8.1.25

# Electrical Machines - I (EEC402)

→ A electromagnetic rotating device which is used to convert electrical energy into mechanical energy and vice versa.

## Advantages of Electrical Energy:-

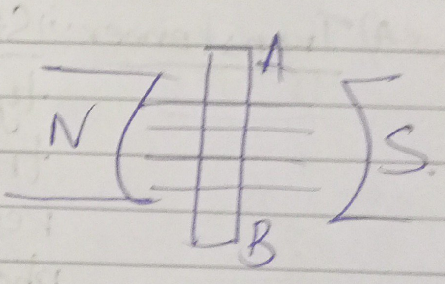
→ Transportation/Transmission of Electrical energy in large distance & less time.

→ Conversion of Electrical energy into other form of energy is easy.

→ Electrical energy is easily controllable.

→ Efficiency of electrical energy transmission is very high (very low loss).

Faraday's Laws: $\left( EMF(e) \propto \frac{d\phi}{dt} \right)$




e.m.f.

- Dynamical induced e.m.f.
- Statically induced e.m.f.

Machines

- Generator
- Motor.

8.1.25

Syllabus:

JEB 1) DC Machines: Armature winding, Lap winding, wave winding, equaliser rings.

2) Generator: Construction of DC Machines, EMF equation, types of generators, losses, efficiency, armature reaction, commutation, interpoles, compensating winding, DC generator characteristics, voltage build-up of DC shunt generator, parallel operation of DC generators.

3) Motor: DC Motor principle, counter emf, speed and torque equations, load characteristics, speed control, starting of DC motors, three-point and four-point starters, testing of DC machines.

New 4) Transformer: i) Single-phase transformer: Construction, types, principle of operation, emf equation, transformer at no-load and load, equivalent resistance, magnetic leakage, equivalent circuit, phasor diagram, open and short-circuit tests, voltage regulation, losses, efficiency, all-day efficiency, separation of hysteresis and eddy current losses, parallel operation, auto-transformers.

ii) Three-phase transformer: Connections and vector groups, equivalent circuit, determination of equivalent circuit parameters, parallel operation, three-phase to two-phase conversion and vice-versa, tap changers on transformers, testing of transformers, cooling.

## Name of Books (recommended):

1. Electric Machinery: Fitzerald, Kingsley and Umans.
2. Electric Machines - Nagrath and Kothari
3. Alternating Current Machines - M. G. Say
4. Theory of Alternating Current Machines - Langsdorf.
5. Electrical Machinery - P. S. Bimbhra.
6. Electrical Machines - J. B. Gupta.

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## Electrical Machines

- Electrical Generator
- Electrical Motor

### Basic Principle of Generation:- (Faraday's Law of Electromagnetism)

→ Requirement: ① Magnetic field ② Conductor ③ Prime-mover (Turbine)

→ The magnetic field is static but the conductor is in motion

→ The conductor is static but the magnetic field in itself is changeable in nature.

→ Dynamically induced and Statically induced EMF

$e = Blu$ → 'B' and 'l' are almost fixed.

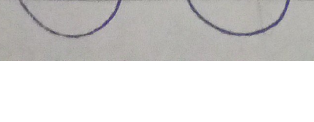
$B$ → Magnetic Flux Density

$l$ → Length of Conductor

$u$ → Angular speed

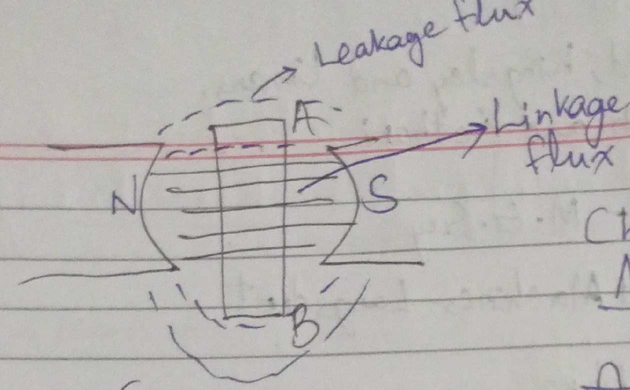
→ Generator can't generate energy by its own, but convert only mechanical energy to electrical energy.

### Direction of Magnetic Field:- Cross & Dot Notation



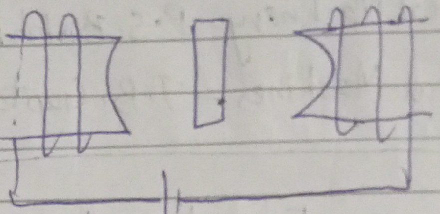
Flux

- Linkage




## Nature of Induced E.M.F

### Characterstics of Magnetic Material →



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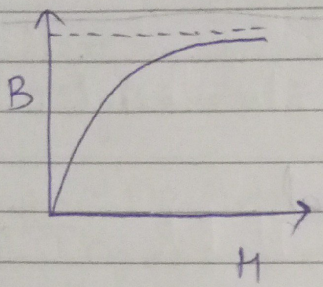
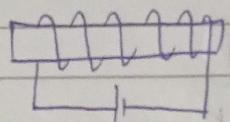
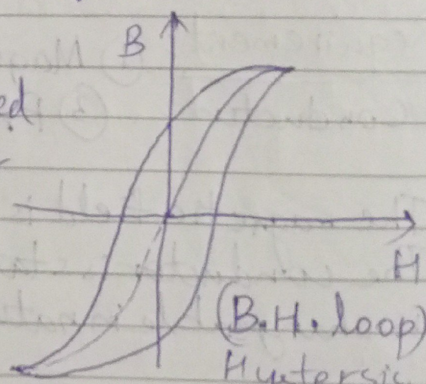


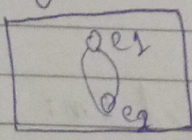
mmf = NI

→ When current is removed, retentibity of residual magnetism is present.

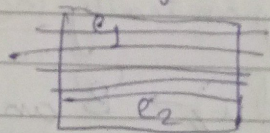



B.H. Loss – Energy (residual) remained in electromagnet after its use

Hystersis – Lagging.




~~[illegible]~~ Eddy Loss Reduce → Piecewise




Core is laminated.

### Basic Principle of Motor :-

1) Faraday's Law. $F = BIl$

Requirement :-

1) ~~Magnetic field~~ Electric Energy 2) Conductor 3) Prime mover (Turbine)

Electrical Machine

Generator — Motor — Braking — Drive

Single-
M

Transform
Generator,

7.1.25

DC Gen

• Basic p

→ If a
magnet
through

If the c
change

$e \propto \frac{d\phi}{dt}$

Depends o

i) Length
iii) Rot

* Basic

If cu
Then, ce

# Type of Electrical Machine

- AC
  - Single-phase M/C
  - 3-phase M/C
    - 3-$\phi$ Asynchronous (3-$\phi$ induction motor)
    - 3-$\phi$ Synchronous
      - 3-$\phi$ syn. Generator
      - 3-$\phi$ syn. Motor
- DC
  - DC Generator
  - DC Motor

Transformer – Electromagnetically static
Generator/Motor – Electromagnetically dynamic

- Trf.
  - 1-$\phi$ Trf.
  - 3-$\phi$ Trf.

