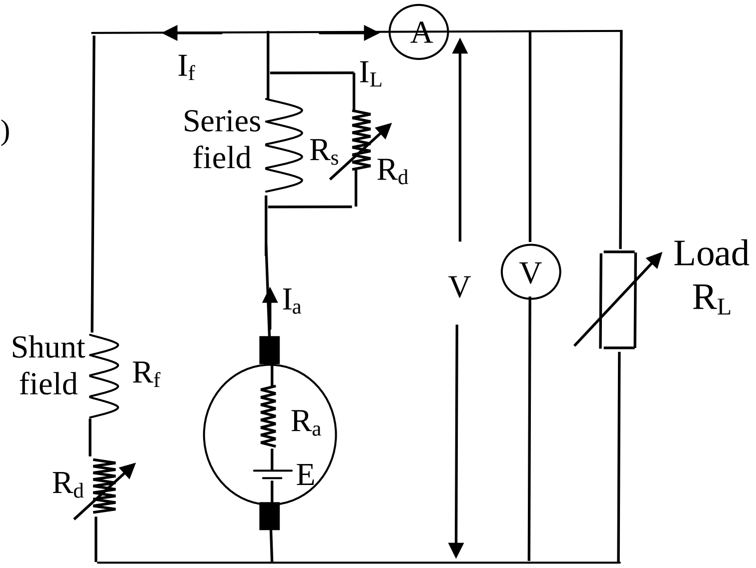
1.7.3.3 Series Excitation

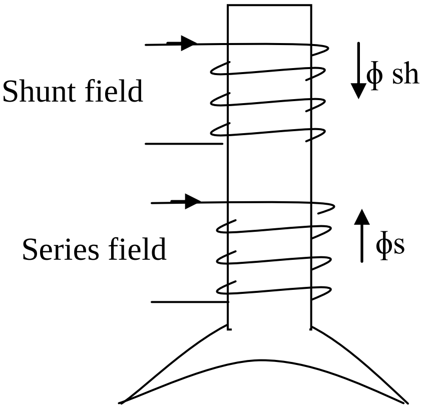




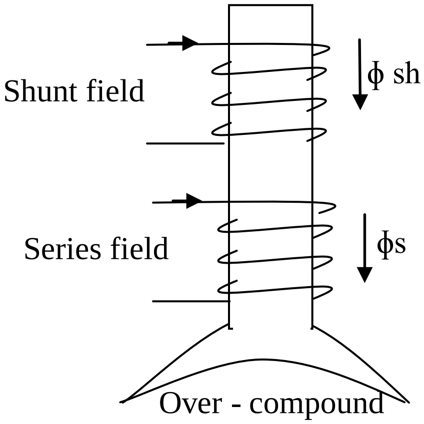
1.7.3.1 Compound Excitation







Under - compound



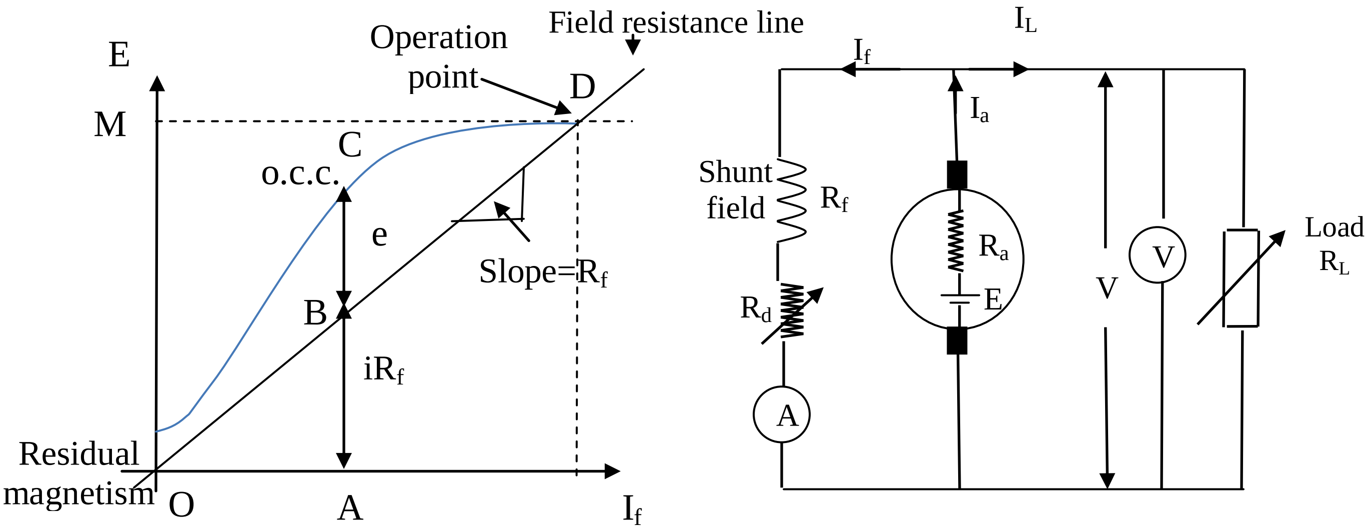
Over - compound

For the level compound $E_o = V_{full\ load}$

For the over compound $V_{full\ load} > E_o$

For the under compound $V_{full\ load} < E_o$

1.8 The process of Self _excitation



If the generator is run at a constant speed, some e.m.f. will be generated due to residual magnetism in the main poles. This small e.m.f. circulates a field current which in turn produces additional flux to reinforce the original residual flux (provided field winding connections are correct). This process continues and the generator builds up the normal generated voltage following the O.C.C. shown in above Fig.

Since the field circuit is inductive, there is a delay in the increase in current. suppose at any instant, the field current is the generated e.m.f. is A.C. and is increase at the rate di/dt, then

$$V = E_o = R_f I_f + L_f \frac{dI_f}{dt}$$

$$V = E_o = R_f I_f + e$$

Where

$e = L_f \dfrac{dI_f}{dt} = N_f \dfrac{d\phi}{dt}$ = induced e.m.f. in the field coil due to change in I_f

