Ch-1

Faraday's law of Electromagnetic Induction :-

An emf is induced in a circuit when the magnetic flux enclosed by the circuit changes with respect to time.

$$e = \frac{d\lambda}{dt} = \frac{d(N\phi)}{dt} = \frac{N d\phi}{dt}$$

DC Generator :-

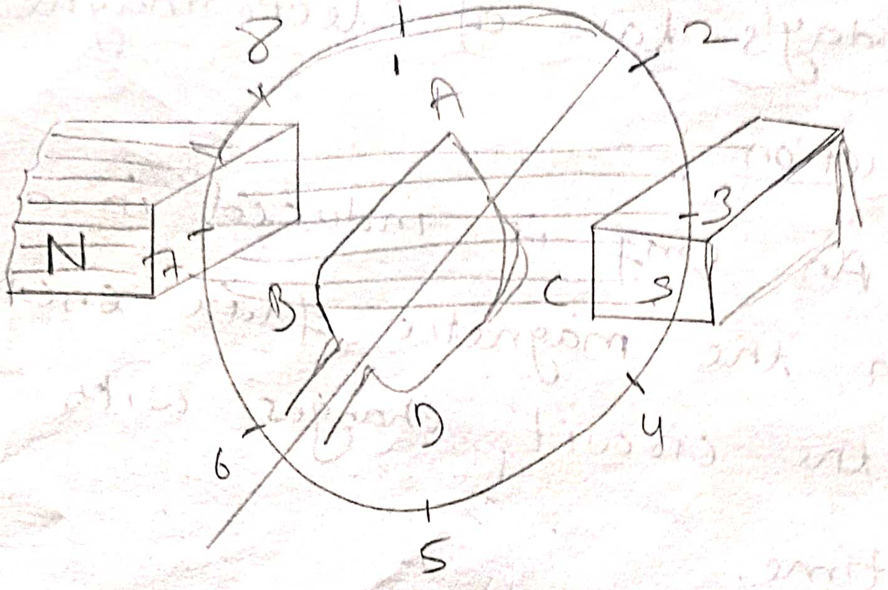
Generator is a device which converts mechanical energy into electrical energy.

principle

Whenever a conductor cuts magnetic flux, dynamically induced emf is produced in it according to faraday's law of electromagnetic induction. This emf causes a current to flow if the conductor circuit is closed.

Simple loop Generator

A single turn rectangular copper coil ABCD rotating about its own axis in a magnetic field.



1. coil is rotating in clock wise direction.

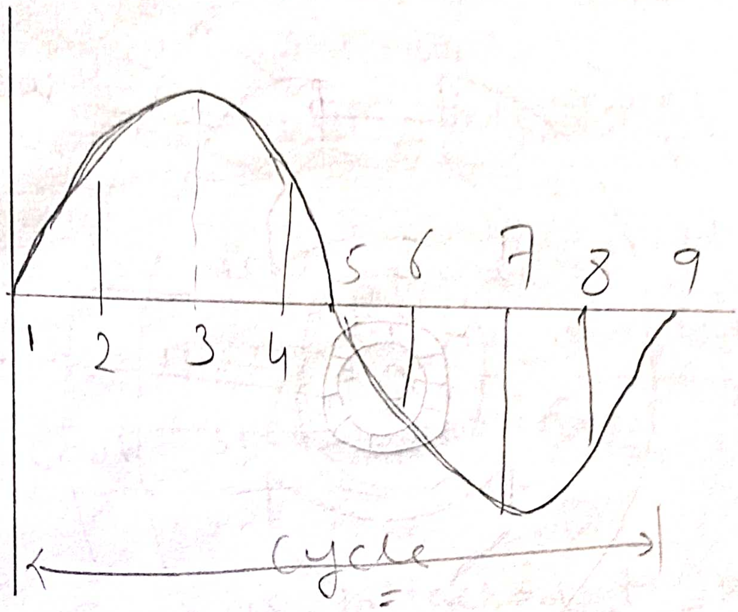
2. At position 1 the flux linked with the coil is maximum but rate of change of flux linkage is minimum.

3. As coil continues to rotate the rate of flux linkages increases till position 3.

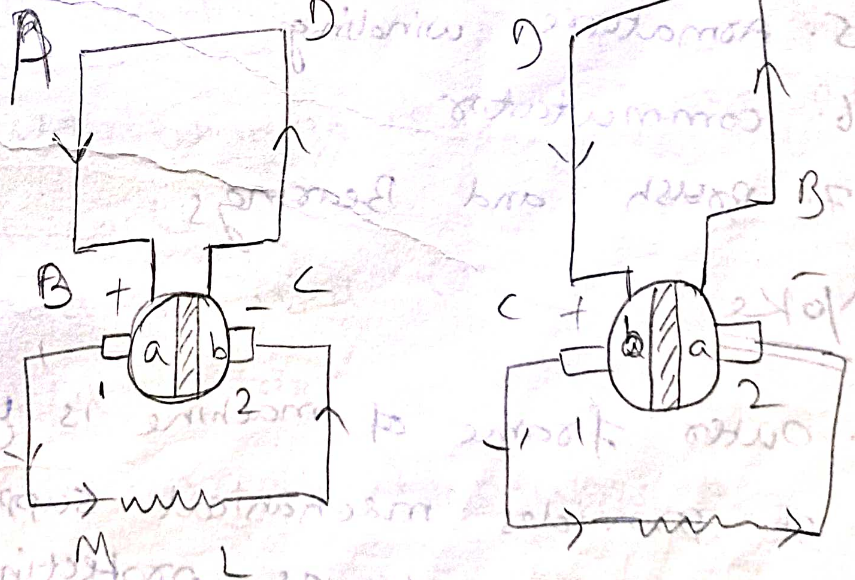
4. At position 3 flux linkage is minimum but the rate of flux linkage is maximum.

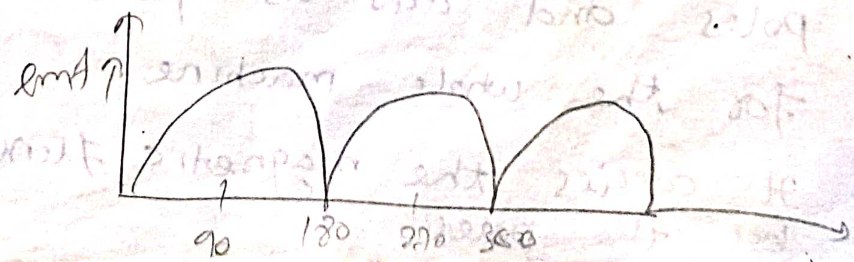
5. Next quarter emf gradually decreases.

6. In the same way next half revolution.

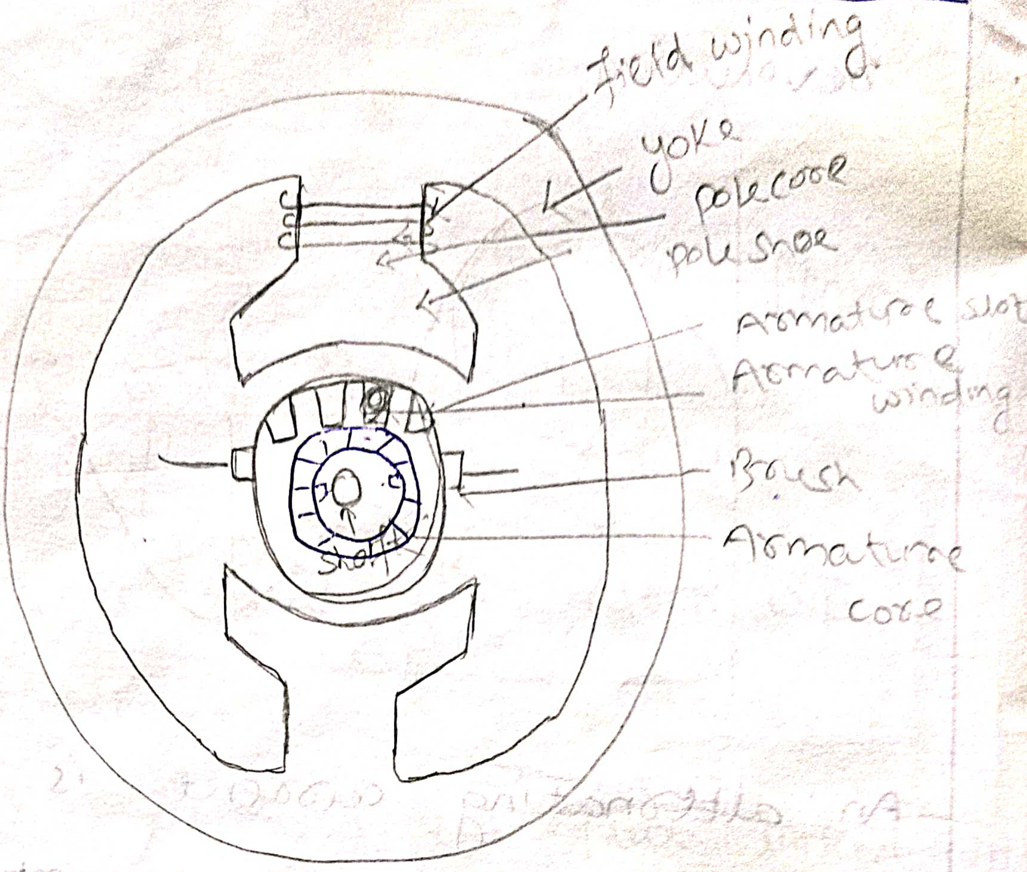


An alternating current is produced in the armature. To convert this current into unidirectional we use split rings.





constructional features of DC machine



1. yoke
2. pole core and pole shoes
3. field winding
4. Armature core
5. Armature winding
6. commutator
7. Brush and Bearings.