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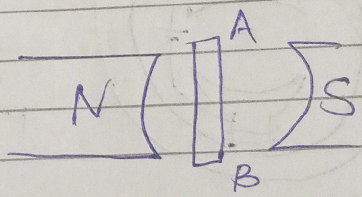
## DC Machines:-

- DC Generator
- DC Motor

· Basic principle of Generator (DC):-

→ If a conductor is placed in a magnetic field then a flux is passing through the conductor.



If the conductor rotated by external force, the flux linkage changes and EMF is induced by Faraday's law of electro-magnetism

$e \propto \frac{d\phi}{dt}$ or $e = N\frac{d\phi}{dt}$ $\Rightarrow e = Blu$.

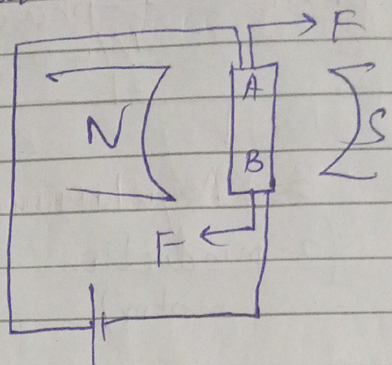
Depends on:-

i) Length of the conductor ii) Magnetic field
iii) Rotating speed.

* Basic principle of DC motor is-

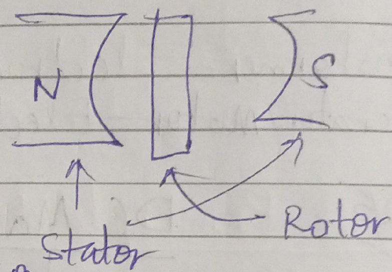
If current carrying conductor is kept in a magnetic field. Then, conductor experience some force.

* Nature of force is parallel & opposite. So, conductor rotate
So, some arrangement can be used both as D.C. Motor or D.C generator.



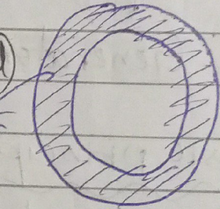

## Construction of DC Machine

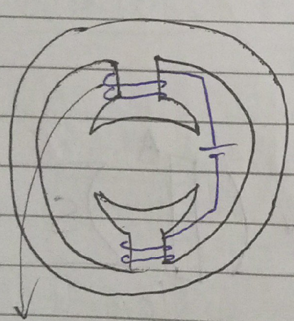
- Stator (static)
- Rotor (Armature) (Rotational).

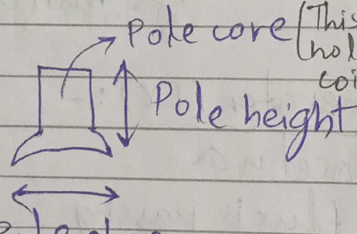



## Stator:

The physical shape of stator is a hollow cylinder. The cross-section or top-view of stator :-






Field coil (or) Field winding

**Pole core Function:-**

* Pole core holds the field winding
* In the pole core, the magnetic field will be developed.

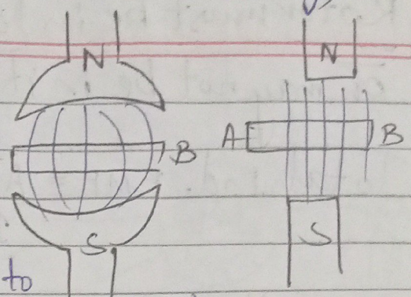
**Pole height Function:-**

* To increase no. of turns by increasing the height of pole.

Practically:- Cast iron (ferromagnetic Material)

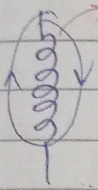
## Pole shoe:

* Avoid slipping of windings from pole core (mechanically)
* Flux passes through more length (of the conductor) when it is radially flux generated (electrically)
* It helps for signals to have less loss with sinusoidal (compared to square wave)




## Field winding:-

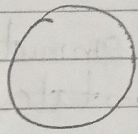
i) Helps to produce magnetic flux. (Copper).



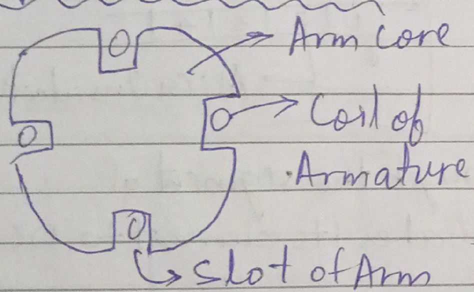
Q) Why conductor is cylindrical along with armature
if rotated, then centrifugal force will act and mechanical breakdown may occur.

* Armature is also cylindrical

Cross-sectional view of conductor - (Basic)



To place the conductor -




No centrifugal force is then prevented.
Insulator are used above it to wrap up.

## Armature core:- (Cast iron or Cast steel).

To hold the armature winding (just like house) present through out like perisphery

## Armature winding:-

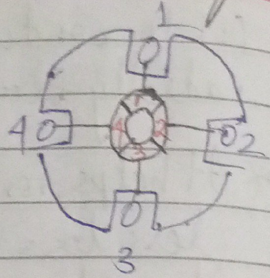
To produce induce EMF (voltage).

* Ferromagnet used in armature core to reduce ~~eddy current~~, hysteresis loss.

* Eddy current will not develop in stator but will develop in rotor.

* Rotor must be in laminated sheet, while stator may or may not be in it.

Total Ind. EMF = Alternating in nature
$\underline{1+2+3+4}$

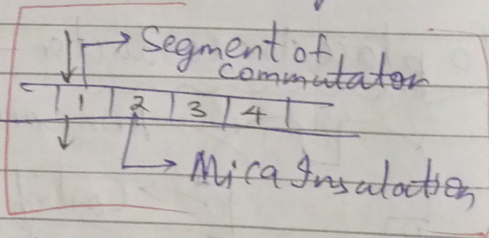



Electrically, AC is induced in rotor, which is not desirable as DC generator

* Electrically, rectifier and filter are used, but Mech., commutator is used.

* Commutator is connected to shaft, about which it rotates. Commutator is also connected to windings.

* In between 2 segment, there is no conductivity.




→ When the current passes through the segment of commutator, its mechanism makes its current to DC.

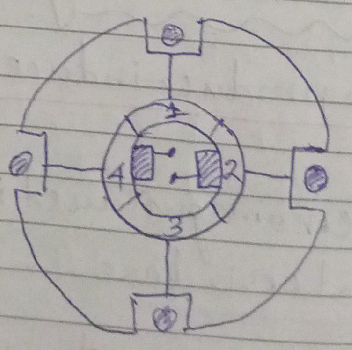
Material of commutator :- Hard drawn copper.