R_f = field resistance

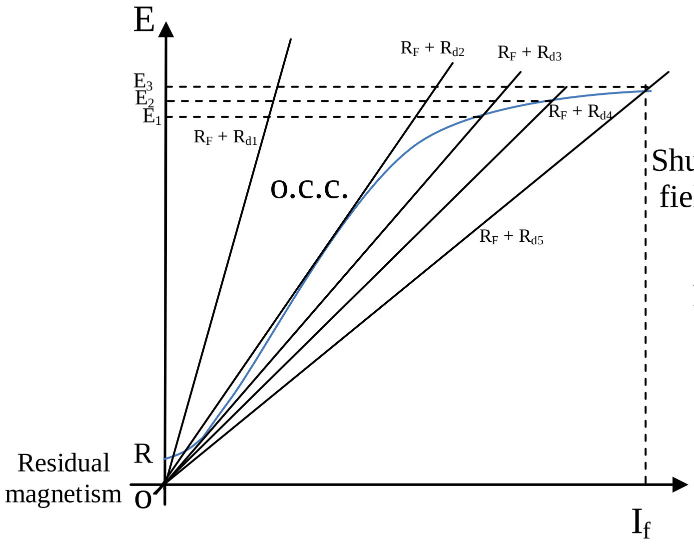
L_f = field resistance

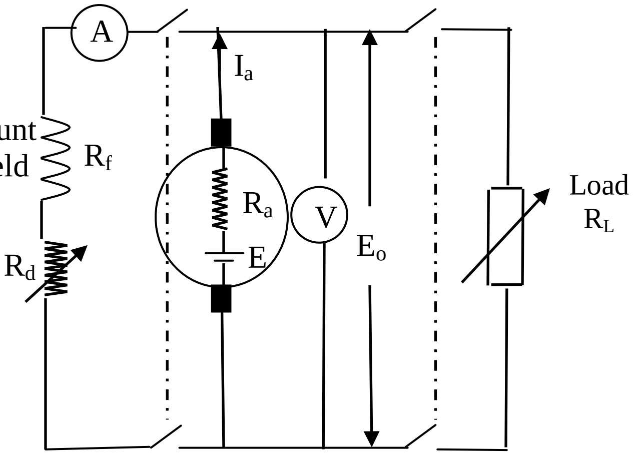
N_f =No. of field turns

At the considered instant, the total e.m.f. available is A.C. An armature AB of the e.m.f. AC is absorbed by the voltage drop iR_F and the remainder part BC is available to overcome L di/dt. Since this surplus voltage is available, it is possible to field current to increase above the value OA. However, at point D, the available voltage is OM and is all absorbed by iR_F drop. Consequently, the field current cannot increase further and the generator build up stops.

We arrive at a very important conclusion that the voltage build up of generator is given by the point of intersection of O.C.C. and field resistance line.

1.9 Critical Resistance and Critical Speed

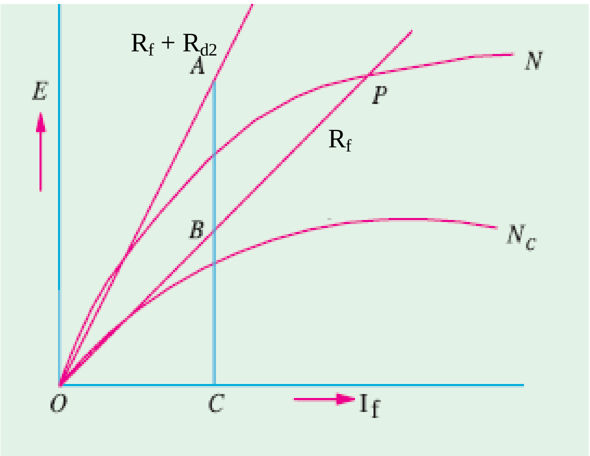




When the shunt circuit is broken , the resistance is infinite and e.m.f (OR) is due to residual magnetism. When the shunt circuit is closed and the resistance (Rf + Rd1) the e.m.f is long slightly large than OR. The field resistance (R_f + R_{d2}) reperesented by line OC (tangent to O.C.C.) is called critical resistance R_c. It is the maximum field resistance (for a given speed) with which the shunt generator would just excite. The shunt generator will build up voltage only voltage only if the field circuit resistance is less than critical field resistance.

$E_1 < E_2 < E_3$

(Rf + Rd3) > (Rf + Rd2) > (Rf + Rd1)



Critical speed

Critical speed of a shunt generator is the minimum speed below which it fails to excite. Clearly it is speed for which the given shunt field resistance (R_f) represents critical resistance.

curve 2 corresponding to critical speed because the shunt field resistance (R_{sh}) line is tangent to it. If the generator run at full speed N the new O.C.C. moves upward and the R'_{sh} line represents critical resistance for the speed.

speed α critical resistance

Then

$$\frac{Ac}{Bc} = \frac{N}{Nc} \Rightarrow \therefore Nc = \frac{Bc}{Ac} N$$

The speed N must be greater than Nc

Nc = critical resistance

Example:-*The magnetization characteristic curve for a 4-pole, 220-V, 800 r.p.m. shunt generator with Armature is lap-connected with 576 conductor is as follows :*