Yoke

1. Outer frame of machine is yoke.
2. It provides mechanical support for the poles and acts as protecting cover for the whole machine.
3. It carries the magnetic flux produced by the poles.

4. for small generator yoke are made of cast iron but for large machines cast steel or rolled steel. employed

pole cores and pole shoes :-

1. pole core is to house field winding and It is made up of cast iron or cast steel. No need to laminate It.
2. pole shoe is attached to pole core by means of counter sunk screws.
3. pole shoes spreads out the flux uniformly the air gap.
4. pole shoe provides low reluctance path for main field flux.

Field winding

1. Field winding is made up of cu coils.
2. Field is used to produce main field flux.
3. field current is always D. C

Armature core

1. Armature houses armature winding.
2. It is cylindrical shaped.
3. Armature is laminated in order to reduce eddy current loss.
4. Made of silicon steel to reduce hysterisis loss.

Commutator :-

1. Commutator segments made of high conductivity hard drawn copper.
2. Ends of Armature winding connected to commutator by riser.
3. Between commutator segments insulating materials are used usually 8mm.

Number of commutator segments = number of coil

Brushes

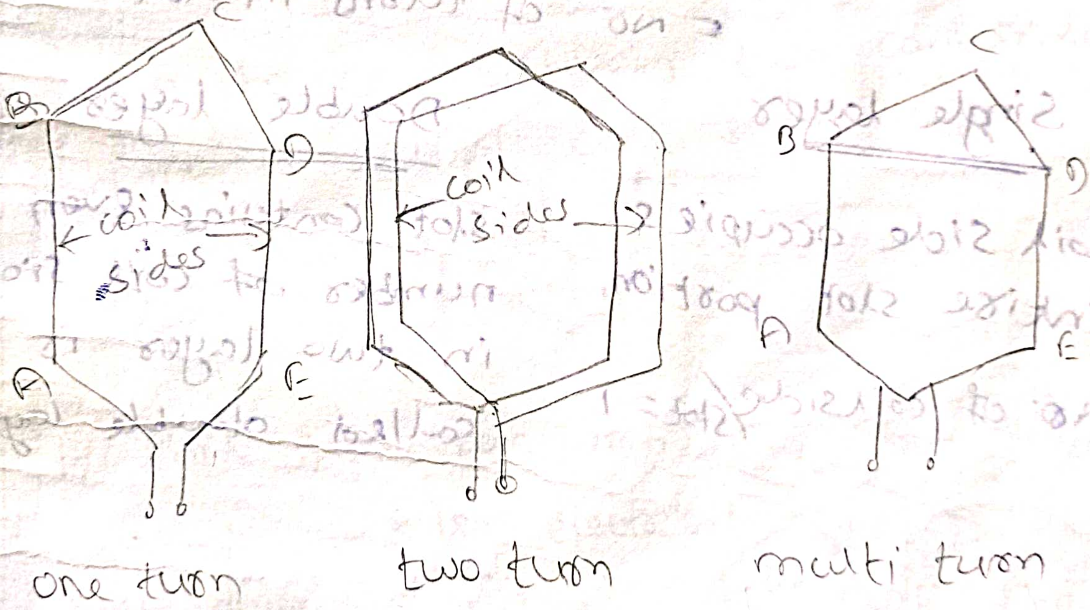
1. Function of Brush is to collect current from commutator.
2. In small machines brushes are made up of Cu or carbon.
3. In large machines brushes are made up of electro graphite (or) carbon graphite.

Armature winding

Two types

open type	closed type
Two ends are not at same location.	Two ends of winding placed on same commutator segment.
e.g.:- AC machines	DC machine.

~~Single layer~~ ~~Double layer~~



Conductor (Z)

Length of wire lying in magnetic field is called conductor.

AB, DE etc

Turn (T)

Turn consists of two conductors.

$$T = \frac{Z}{2}$$

Coil (C)

Coil consists of many turns.

Coil side (c)

Coil have two coil sides.

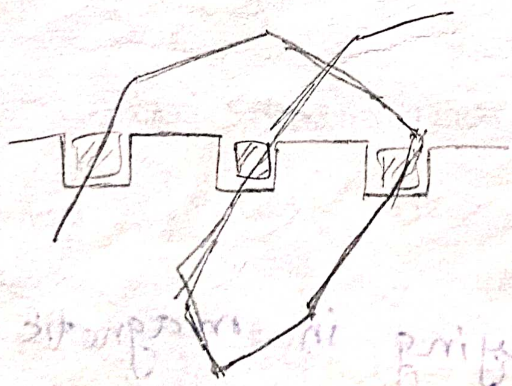
Coil side = 2 × no of coil

No of conductors in each coil side = No of turns in that coil

Single layer

Coil side occupies entire slot portion.

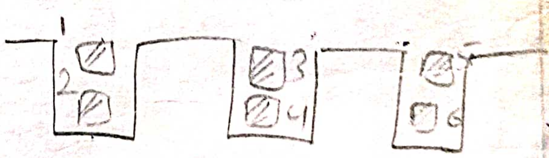
No of coilside/slot = 1

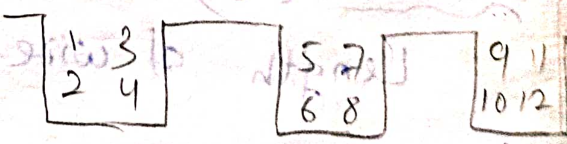


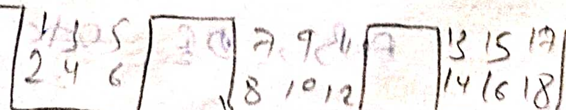
Small AC machine

Double layer

Slot contains even number of coil sides in two layers is called double layer.





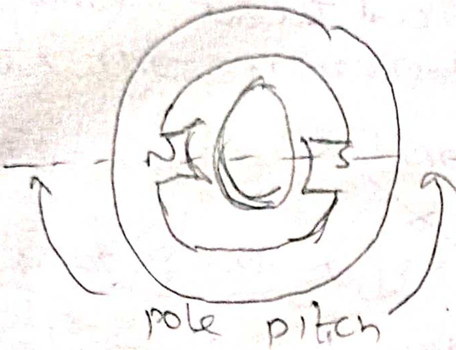


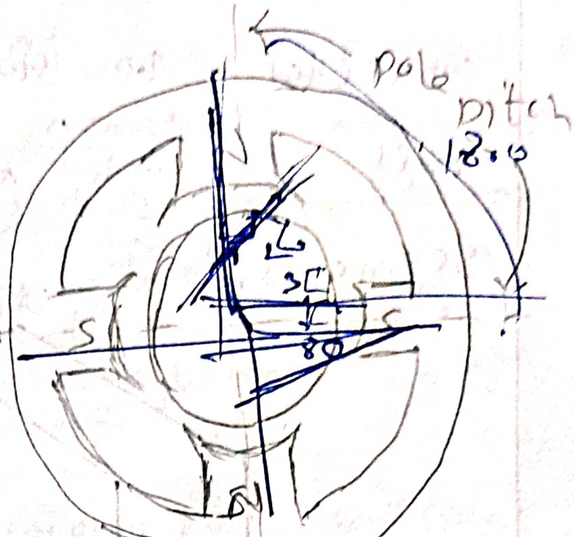
Large AC machine

& All Dc ...

pole pitch

Distance between identical points of adjacent poles.





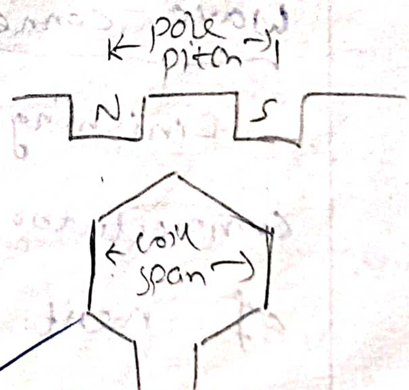
pole pitch = 180 electrical degree

$$\text{pole pitch} = \frac{\text{slots}}{\text{pole}} \quad (S/P)$$

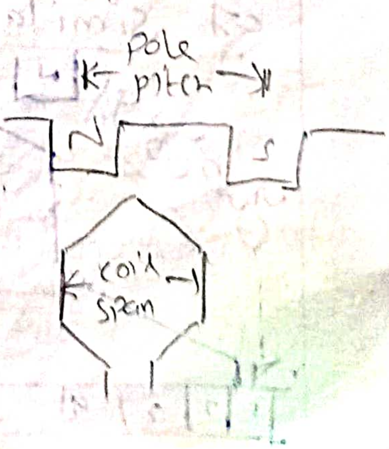
Coil span (or) coil pitch

Distance between two coil sides of a coil is called coil span.