Function of commutator - Convert AC into DC.

Brush :- Through brush current comes out.

Parts of the D.C. Machine :-

1. Yoke
2. Pole core & Pole Shoes
3. Field winding
4. Armature core
5. Armature winding




6. Commut
7. Brush &
8. Shaft

22.1.25

Yoke →

→ It is the covering of t system

Mechanica

→ It provid mechanical to the inne

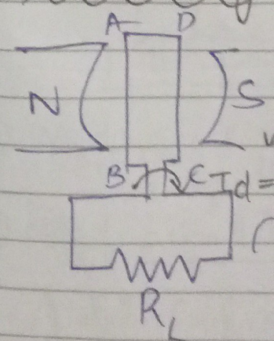
Electrical

→ It provi flux to

* Commut

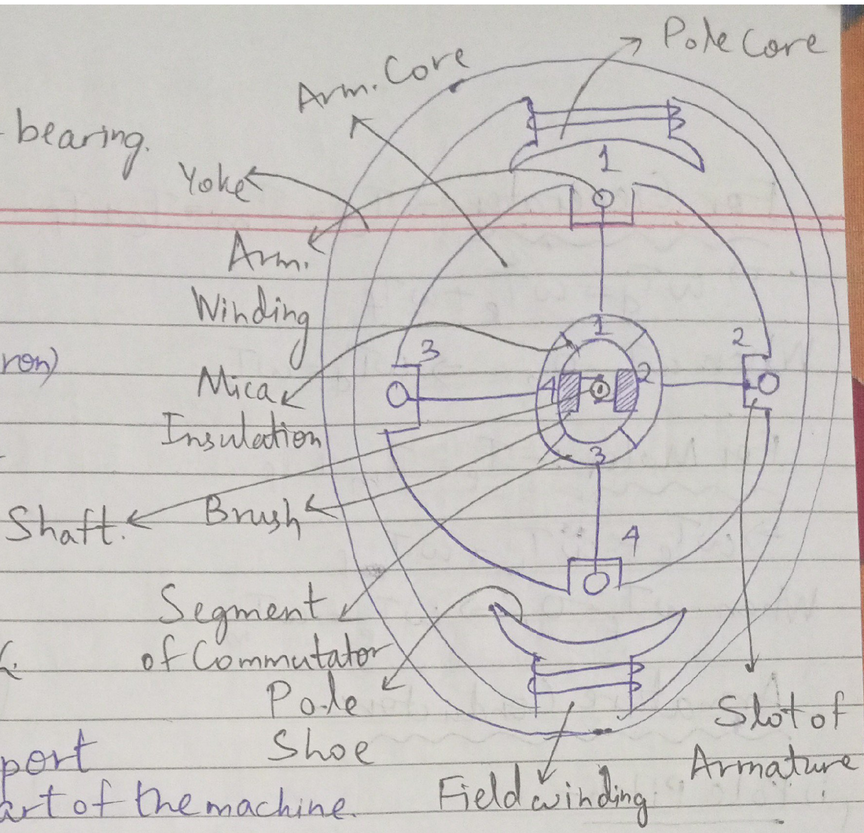
→ Makes AC current to DC current.

Elementary




Generator

6. Commutator
7. Brush & Ball-bearing.
8. Shaft

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Yoke → (cast iron)

→ It is the outer covering of the system

Mechanical adv.

→ It provides mechanical support to the inner part of the machine.

Electrical adv.

→ It provides the continuation path of magnetic lines/ flux to pass through it.

## * Commutator function:-

→ Makes AC current to DC current.

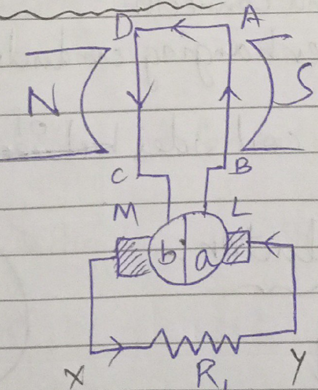



Fig-2

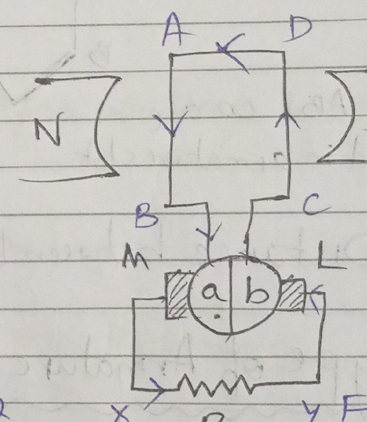
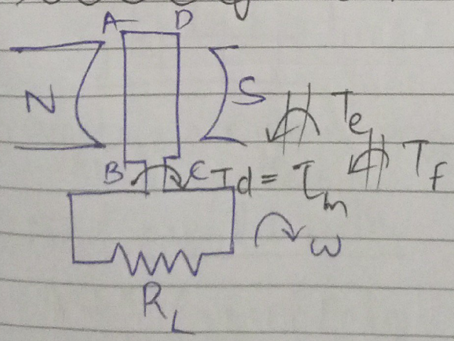
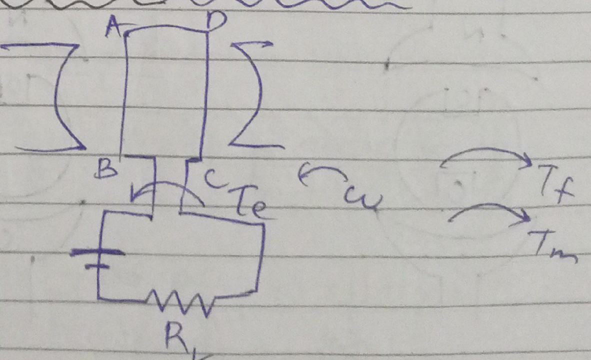



Fig-1

## Elementary Concept of ~~Generator~~ DC Machine →




Generator




Motor

For Generator:- $T_d = T_m = T_e + T_f$

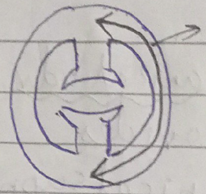
$\Rightarrow \omega T_d = \omega T_e + \omega T_f$

When $\omega T_f = 0$, $\Rightarrow \omega T_d = \omega T_e$

For Motor:- $T_e = T_m + T_f$

$\Rightarrow \omega T_e = \omega T_m + \omega T_f$

When $\omega T_f = 0$, $\Rightarrow \omega T_e = \omega T_m$

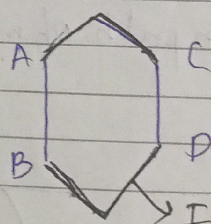


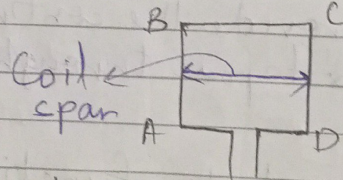

Armature Conductor:-

(i) Pole Pitch-

It is the pheripherial distance between the two poles

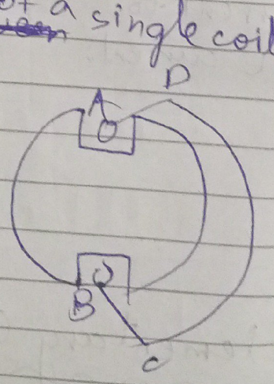
(ii) Coil span-



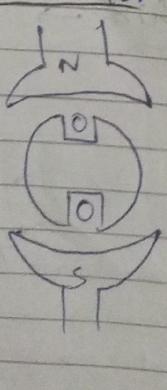

Here AB & CD are placed in armature slot

→ Distance between the 2 coil sides ~~between~~ of a single coil.