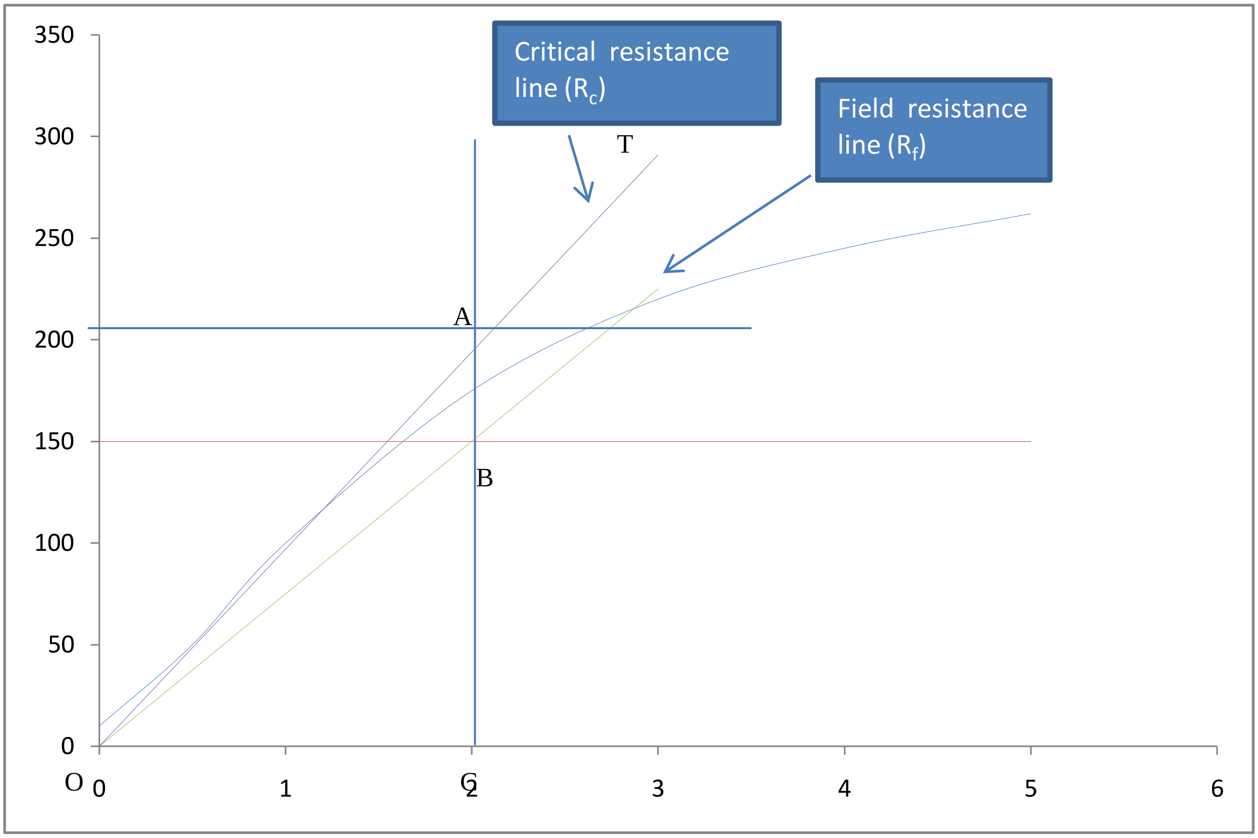
Field current	*0*	*0.5*	*1*	*2*	*3*	*4*	*5A*
O.C. voltage	*10*	*50*	*100*	*175*	*220*	*245*	*262 V*

Field resistance is 75 ohms. Determine

(*i*) *the speed at which the machine just fails to excite.*

(*ii*) *the flux per pole if the open circuit P.d. is 225v.*

(*iii*) *residual flux per pole*.



$R_f = 75\Omega$, $I_fR_f = 2\times75 = 150$ volt

Plot the straight line between (0,0) and (2,150) , this line of resistance ($R_f = 75\Omega$).

Plot line of tangential of the magnetisation curve , this line of critical resistance (R_c).

Any line AC is drawn perpendicular to the base , cutting lines OB and OT at point B and A.