If coil span = pole pitch =
= 180° electrical
= S/P
coil is called full pitched
(for DC machine)

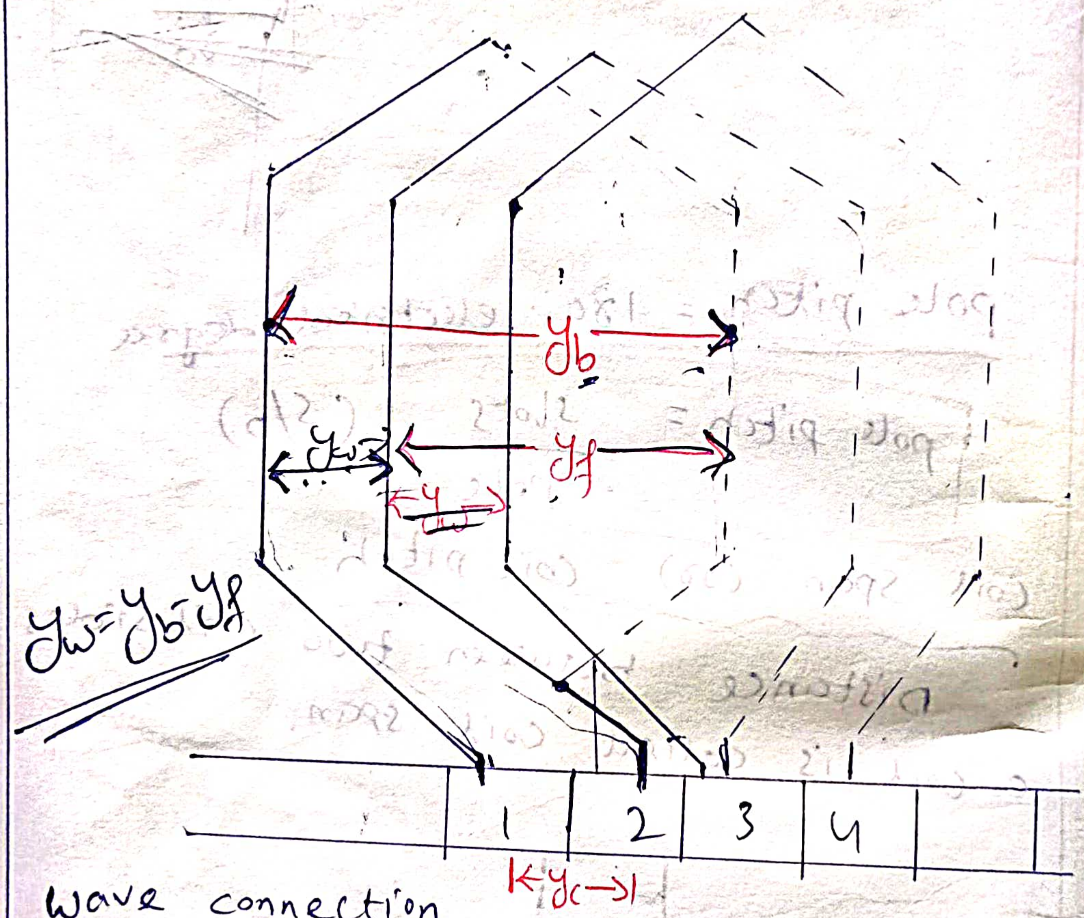


If coil span < pole pitch
< 180° electrical
< S/P
coil is called short pitched



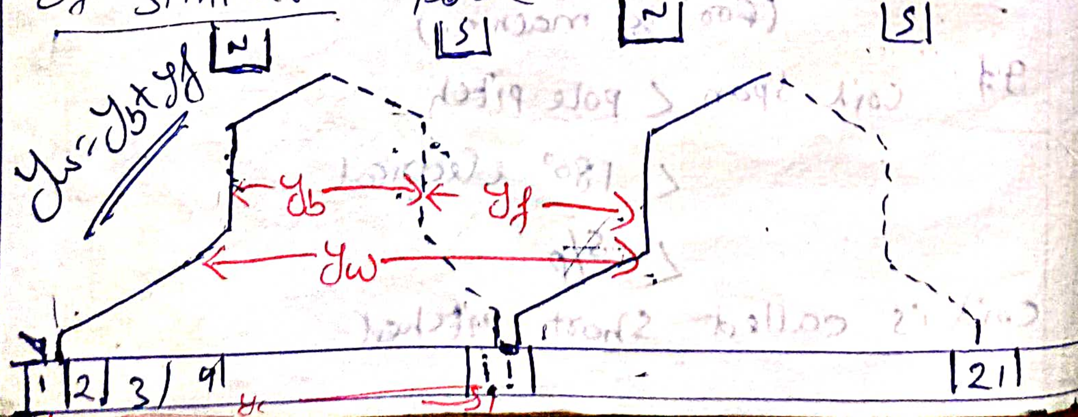
Lap connection

Finishing end of 1st coil is connected to starting end of next coil through the adjacent commutator segments.



Wave connection

Finishing end of 1st coil through commutator connected to starting end of next coil which is under adjacent of similar pole



Back pitch (y_b)

The distance between the top and bottom coil-sides of one coil, measured at the back of the armature or measured at the other side of the commutator is called back pitch.

For lap: $y_b = \frac{2C}{P} \pm K$

K is to make y_b odd.

Front pitch (y_f)

The distance between two coilsides which are connected to same commutator segment is called front pitch (y_f).

For lap: $y_f = y_b \pm 2m$ (pro)

$y_f = y_b + 2m$ (ret)

Winding pitch (y_w)

The distance between adjacent top coil sides (or) adjacent bottom coilsides is called winding pitch (or) resultant pitch.

For lap: $y_w = y_b - y_f$.

$y_w = \pm 2m$

For wave: $y_w = y_b + y_f$

$y_w = \frac{2C \pm 2m}{(P/2)}$

Commutator pitch (y_c)

The distance between commutator segment to which two ends of same coils are connected.

For Lap

$y_c = \pm m$ + (pro)   − (ret)

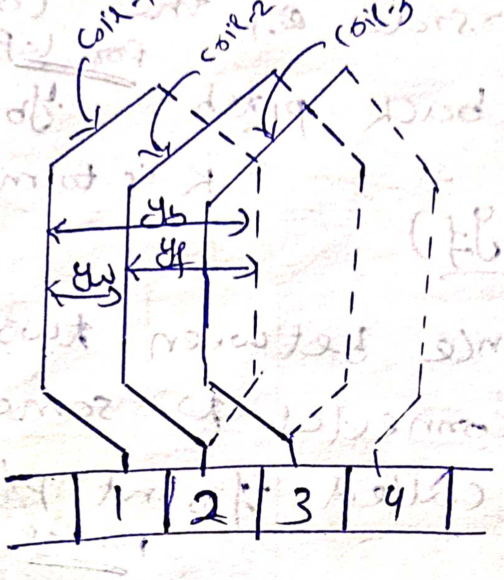
For wave

$y_c \approx 2$ pole pitch.

$y_c = \frac{C \pm m}{P/2}$.

Simplex progressive lap

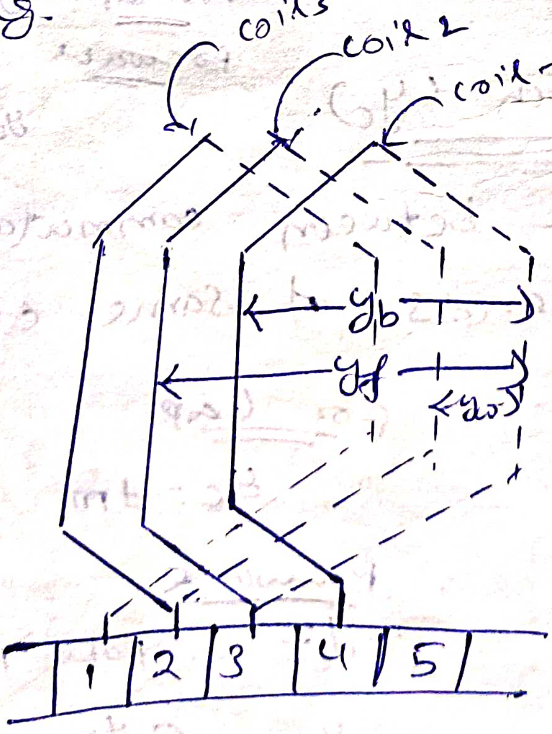
As winding progresses which moves from left to right as seen from commutator side is called progressive winding.



$y_b > y_f$

Simplex retrogressive lap

As winding progresses which moves from right to left is called retrogressive winding.



$y_f > y_b$

Split coils:

Coils with their top coil-sides in one slot and bottom coil-sides in two different slots are called split coils.

$$u = \text{Coil Sides}/\text{Slot}$$

Split coils can be avoided only when $\frac{y_b - 1}{u}$ is an integer.

Dummy coils

These are used in wave-winding. These dummy coils do not influence the electrical characteristics of the winding because they are not connected to the commutator. They are simply to provide mechanical balance for the armature.

Dummy coils are to be avoided if $\frac{S}{P/2}$ is not an integer.

Uses of Lap and wave winding

-> Wave winding gives more emf than the lap winding. Hence wave winding is suitable for small generators especially 500 - 600 V circuits.

Lap winding is suitable for comparatively low-voltage but high current generators where as wave-winding is used for high voltage low-current machines.

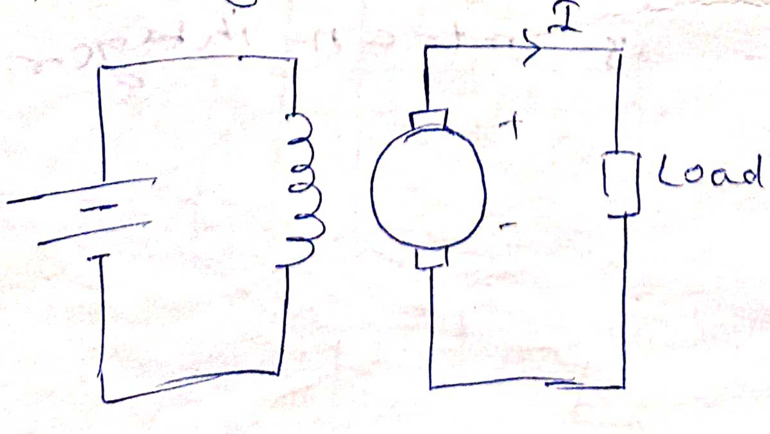
—x—

Types of Generators

a) Separately - excited generators.
b) Self - excited generators

a) Separately excited generators

Generators whose field magnets are energised from an independent external source of d.c. current is known as separately excited generators.