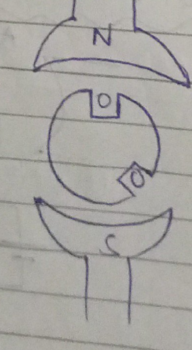



* Type of Armature Conductor:-

Full-Pitch




Short-Pitch



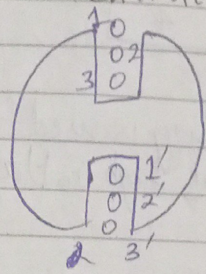

* In a Full-Pi

coil span = P

* In a Short-

coilspan < P

Concentrate




→ If all the arma

of slot, then it

→ If all the armat

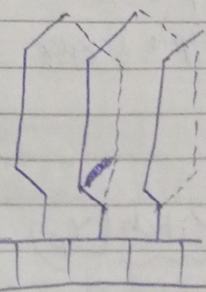
throughout the p

Closed winding

24.1.25

Typ

Lap winding



① Winding are overla

in pattern

② No. of parallel pat

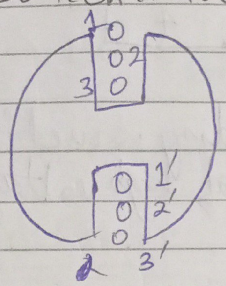
A = P (no. of Po

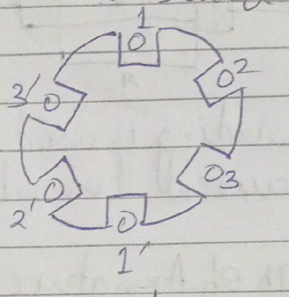
* In a Full-Pitch armature winding, $\alpha = 180^\circ$
coil span = Pole Pitch.

* In a Short-Pitch armature winding,
coilspan < Pole Pitch.

Type

Concentrated — Distributed.




→ If all the armature winding are placed only on one pair of slot, then it is concentrated.

→ If all the armature winding are uniformly distributed throughout the periphery of

Type

Closed winding — Open winding

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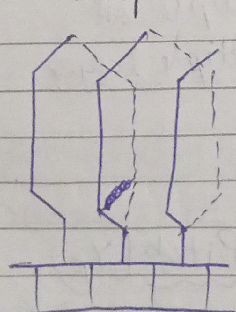
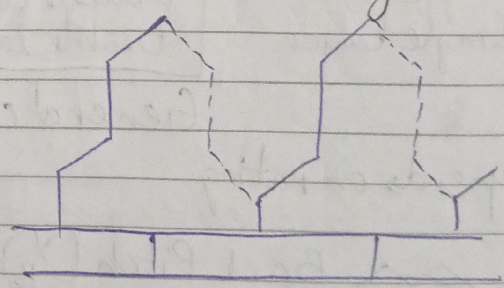
Type of Armature Winding

Lap winding — Wave winding.





**Lap winding**

① Winding are overlapping in pattern.

② No. of parallel path
$A = P$ (no. of Pole)

**Wave winding**

① Windings are waveform in pattern.

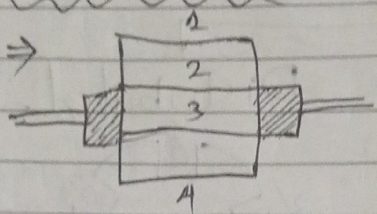
② No. of parallel path is always ②.

③ No. of brush in a lap winding is equal to no. of poles of machine.

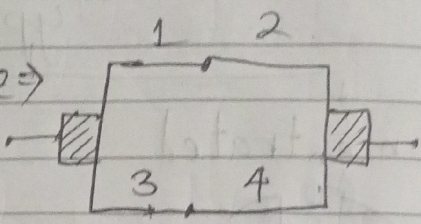
③ No. of brushes in a wave winding is equal to 2.

4 – Conductor (P=4)

Lap ⇒




Wave ⇒

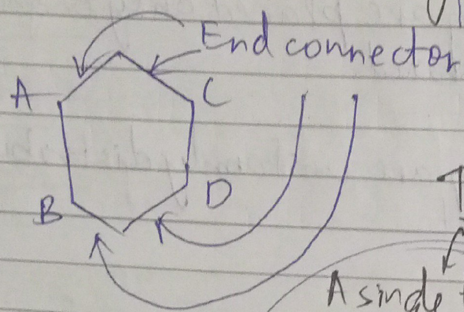



④ Lab winding is used for high current, Low voltage

④ Wave winding is used for Low current, high voltage

* Design of Armature Winding :-

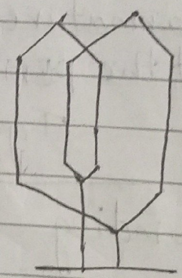
coil:

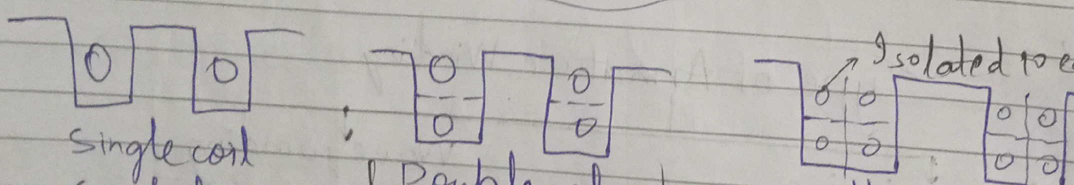



Conductor : AB & CD

Turn:

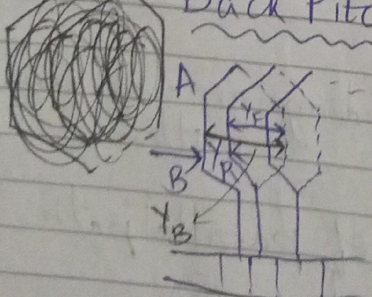
A single turn has 2 conductor






Single coil single layer ; Double coil Double layer — General case. Multiple coil Multiple layer

*depends on rating.