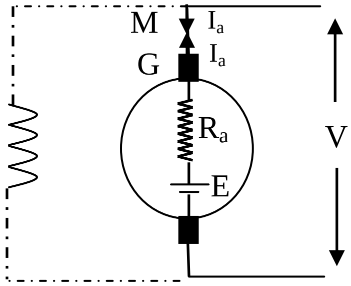
$$\frac{Ac}{Bc} = \frac{N}{Nc} \Rightarrow \therefore Nc = \frac{Bc}{Ac} N = 800 \times \frac{150}{194} = 618.5 r.p.m$$

(ii) $E = \frac{2p}{2a}\phi nZ \Rightarrow \phi = \frac{2a}{2p}\frac{E}{nZ} = \frac{225}{576 \times \frac{800}{600}} = 0.0293wb = 29.3mwb$

(iii) The residual flux per pole at $I_f = 0$, E=10.

$$E = \frac{2p}{2a}\phi n Z \Rightarrow \phi = \frac{2a}{2p}\frac{E}{nZ} = \frac{10}{576\times\frac{800}{600}} = 1.3mwb$$

1.10 Power Balance



For D.C. machine equation

$$V = E \overset{M}{\underset{G}{\pm}} R_a I_a$$

Multiply each term of eq. by I_a

$$VI_a = EI_a \overset{M}{\underset{G}{\pm}} R_a (I_a)^2$$

Where

VI_a = Total electrical power supplied to the armature (watt)

$(I_a)^2 R_a$ = The loss due to the armature resistance (watt)

EI_a = The mechanical power developed by the armature $T_a W = T_a 2\pi n$ (watt)

T_a = The torque developed by the armature or (electromagnetic torque) (N.m.)

$W = 2\pi n$ = angular velocity (rad/sec)

Loss torque = $T_a + T_m$ for generator

Loss torque = $T_a - T_m$ for motor

T_m = The mechanical torque or useful torque (N.m.)

Loss torque from iron and friction losses

Motor

$$Pin = VI_L$$

$$I_L = I_a + I_f$$

$$Pin = V(I_a + I_f)$$

$$Pin = VI_a + VI_f$$

Where

VI_f = field copper loss $R_f (I_f)^2$ (watt)

From eq.1

$$VI_a = EI_a + R_a (I_a)^2$$

$$VI_a = EI_a + R_a (I_a)^2$$

$$EI_a = T_a W = T_m W + P_{mi}$$

P_{mi} = mechanical + iron + stray load loss

$$P_{out} = T_m W$$

Generator

$$Pin = T_m W = T_a W + P_{ml}$$
$$EI_a = T_a W$$
$$EI_a = VI_a + R_a (I_a)^2$$
$$[I_a = I_f + I_L]V$$
$$VI_a = VI_f + VI_L$$

Where

VI_f = field copper loss $R_f (I_f)^2$(watt)

$$P_{out} = VI_L$$

For motor or generator

$$\text{Efficiency} = \eta = \frac{P_{out}}{P_{in}} \times 100\%$$

Electromagnetic (T$_a$)

$$E = \frac{2p}{2a} Zn\phi \frac{2\pi}{2\pi}$$
$$E = \frac{2p}{2a} \frac{Z}{2\pi} \phi 2\pi n$$
$$E = k\phi W$$

Where

$$k = \frac{2p}{2a} \frac{Z}{2\pi}$$

While

$$EI_a = T_a W$$
$$T_a = \frac{EI_a}{W} = \frac{k\phi W I_a}{W}$$
$$T_a = k\phi I_a$$

For series machine $\phi \propto I_a$, $T_a \propto (I_a)^2$

For series machine $\phi =$ constant , $T_a \propto I_a$

Example:- A shunt generator delivers 195A at a terminal P.d. of 250V . The armature resistance and shunt field resistance are 0.02Ω and 50Ω respectively. The iron and friction losses equal 950w. Find (a) E.M.F. generated (b) Copper losses (c) B.H.P. of the prime mover (d) Efficiency

(a) $I_f = \frac{V}{R_f} = \frac{250}{50} = 5A$

$$I_a = I_L + I_f$$
$$I_a = 195 + 5 = 200A$$
$$E = V + I_a R_a$$
$$E = 250 + 200 \times 0.02 = 254V$$