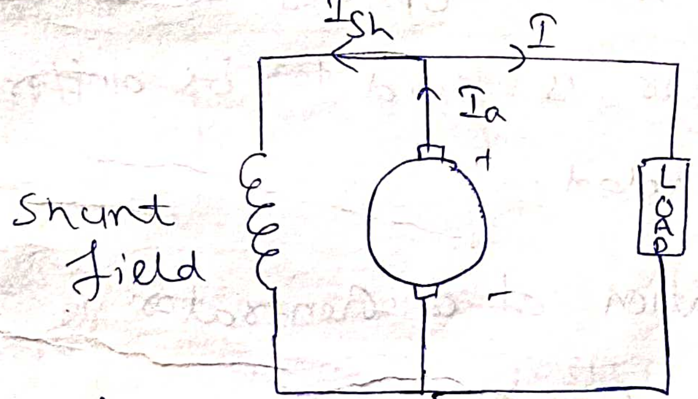
Self excited generators

Generators whose field magnets are energised by the current produced by themselves is known as self excited generator.

3 types
- (i) Shunt wound
- (ii) Series wound
- (iii) compound wound.

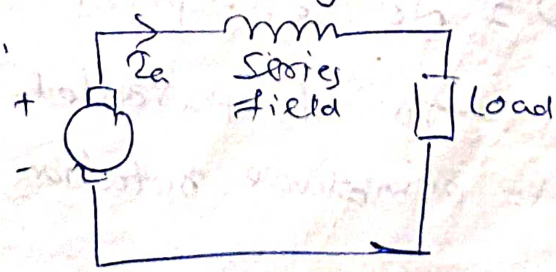
Shunt wound

The field windings are connected across ~~or the~~ the armature conductors and have the full voltage of the generator applied across them.



Series wound

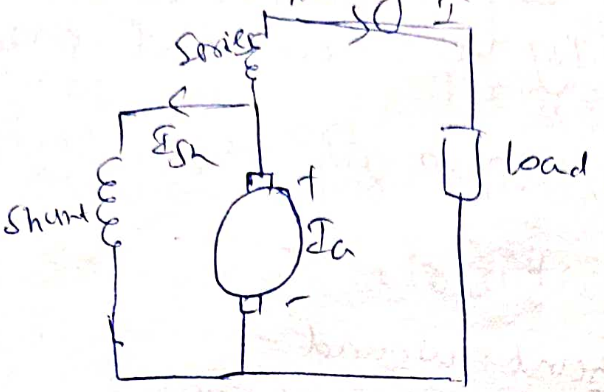
Field windings are Joined in series with the armature conductors. As they carry full load current, they consist fewer turns of thick wire.

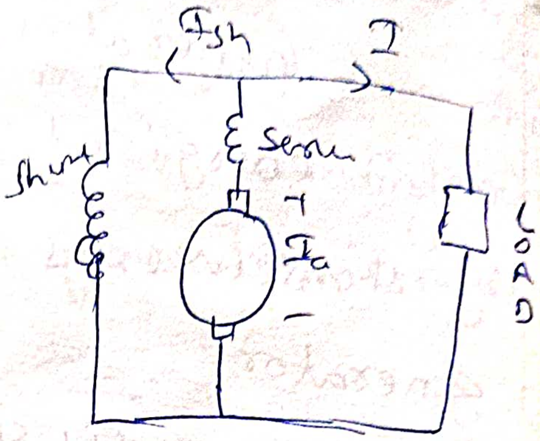


Compound wound

→ Short-shunt

→ long-shunt





In a compound generator shunt field is stronger than the series field.

When series field aids shunt field generator is said to be cummulatively - compounded.

If series field opposes the shunt field, generator is said to be differentially compounded.

E.m.f. equation of a Generator :

ϕ = flux/pole in wb.

Z = total number of armature conductors.

P = No. of poles

A = no. of parallel path

N = armature rotation in r.p.m

E =

Average e.m.f generated / conductor = $\frac{d\phi}{dt}$ ✓

$$d\phi = P \times \phi$$

No. of rev. per second = $\frac{N}{60}$

Time for one rev. = $\frac{60}{N}$

$$\text{Emf} = \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{P\phi N}{60}$$

$$\text{Total emf} = \frac{P\phi N}{60} \times Z$$

$$\text{emf / path} = \frac{P\phi N}{60} \times \frac{Z}{A} \text{ volt}$$

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

$$\boxed{E_g = K_a \phi N} \quad K_a = \frac{Z \times P}{60A}.$$

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

Losses in D.C. generator

- copper losses
- core losses
- Mechanical losses.

copper losses

- armature copper loss
- Field copper loss.

Armature copper loss = $I_a^2 R_a$

30% to 40% of full load loss.

<u>field copper loss</u>

In case of Shunt generators

It is const. $I_{sh}^2 R_{sh}$

In case of series gen. = $I_{se}^2 R_{se}$

20 to 30% of f.l. Loss.

<u>Magnetic (or) core losses</u>

Hysterisis loss
eddy current Loss.

<u>Hysterisis Loss</u>

This loss is due to the reversal of magnetisation of the armature core.

$W_h = \eta B_{max}^{1.6} f V$ watts.

<u>Eddy current loss</u>

When the armature core rotates, it also cuts the magnetic flux. Hence an e.m.f. is induced in the body of the core due to its small resistance This current is known as eddy current. The power loss due to this current is known as eddy current loss.

$$W_e = K B_{max}^2 f^2 t^2 V^2 \text{ watt}$$

It can be reduced by using a core of laminations.

20 to 30% of full load loss.

Mechanical loss

(i) Friction loss at bearing & commutator

(ii) Air friction or windage loss of rotating armature

This is about 10 to 20% of F.L.

- Total loss
  - Copper loss
    - Series field loss
    - Shunt field loss
    - Armature cu. loss
  - Core loss
    - Hysteresis
    - Eddy current
  - Mechanical loss
    - Friction
    - Windage

(Core loss + Mechanical loss) = Stray or Rotational loss.

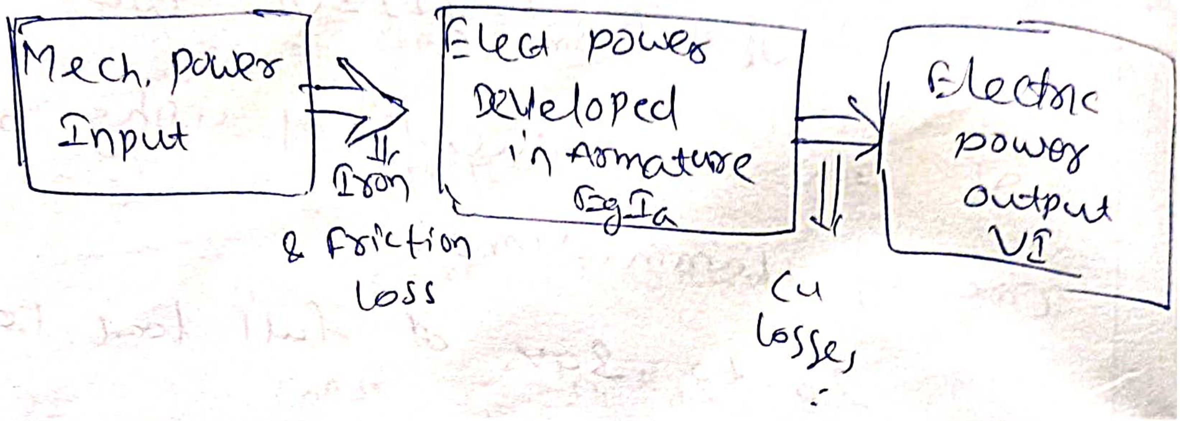
Field cu loss is constant for shunt and compound generator. Hence

stray loss + shunt cu loss = const. loss W_c

Total loss = Armature cu loss + W_c

Total loss = variable loss + W_c

power stages



Generator Efficiency

$$\eta = \frac{\text{output power}}{\text{total power developed}} = \frac{VI}{E_g I_a}$$

Condition for maximum efficiency

Generator o/p = VI

Generator I/p = $VI + I_a^2 R_a + W_c$

$= VI + (I + I_{sh})^2 R_a + W_c$

$I_a = I$ as I_{sh} is negligible

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

$$\eta = \frac{1}{1 + \left(\frac{I R_a}{V} + \frac{W_c}{VI}\right)}$$

Now efficiency is max. when denominator is min.

i.e. $$\frac{d}{dI}\left(\frac{IR_a}{V} + \frac{W_c}{VI}\right) = 0$$

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

$$I^2 R_a = W_c$$

Hence generator efficiency is max, when variable loss = const loss.

$$I = \sqrt{\frac{W_c}{R_a}}$$

Armature Reaction :-

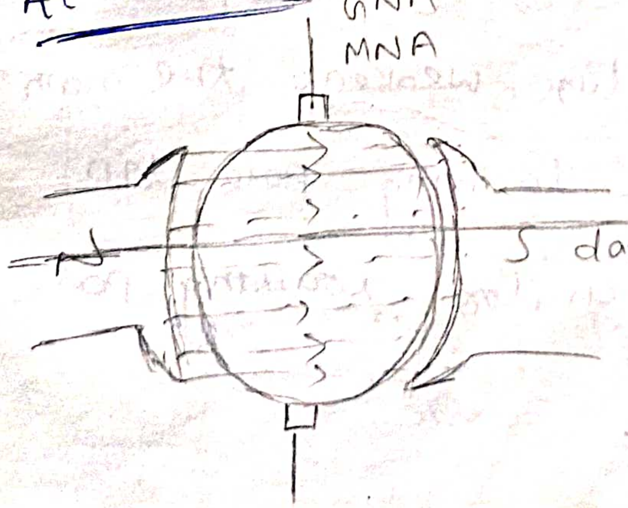
~~Armature reaction~~ is. The effect of armature mmf on the main field flux distribution in the air gap is called armature reaction.