Back Pitch ($Y_B$)

Front Pitch ($Y_F$)

Bot

Back Pi

The dist

conduct

conduct

Front Pit

The dis

are c

Resultant

No. of sl

– Dist. of

* For AC ma

and no. of

required

⇒ ($Y_R = Y_F$

* Commutat

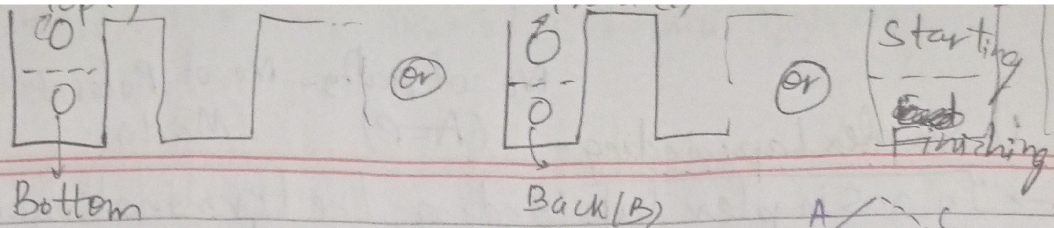
Distance

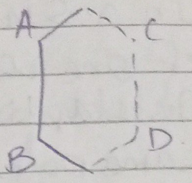
Progressive

Regressive

1) Simplex

winding




**Back Pitch:**

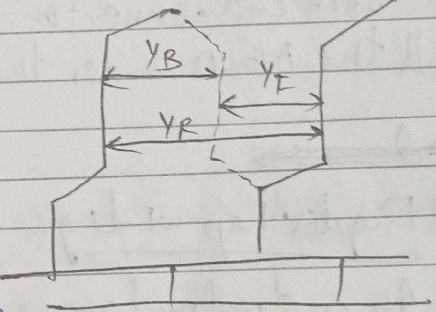
The distance btw two coils of the same conductor (or) btw first conductor and last conductor of same coil.

**Front Pitch:**

The distance btw two coils of the different coil, which are connected to the same commutator.

**Resultant Pitch:-**

No. of slots/pole
= Dist. of Front Pitch + Back Pitch.




* For AC machine, no. of slots/pole and no. of slots per phase is required.

$\boxed{\cancel{Y_R = Y_F + Y_B}} \xrightarrow[\text{correct}]{\text{not always}}$ Modification

$\boxed{Y_R = Y_F \pm Y_B}$

+ (Progressive)
− (Regressive)

* Commutator Pitch ($Y_C$):

Distance between two consecutive coils.

$Y_C = \pm 1$

Progressive → Follows forward movt.
Regressive → Follows backward movt.

## Lap winding

1) Simplex Lap winding
2) Duplex Lap winding
3) Triplex Lap winding

No. of paths = No. of Poles of Machin
(A=P)

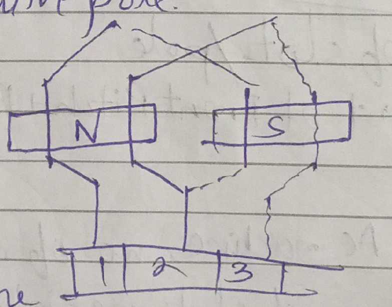
1) Simplex Lap winding –

→ In a simplex lap winding, the terminating end of one coil is joint to the commutator segment and the starting end of next coil is placed under the same pole.

* Front end → A wire which is used to connect the end of a coil at the front to the commutator segment is called as front end connecter.

* Back end –
Whereas a wire which is used to connect one coil side to the other coil side at the back is called as back end connector

* All the ABCD under the 2 consecutive pole.




~~An exam~~

2) Duplex Lap winding –

→ In a duplex lap winding, no. of parallel paths is double the no. of simplex lap winding (no. of poles).

Points req. to design Arm. wdg.

1) The back pitch & front pitch value must be odd number but they can't be equal.
* So, they differ by multiples of (2).

2) The back pitch $Y_B$ is basically nearly equal to pole pitch. Pole pitch can be defined as no. of ~~poles~~ conductors per pole.

3) The avg. pitch $Y_A$ equals to $(Y_B + Y_F)/2$ = Pole Pitch.
Pole pitch = $\frac{Z}{P}$

4) Value of the commutator pitch $Y_C = \pm 1$ (For simplex winding)

In general, Y
of the winding
~~5) The resultant~~
6) For a 2-layer
of commutato
7) The no. of par
Further, Let $Y_B$
① If $Y_B > Y_F$,
commutative
② If $Y_B < Y_F$,
commutative p
③ In general t
$2a, 1.25$
Q) Draw a dev
layer lap w
16 coils. A
diagram with
representing
Ans: C = 16,
$Y_B = \frac{Z}{P} +$
$Y_F = \frac{Z}{P} -$
$\Rightarrow Y_F = Y_B \pm 2$

In general, $Y_C = \pm m$, where 'm' is the multiplicity of the winding.

~~5) The resultant piece is always even number~~

6) For a 2-layer/double-layer wdg., the no. of slots & no. of commutator segment are equal to the no. of coils

7) The no. of parallel path is the armature = $(A = n * p)$

Further, Let $Y_B = Y_F \pm 2$

① If $Y_B > Y_F$, then we can get progressive winding and commutative pitch $Y_C = +1$.

② If $Y_B < Y_F$, then we can get regressive winding and commutative pitch $Y_C = -1$.

③ In general therefore, $\left(Y_B = \frac{Z}{P} + 1\right)$ & $\left(Y_F = \frac{Z}{P} - 1\right)$

29.1.25

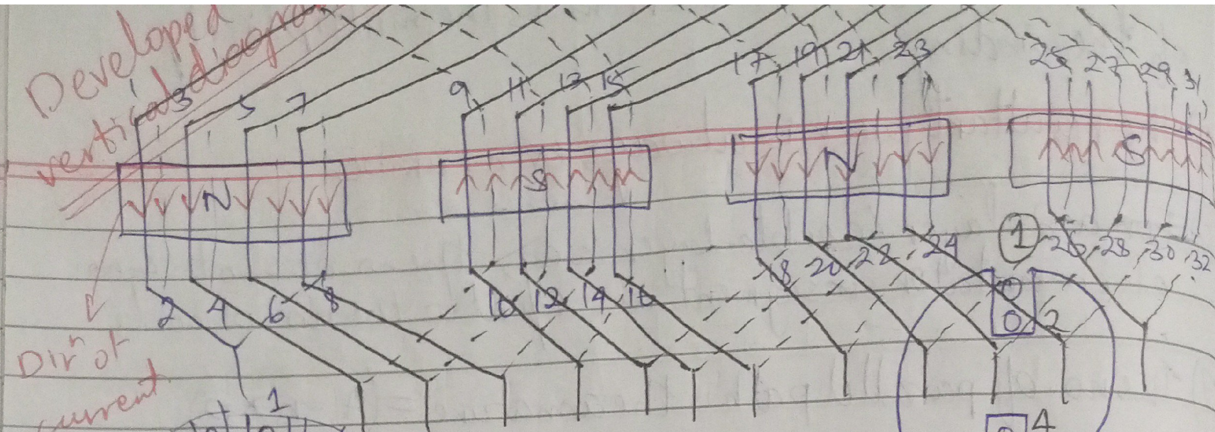
Q) Draw a developed winding diagram of simple two-layer lap winding for a 4-pole generator with 16 coils. Also draw the ~~equipment~~ equivalent ring diagram with position of brush and diagram representing the parallel circuit thus formed.