(b) copper losses $= R_a (I_a)^2 + R_f (I_f)^2$

$$= 0.02(200)^2 + 50(5)^2$$
$$= 2050w$$

(c) $Pin = T_m W = T_a W + P_{ml}$

$$EI_a = T_a W$$
$$Pin = EI_a + P_{ml}$$
$$Pin = 254 \times 200 + 950 = 51750w$$

B.H.P (British Hours power) $= \frac{51750}{746} = 69.37H.P$

(d) Efficiency $= \eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{195 \times 250}{51750} \times 100\% = 94.2\%$

Example:- The armature of a 4-pole D.C. shunt motor has a lap – connected armature winding with 740 conductors. The no-load flux per pole is 30mwb. If the armature current is 40A and the effect of armature at this current is to reduce the air-gap flux per pole by 4% , determine the torque develop

$2p = 4$, lap $=2$, $Z=740$, $\varphi_{N.L} = 30$mwb , $\varphi = 0.96\,\varphi_{N.L}$, $I_a = 40A$

$\varphi = 0.96 \times 30 = 28.8$ mwb

$$T_a = \frac{2p}{2a}\frac{Z}{2\pi}\phi I_a = \frac{740}{2\pi} \times 28.8 \times 10^{-3} \times 40 = 135.67 N.m$$

1.11 Speed _Torque Characteristics for D.C. Motor

1.11.1 Shunt Motor

$$E = k\phi w = V - I_a R_a$$

$$w = \frac{V}{k\phi} - \frac{I_a R_a}{k\phi} \qquad \text{……………..(1)}$$

$$T_a = k\phi I_a \Rightarrow I_a = \frac{T_a}{k\phi}$$

Put this equation in (1) yields

$$w = \frac{V}{k\phi} - \frac{T_a R_a}{(k\phi)^2} \qquad \text{………..Speed-Torque characteristics}$$

$$T_m = T_a - T_{losses}$$

For constant supply voltage and constant field resistance, then

$$I_f = \frac{V}{R_f} = \text{constant} \longrightarrow \varphi \text{ constant} \longrightarrow k\varphi = \text{constant}$$

$$w = k_1 - k_2 T_a$$

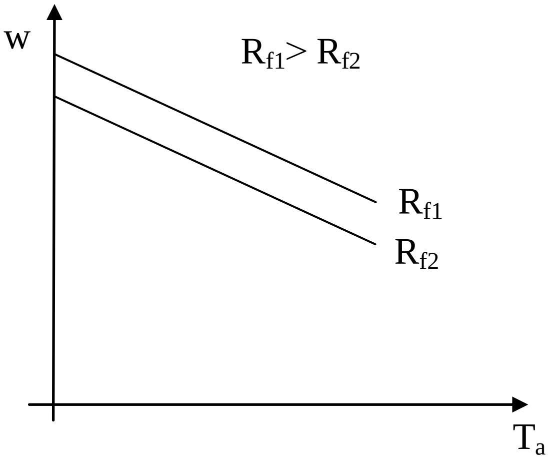
Where,

$$k_1 = \frac{V}{k\phi} \;,\; k_2 = \frac{R_a}{k(\phi)^2}$$

$T_a\uparrow \quad w\downarrow$

$R_f\uparrow \quad I_f\downarrow \quad \varphi\downarrow \quad k\varphi\downarrow \quad w\uparrow$

$$\text{w constant if } \begin{cases} \text{V constant} \\ R_f \text{ constant} \end{cases}$$



The D.C. motor can be considered as a constant speed motor when the source voltage and field resistance are constant.

1.11.2 Series Motor

The series motor has high starting torque and its speed changes greatly with the load.