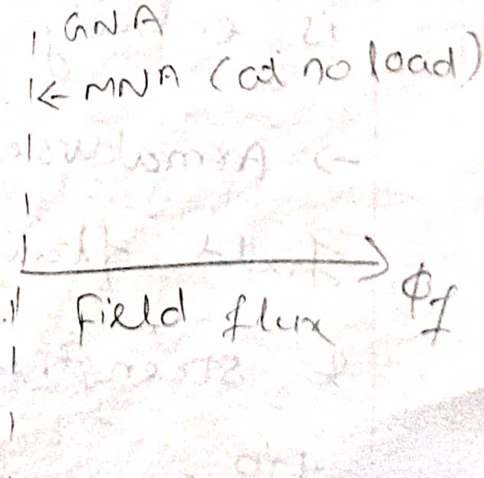
It has two effects

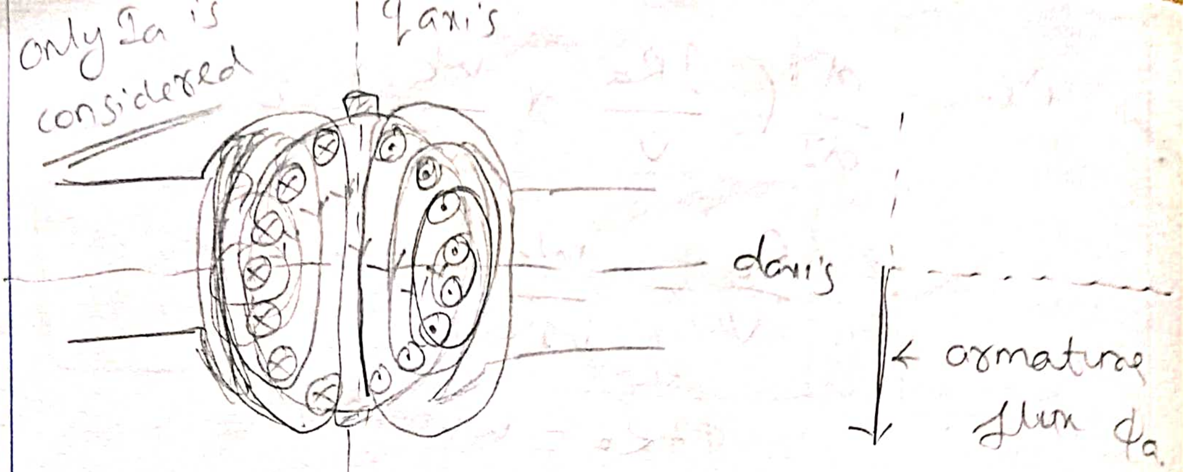
(i) It demagnetises or weakens the main flux.

(ii) It cross magnetises or distorts it.

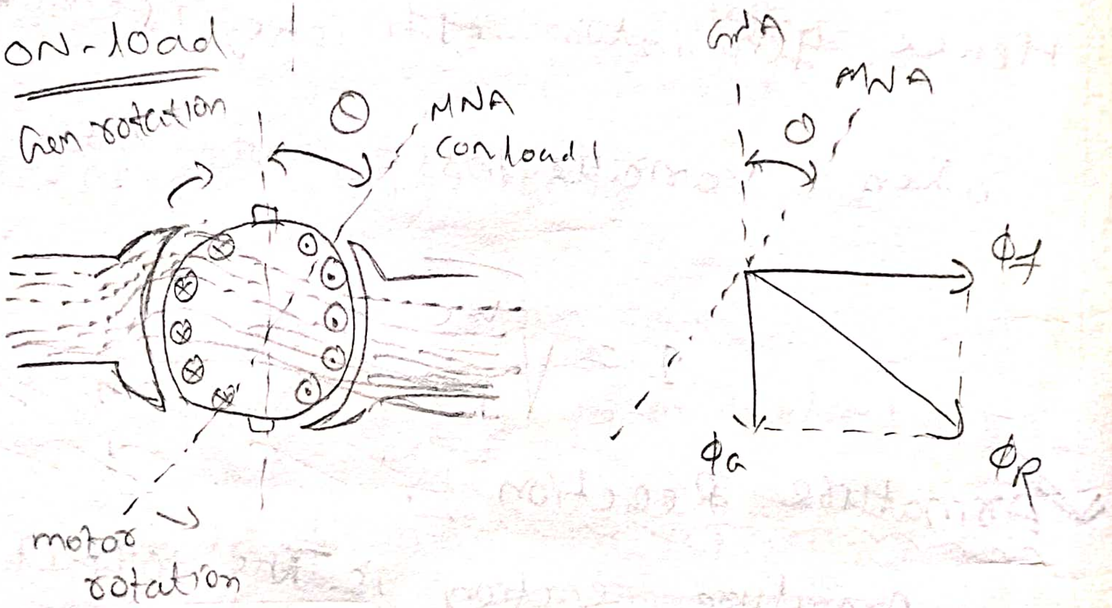
At No-load







ON-load



→ The path of armature flux ϕ_a is perpendicular to the main field flux path ϕ_f. The path of the armature flux crosses the path of the main field flux. Thus the effect of the armature flux on the main field is entirely cross-magnetizing.

→ Armature flux weakens the main field flux at leading pole tip & strengthens under trailing pole tip.

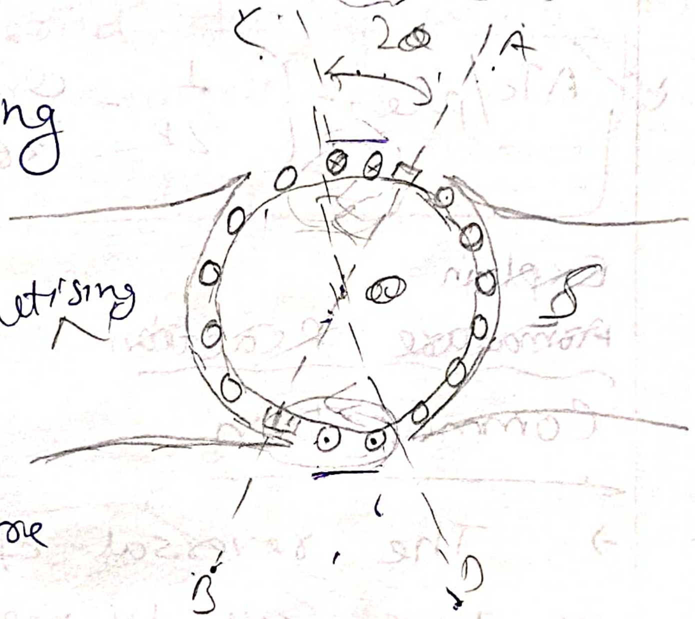
Amount of weakening = Amount of strengthening

But due to saturation strengthening will be less so net flux reduced.

This is called demagnetizing effect.

Demagnetising and cross-magnetising conductors

Conductors lying within AOC & BOD are demagnetising conductors & The remaining are cross magnetising conductors.



Demagnetising AT per pole

$$\theta_{mech} = \frac{\theta_{elec}}{(P/2)}$$

Total of armature conductors in angles AOC & BOD is $= \frac{4\theta_m}{360} \times Z$

$$AT_d / pole = \frac{4\theta_{ele}}{360^\circ}\left[\frac{I_a}{A} \times \frac{Z}{2P}\right]$$

$$I_{path} = \frac{I_a}{A}$$

$$AT_d / pole = \frac{\theta_m}{180^\circ}\left[I_{path} \times Z\right]$$

$$\frac{\theta_{ele}}{360}\left[I_{path} \times Z\right]$$

Cross-magnetising AT per pole

$$AT_c/\text{pole} = \left[\frac{360 - 4\theta_{ele}}{360}\right]\left[\frac{I_a}{A} \times \frac{Z}{2P}\right]$$

$$AT_c/\text{pole} = \left(\frac{180 - 2\theta_{ele}}{180}\right)\left(\frac{I_a}{A} \times \frac{Z}{2P}\right)$$