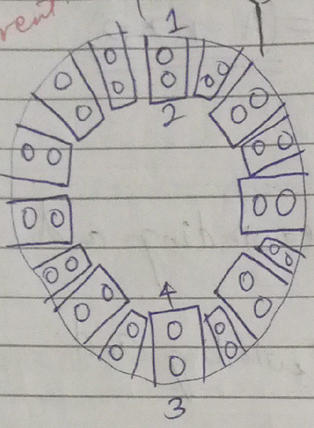
Ans: $C = 16$, $\therefore Z = 16 \times 2 = 32$. Pole Pitch $= (Y_P) = \frac{32}{4} = 8$

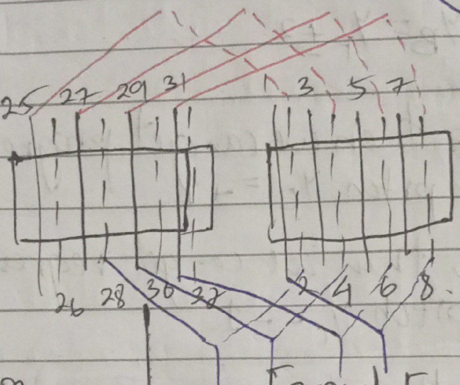
$$Y_B = \frac{Z}{P} + 1 = \frac{32}{4} + 1 = 8 + 1 = 9.$$

$$Y_F = \frac{Z}{P} - 1 = \frac{32}{4} - 1 = 8 - 1 = 7$$

$$\Rightarrow Y_F = Y_B \pm 2m = 9 - 2 = 7.$$




## Back-End Connection

1 to $1 + Y_B = 10$ conductor
(9)

3 to $3 + Y_B = 12$ conductor

5 to $5 + Y_B = 14$ conductor

7 to $7 + Y_B =$ ~~20~~ $16$ conductor

9 to $9 + Y_B = 18$ conductor

11 to $11 + Y_B = 20$ cond.

13 to $13 + Y_B = 22$ cond.

15 to $15 + Y_B = 24$ cond.

17 to $17 + Y_B = 26$ cond.

19 to $19 + Y_B = 28$ cond.

21 to $21 + Y_B = 30$ cond.

23 to $23 + Y_B = 32$ cond.

## Front End Connection

10 to $10 - Y_F = 10 - 7 = 3$ conductor

12 to $12 - Y_F = 12 - 7 = 5$

14 to $14 - Y_F = 14 - 7 = 7$.

16 to $16 - Y_F = 16 - 7 = 9$

18 to $18 - Y_F = 18 - 7 = 11$

20 to $20 - Y_F = 20 - 7 = 13$

22 to $22 - Y_F = 22 - 7 = 15$.

24 to $24 - Y_F = 24 - 7 = 17$.

26 to $26 - Y_F = 26 - 7 = 19$

28 to $28 - Y_F = 28 - 7 = 21$

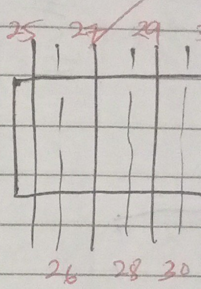
30 to $30 - Y_F = 30 - 7 = 23$

32 to $32 - Y_F = 32 - 7 = 25$

34 i

$Y_B$

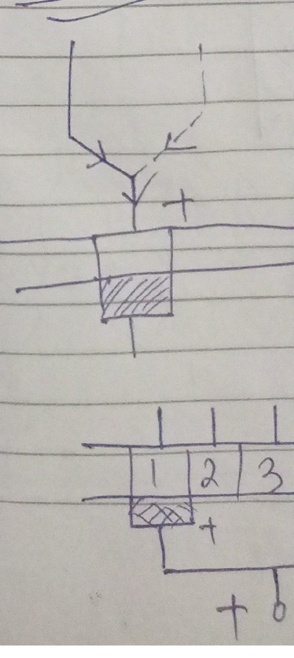
* $25 + 9 = 34$
* $27 + 9 = 36$
* $29 + 9 = 38$
* $31 + 9 = 40$




→ In north pole, direction of cur
upward

→ In south pole, direction of cu
is downward.

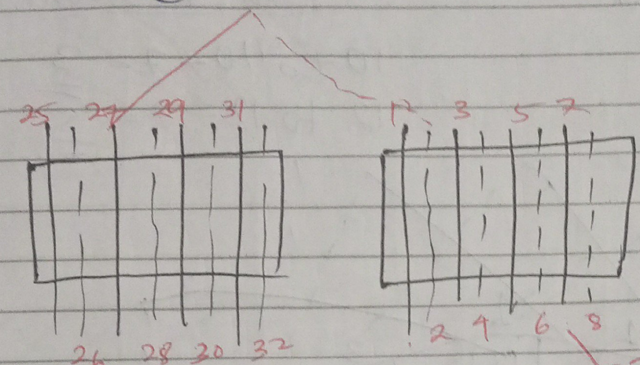
Position of B



34 is not present

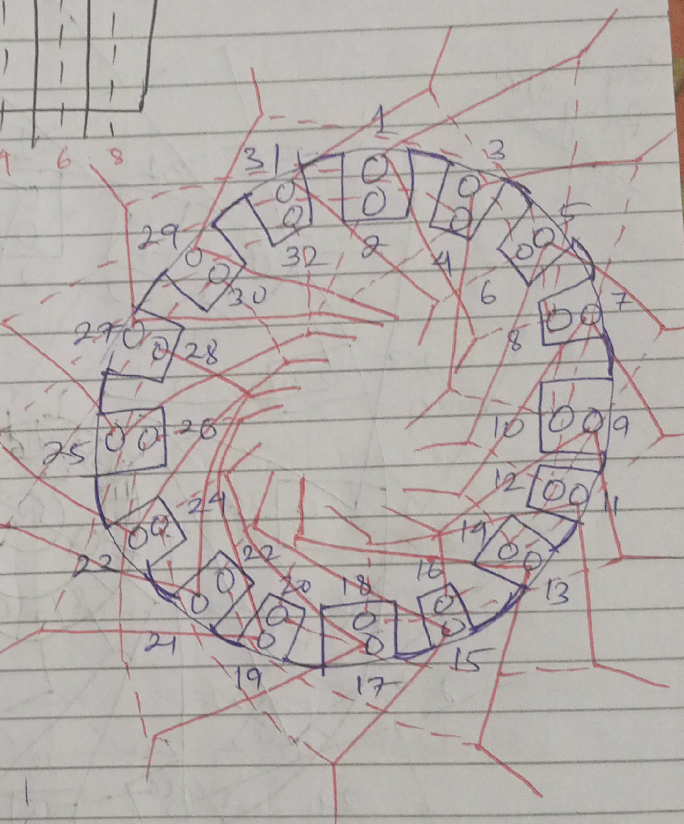
$Y_B$ $\quad$ X

| | |
|---|---|
| * $25+9=34-32=2$ | $34$ to $34-Y_F=27$ |
| * $27+9=36-32=4$ | $36$ to $36-Y_F=29$ |
| * $29+9=38-32=6$ | $38$ to $38-Y_F=31$ |
| * $31+9=40-32=8$ | $40$ to $40-32-Y_F=40-32-7=1$ |