It is clear from the motor speed-torque characteristics. That the series motor speed reaches very high value at no-load and thus the series motor must not operate or start without load.

$$I_f = I_a \frac{R_d}{R_d+R_s}$$

$$\therefore\ I_a \propto\ I_f\ \propto\ \emptyset\ \propto k\emptyset$$

$$\therefore\ I_a = cons.\,k\emptyset$$

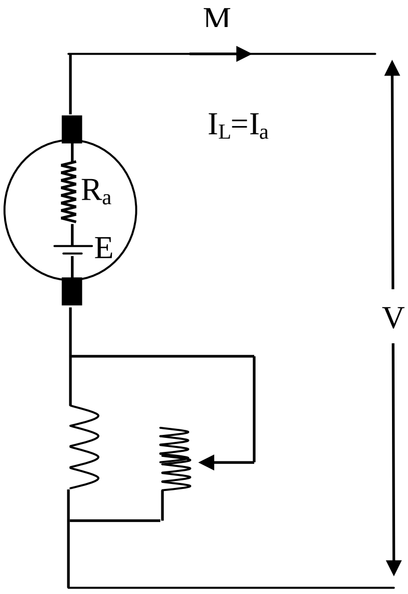
$$T_a = k\ \emptyset\ I_a =\ cons.\,(k\emptyset)^2$$

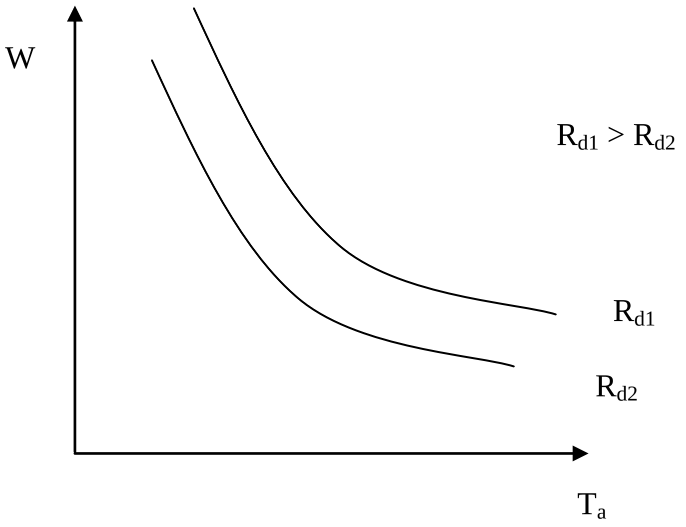
$$\therefore k\ \emptyset\ =\ cons.\sqrt{T_a}$$

$$w = \frac{V}{k\ \emptyset} - \frac{I_a}{k\ \emptyset} \quad \Rightarrow\ w = k_1\frac{V}{\sqrt{T_a}} - k_2 R$$

where

$$R = (R_s//R_d\,) + R_a$$





1.12 Starting of D.C. Motor

$$V = E + I_a R_a \Rightarrow I_a = \frac{V-E}{R_a} \quad , \qquad E = K\phi W$$

At starting $N = zero \Rightarrow W = zero \Rightarrow E = zero \therefore I_a = \frac{V-0}{R_a} \approx$ about 20 times the rated current .

To solve this problem , a resistance is connected in series with armature circuit to limit the starting current to about 1.5-2 the rated value

$$I_{as} = \frac{V}{R_a + R_{st}} \quad , \quad W = \frac{V - I_a R_a}{K\phi} \quad , \quad I_a \downarrow, \ E \uparrow, \ \ W \uparrow$$

$K\phi$ at starting must be large to reduce W this mean that the field resistance R_f must be reduce to increase $K\phi$