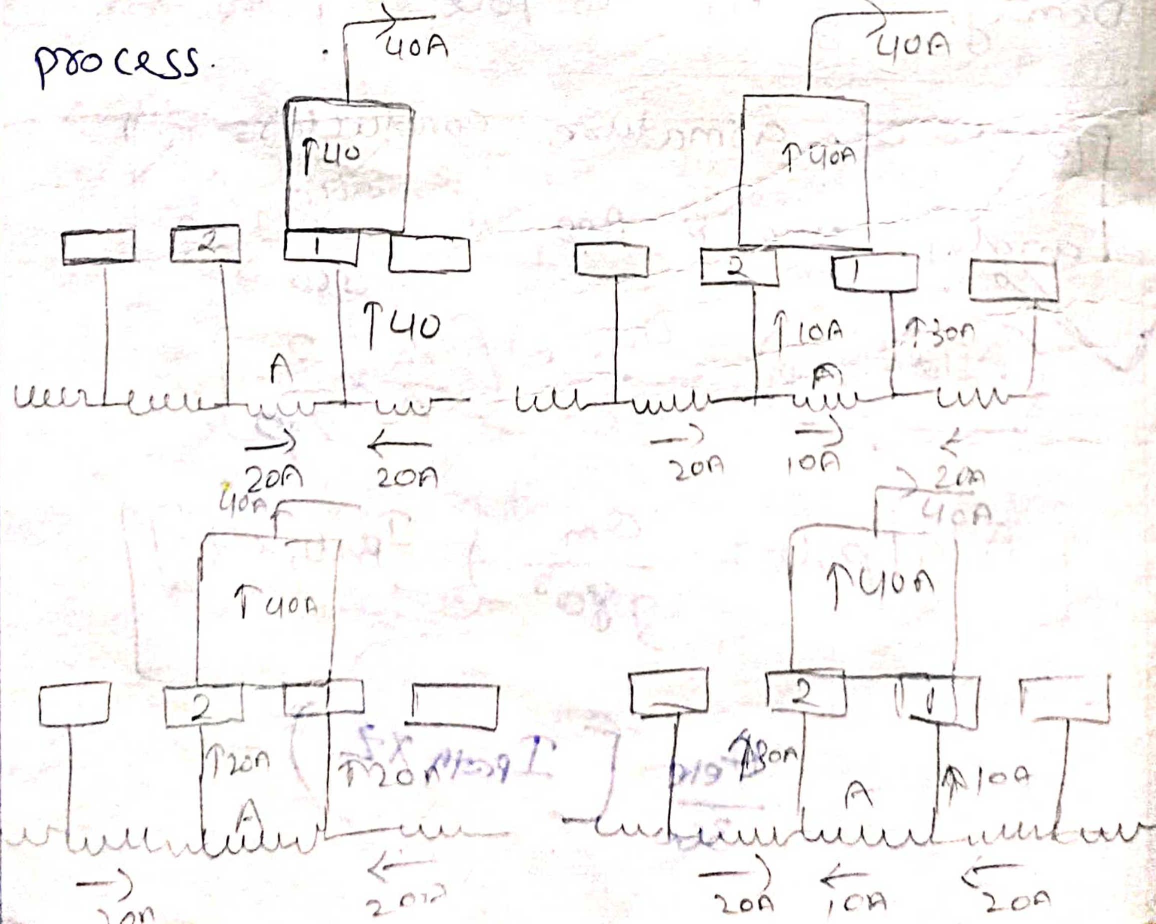
$$AT_c/\text{pole} = \left(\frac{1}{2P} - \frac{\theta_m}{360}\right) Z\, I_{path}$$

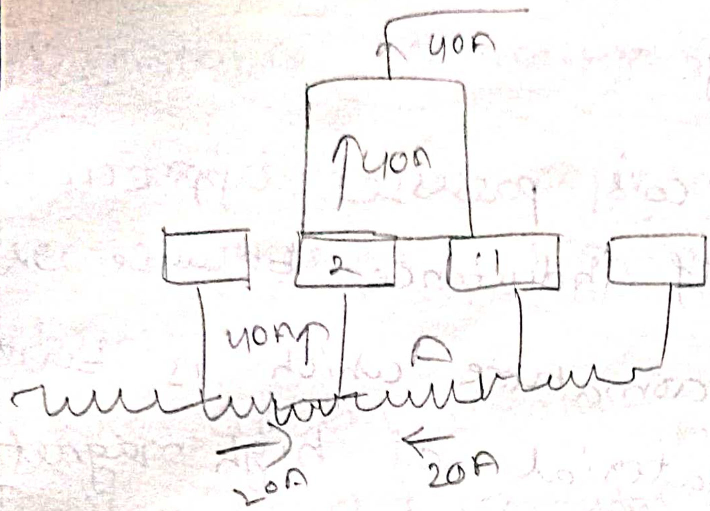
~~Explain~~

~~Armature Reaction~~

Commutation

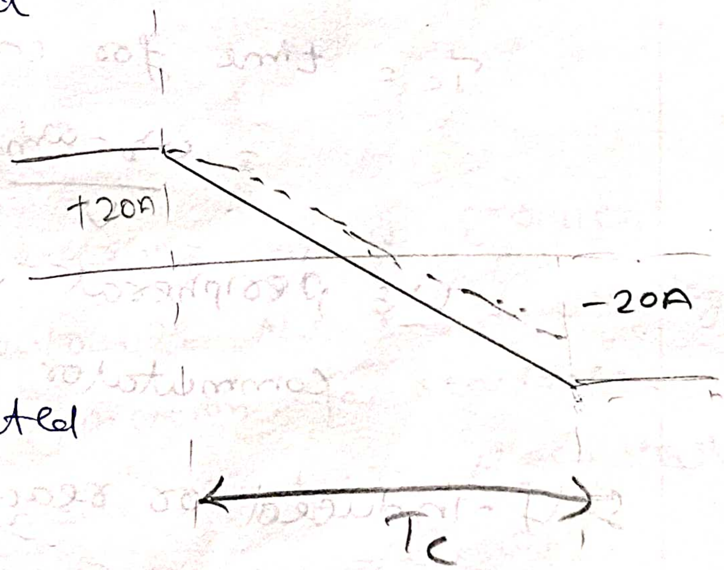
-> The reversal of current in armature coil by means of brush and commutator bars is called commutation process.





→ The brief period during which coil remains short-circuited is known as commutation period. (T_c)

→ If the current reversal i.e. the change from $+I$ to zero and then to $-I$ is completed by the end of short circuit or commutation period, then the commutation is ideal.



→ If the current reversal is not complete within the time, sparking is produced and known as poor commutation.

Reactance voltage

Armature coil possesses appreciable amount of self inductance because it lies within armature which is built up of a material of high magnetic permeability. This self induced emf is known as Reactance voltage.

W_b = Brush width

W_m = width of mica insulation

T_c = time for commutation

$$= \frac{W_b - W_m}{v}$$

v = peripheral velocity of commutator segments.

self-induced or reactance voltage

$$R.V = L \times \frac{2I}{T_c}$$

$$=$$

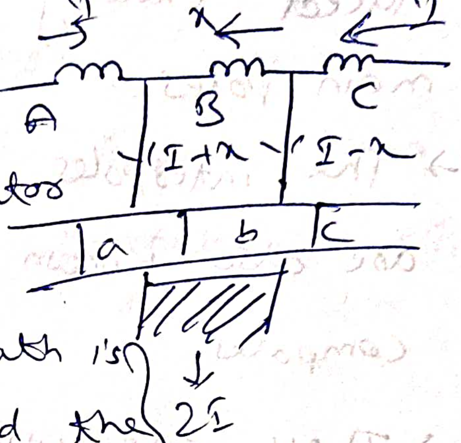
Methods of improving commutation

(i) Resistance commutation

(ii) e.m.f. commutation

Resistance commutation

In this we replace low-resistance cu brushes by high-resistance carbon brushes.



When current from coil c reaches commutator segment b. It has two parallel paths. First path is directly from b' and the other path is via short circuited coil B. so to make current reverse carbon brushes are used.

E.m.f. commutation :-

In this a reversing emf is produced in order to neutralize the reactance voltage. This voltage is opposition to reactance voltage and made equal to it so that it will completely wipe it off. then resulting in sparkless commutation.

this is done by

(a) Giving the brushes a forward lead sufficient enough to bring the short circuits coil under the influence of next pole of opposite polarity.

(b) by using interpoles.

Interpoles

-> The interpoles are narrow poles placed exactly midway between the main poles.

-> The interpoles are fitted to the yoke and are also known as commutating poles or compoles.

-> They are wound with comparatively few heavy gauge cu wire turns and are connected in series with armature.

-> The polarity of interpole is same that of main pole ahead of it in the direction of rotation, for generator.

-> for motor the polarity of the interpole is same that of the main pole behind it.

-> Interpoles induce an emf in the coil which helps the reversal of current. This is known as commutation e.m.f. The commutating emf neutralises the reactance emf and makes commutation sparkless.

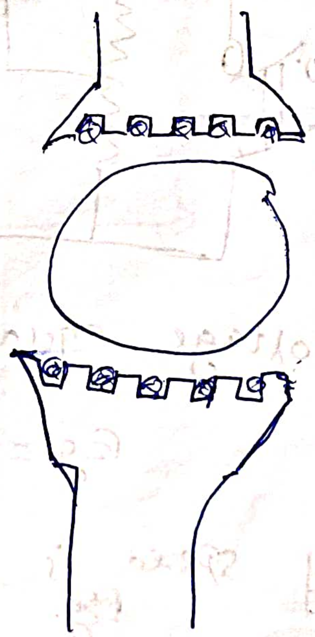
→ As interpoles carry armature current, their commutating emf is proportional to the armature current. This ensures automatic neutralization of reactance voltage which is also due to armature current.

→ Another function of interpoles is to neutralize the cross-magnetising effect of armature reaction.

compensating winding

The function of compensating winding is to neutralize the cross magnetizing effect of armature reaction.

These windings are embedded in slots in the pole shoes and are connected in series with the armature such that current in them flows in a direction opposite to the flow of current in armature conductors.



No of Armature conductors/pole $= \frac{Z}{P}$

No of armature turns/pole $= \frac{Z}{2P}$

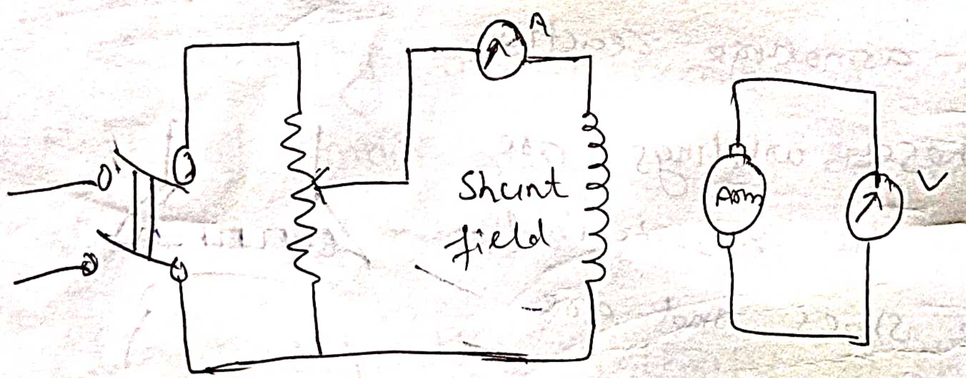
No of armature turns immediately under one pole = $\frac{Z}{2P} \times \frac{\text{Pole arc}}{\text{pole pitch}} = \frac{Z}{2P} \times 0.7$

No of armature Amp-turns/pole for compensating winding = $0.7 \times \frac{Z}{2P}$.