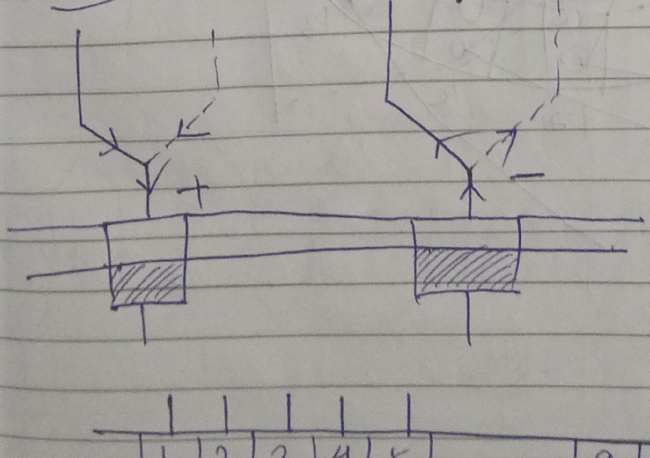


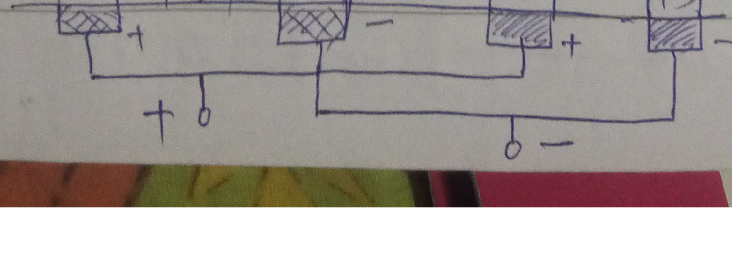

→ In north pole, direction of current is upward

→ In south pole, direction of current is downward.



Position of Brush:-



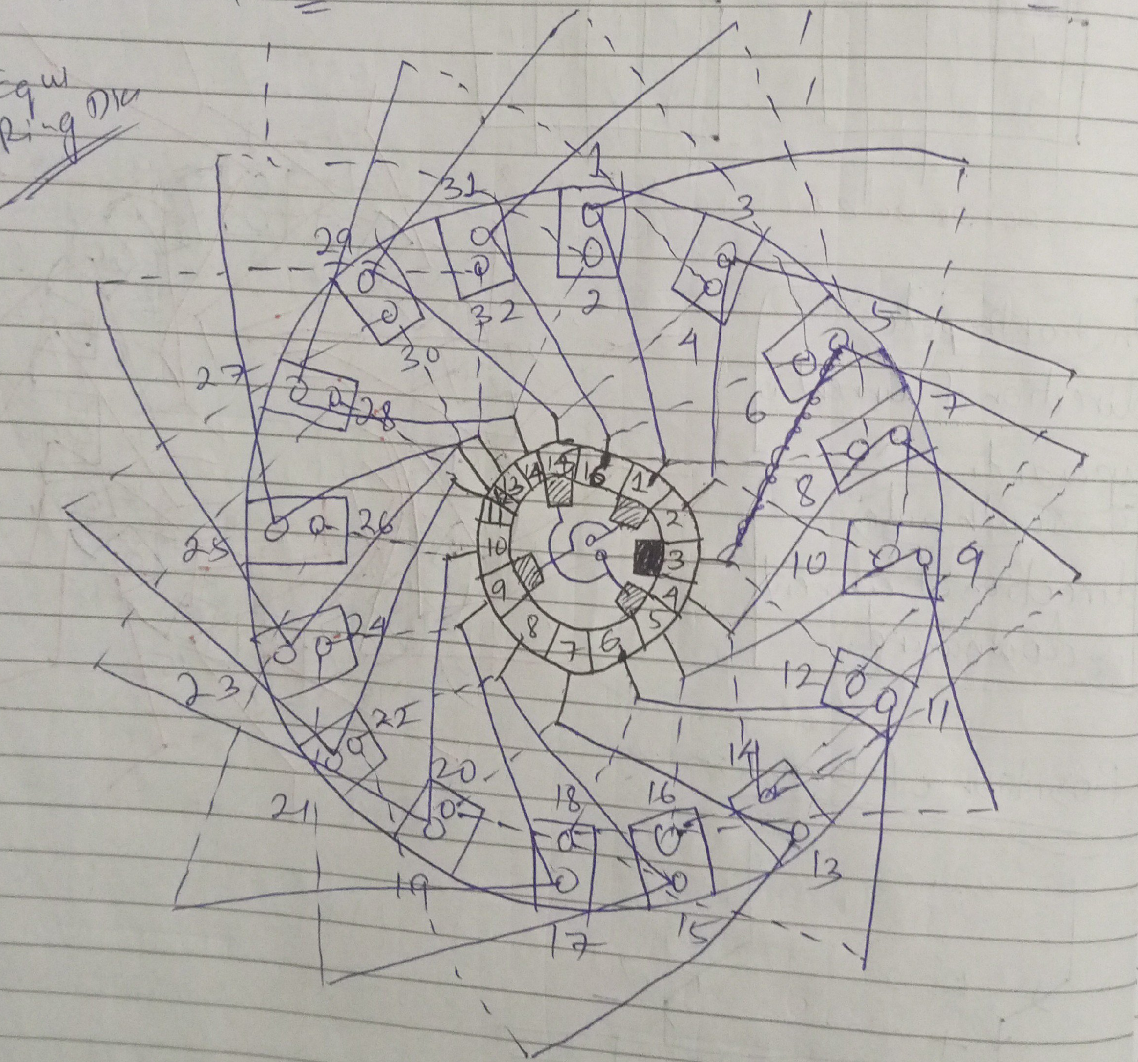
Ans: $C = 16$, $Z = 16 \times 2$, Pole Pitch $= Y_p = \frac{32}{4} = 8$.