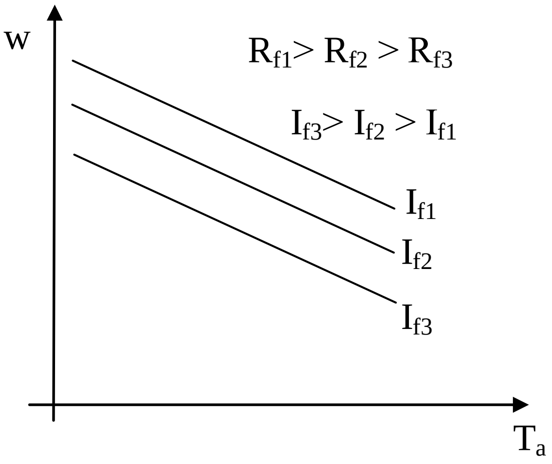
1.13 Speed Control of D.C. Motor

$$E = K\phi W = V - I_a R_a \Rightarrow W = \frac{V - I_a R_a}{K\phi}$$

1.13.1 Field Control

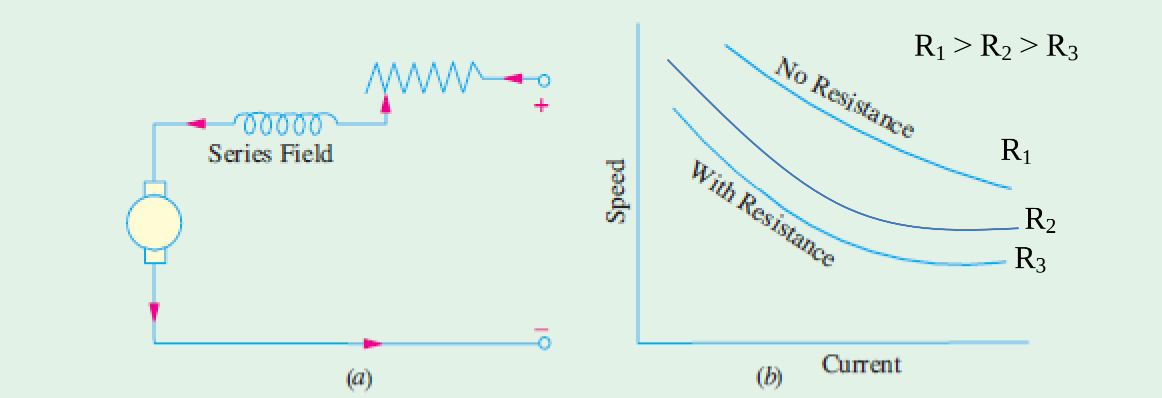
By changing the field resistance R_f

$R_f \uparrow$ $I_f \downarrow$ $\varphi \downarrow$ $k\varphi \downarrow$ $w \uparrow$

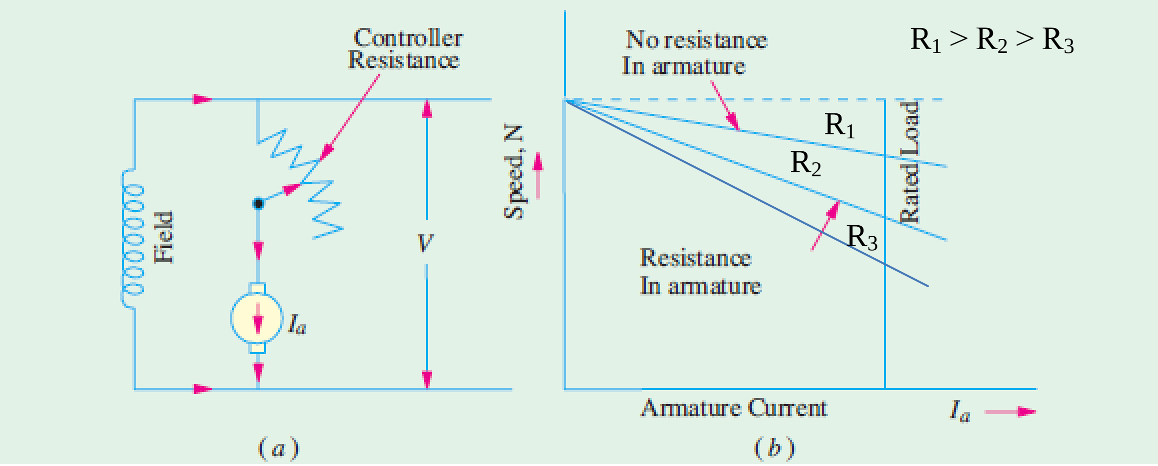


1.13.2 Armature Control

The speed of the motor can be increase by addition a resistance in series with the armature circuit



Series motor



Shunt motor

$R_1 > R_2 > R_3$