Characteristics of D.C. Generator :-

- No-load saturation characteristic (E_0/I_f)
- Internal or Total characteristic (E/I_a)
- External characteristic (V/I)

Separately excited generator :-



Voltage equation of d.c. generator

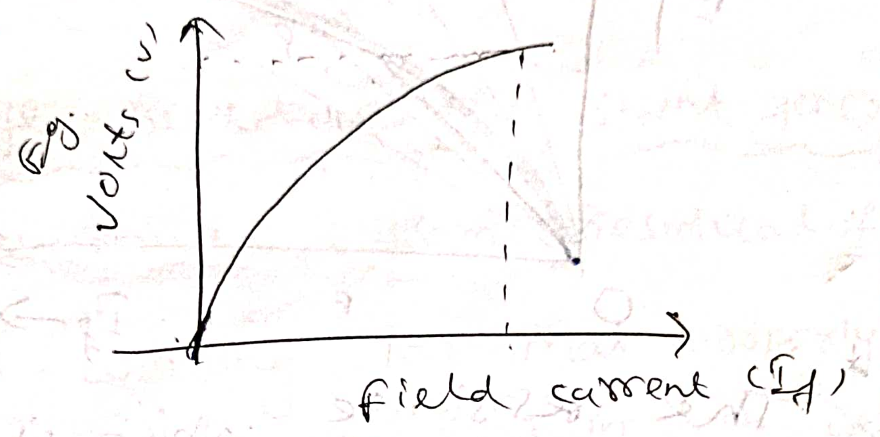
$$E_g = \frac{P\phi NZ}{60A}$$

If speed is constant

$$E = K\phi$$

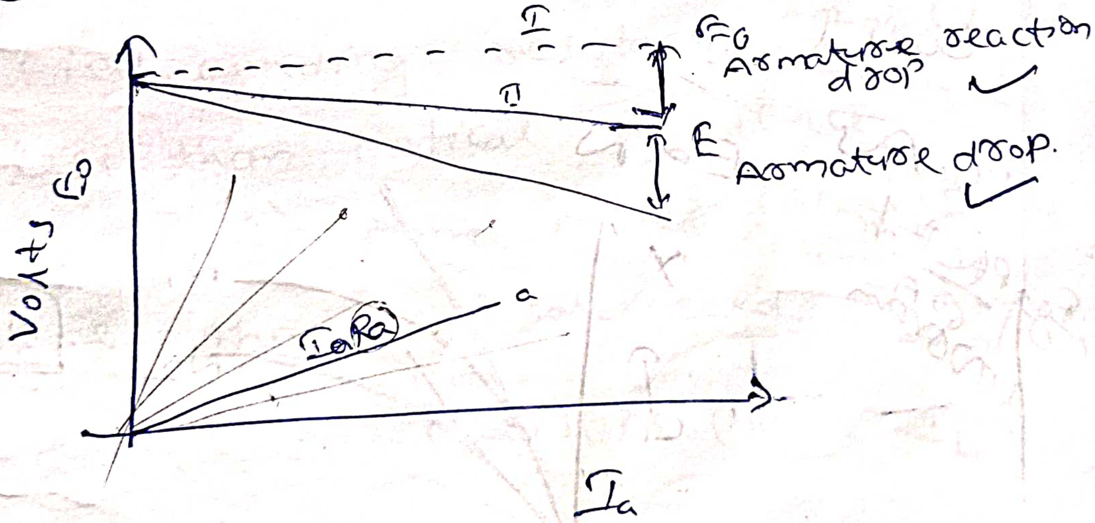
When I_f increased from its initial small value the flux ϕ and hence generated emf E_g increase directly so long as the poles are unsaturated.

When poles get saturated greater value of I_f required to produce a given increase in voltage.



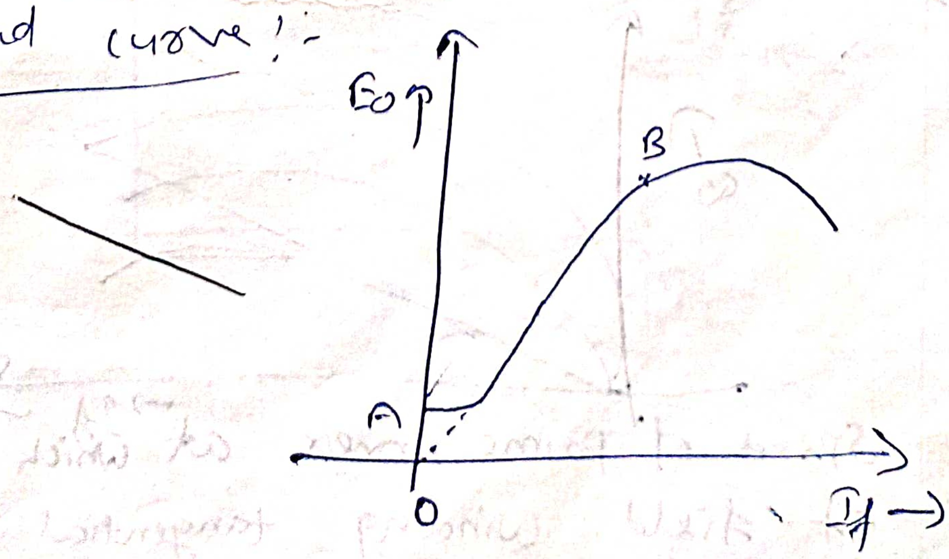
(no load saturation characteristic)

Internal and external characteristics

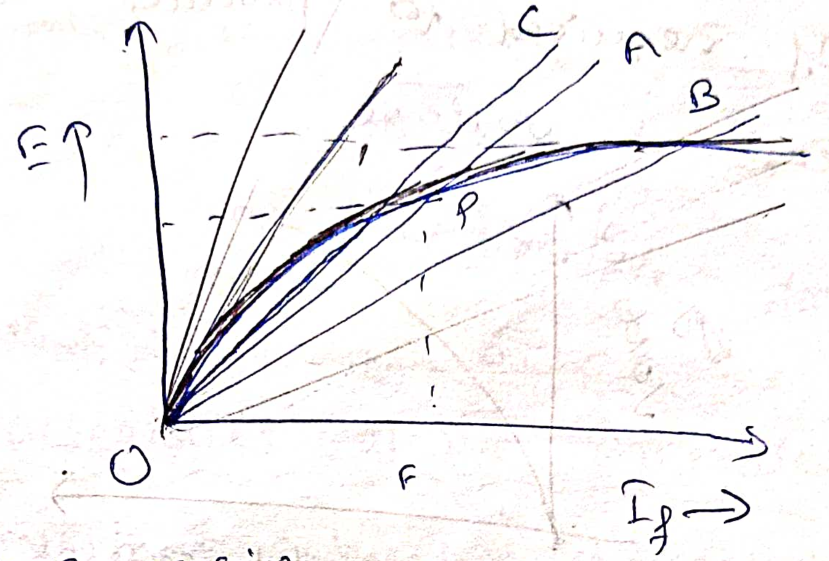


Self excited generator :-

No load curve :-

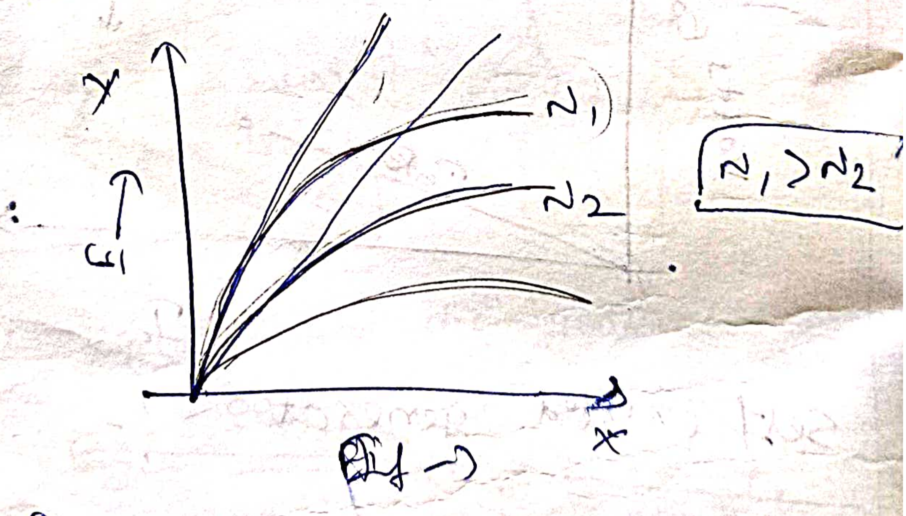


critical Resistance for shunt generator

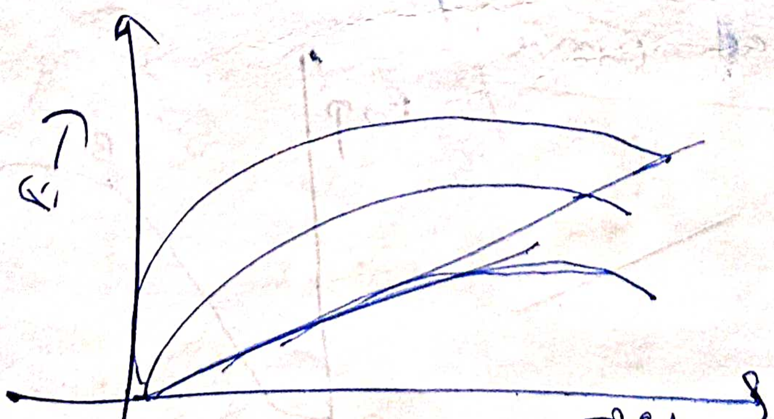


*** The resistance which is tangential to O.C.C. is known as critical resistance.. above which there will be no voltage build up.

$E \propto N$



***



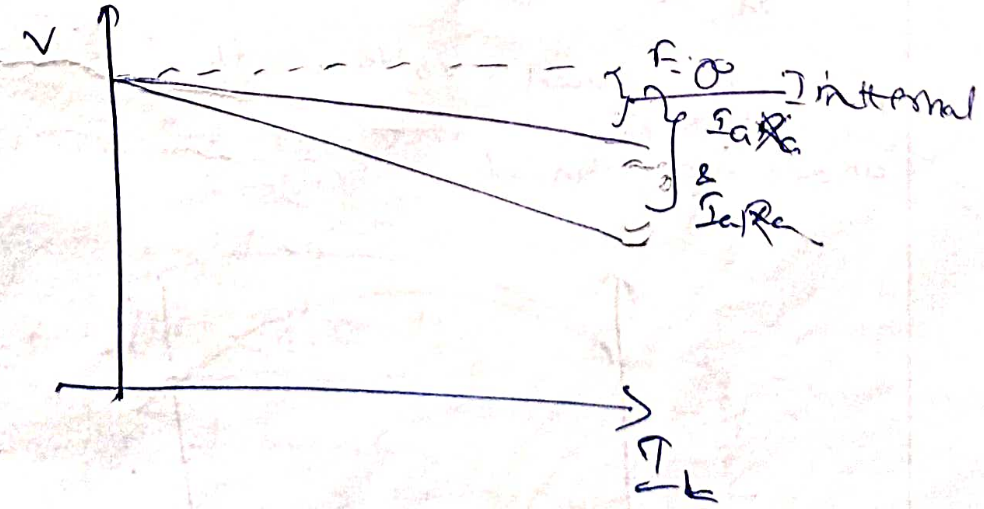
Speed of prime mover at which resistance of field winding tangential to occ is called critical speed.

Below which generator fails to build up voltage.

Voltage Build up of a shunt generator:

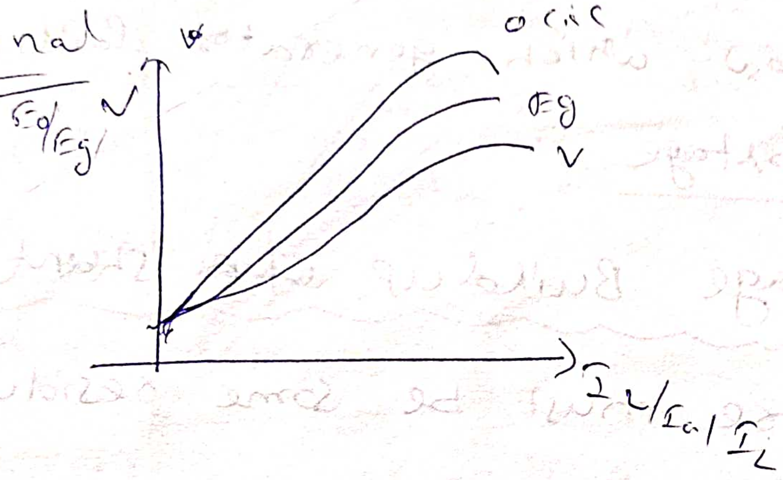
- There must be some residual flux.
- Field winding terminal properly connected to armature in such way further flux produced by field winding should aid the residual flux.
- Field winding resistance should be less than critical resistance.
- Speed of prime mover should be more than critical speed.

External characteristics (V vs I_L)



Series generator :

External

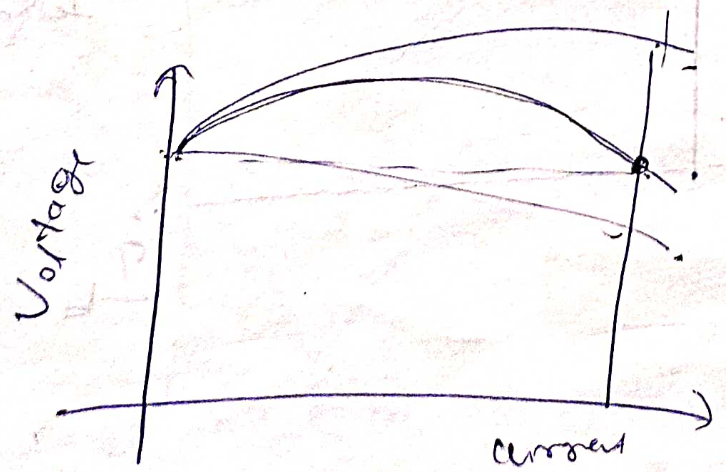


Compound generator :-

If the series field amp-turns are such as to produce the same voltage at rated load as at no load then generator is flat-compounded.

If the series field amp turns are such that the rated-load voltage is greater than the no load voltage then the generator is over compounded.

If the rated load voltage is less than the no-load voltage then generator is under-compounded.



Uses of D.C. generators

Shunt generators:

-> For linghting & power supply

-> charging batteries

Series generators:

-> Used as booster's in tr. line and traction

Compound generator:-

cumulatively compound generator's are used in motor driving which require d.c supply at const. voltage, for lamp loads and for heavy power service such as electric railway's.

Differential compound generator's used in arc welding.

Why parallel operation:

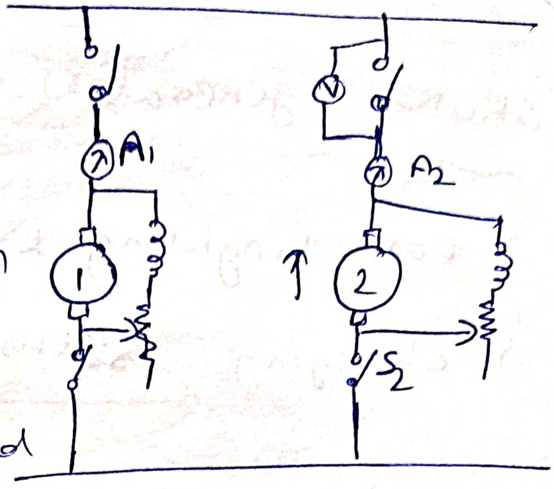
-> continuity of service

-> Efficiency

-> maintenance & Repair

-> Additions to plant.

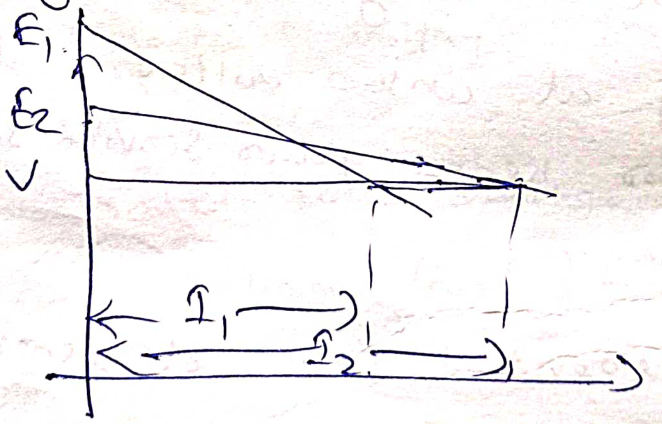
Paralleling DC generators



-> The armature of generator No. 2 is speeded by the prime-mover up to its rated value and then switch S_2 is closed and circuit is completed by putting a voltmeter V across the open switch S_1.

-> The excitation of the incoming generator No. 2 is changed till V reads zero.

-> After this switch S_1 is closed and so the income machine is paralleled to the system.



E_1, E_2 no load voltage of two gen

R_1, R_2 = their armature resistance

V = common terminal voltage

$$I_1 = \frac{E_1 - V}{R_1}, \quad I_2 = \frac{E_2 - V}{R_2}.$$

$$\frac{I_2}{I_1} = \frac{E_2 - V}{E_1 - V} \times \frac{R_1}{R_2}$$

(27.15)

$E_1 = 270V$,

and $V = 220V$ at $I = 35A$.

$E_2 = 280V$, at $V = 220V$ at $I = 50A$

voltage drop of $VD_1 = 50V$

$$\frac{\text{voltage drop}}{\text{Ampere}} = \frac{50}{35} = \frac{10}{7} \text{ V/A}$$

$$\frac{VD_2}{\text{Ampere}} = \frac{280-220}{50} = 1.2 \text{ V/A}$$

$$V = 270 - \left(\frac{10}{7}\right) \times I_1 = 280 - 1.2 I_2$$

$$I_1 + I_2 = 60$$

$I_1 = 23.6A$, $I_2 = 36.4A$

$$V = 280 - 1.2 \times 36.4$$
$$= 236.3V.$$

output of 1st machine $= \frac{236.3 \times 23.6}{1000}$
$= 5.577 kW$

output of 2nd machine $= \frac{236.3 \times 36.4}{1000}$
$= 8.602 kW.$