$$Y_B = \frac{Z}{P} + 1 = \frac{32}{4} + 1 = 8 + 1 = 9.$$

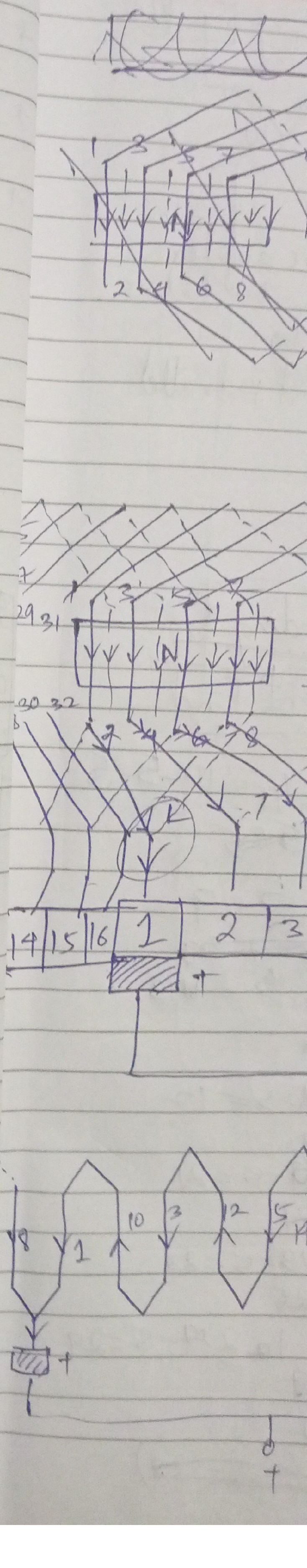
$$Z_F = \frac{Z}{P} - 1 = \frac{32}{4} - 1 = 8 - 1 = 7.$$

| Back-End Conductor | Front-End Cond. |
|---|---|
| 1 to 1+9 = 10 | 10 to 10 − 7 = 3 |
| 3 to 3+9 = 12 | 12 to 12 − 7 = 5 |

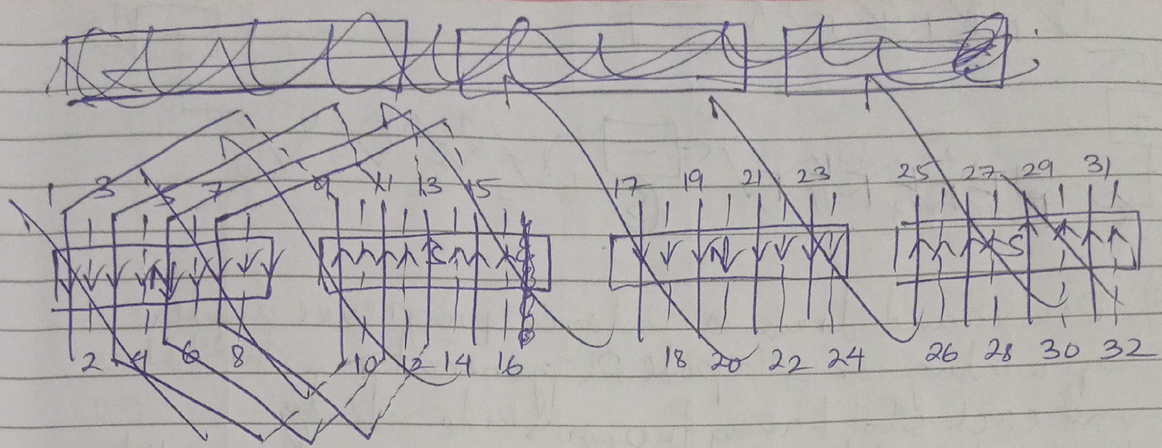
Equi Ring Dia

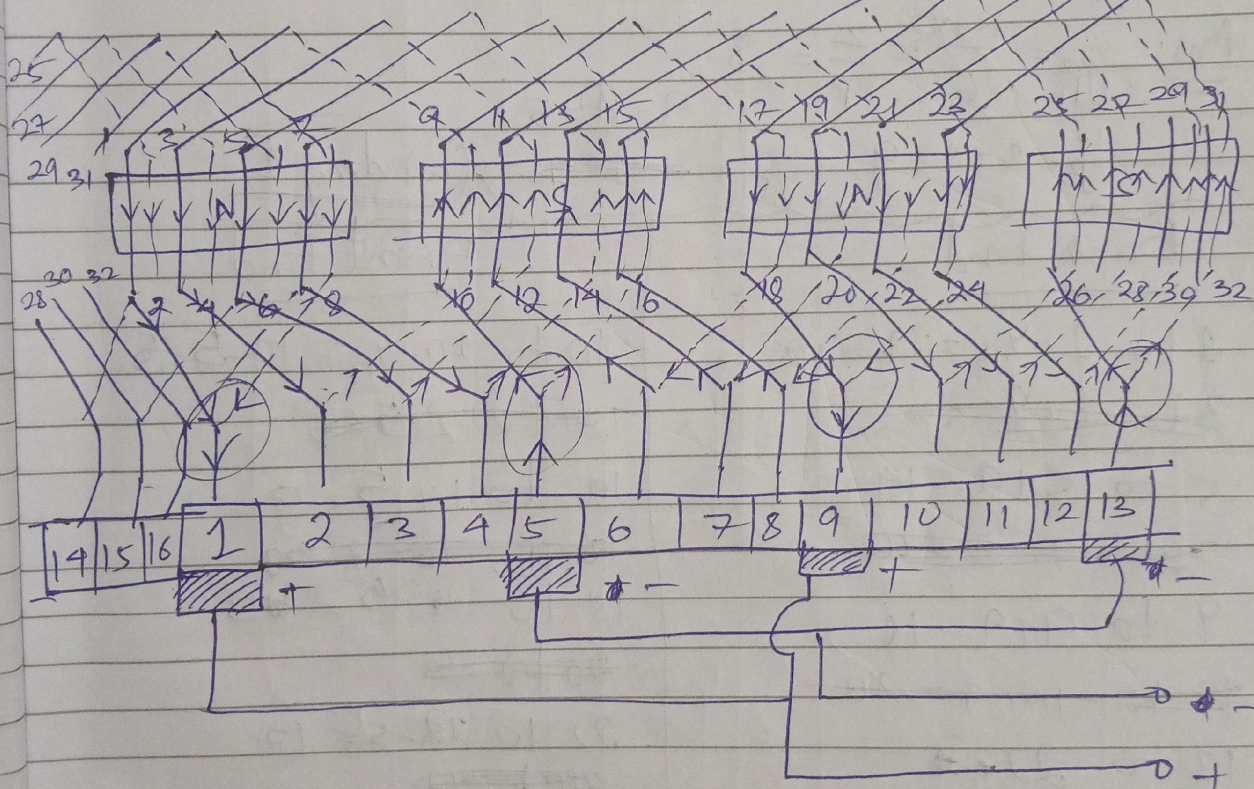


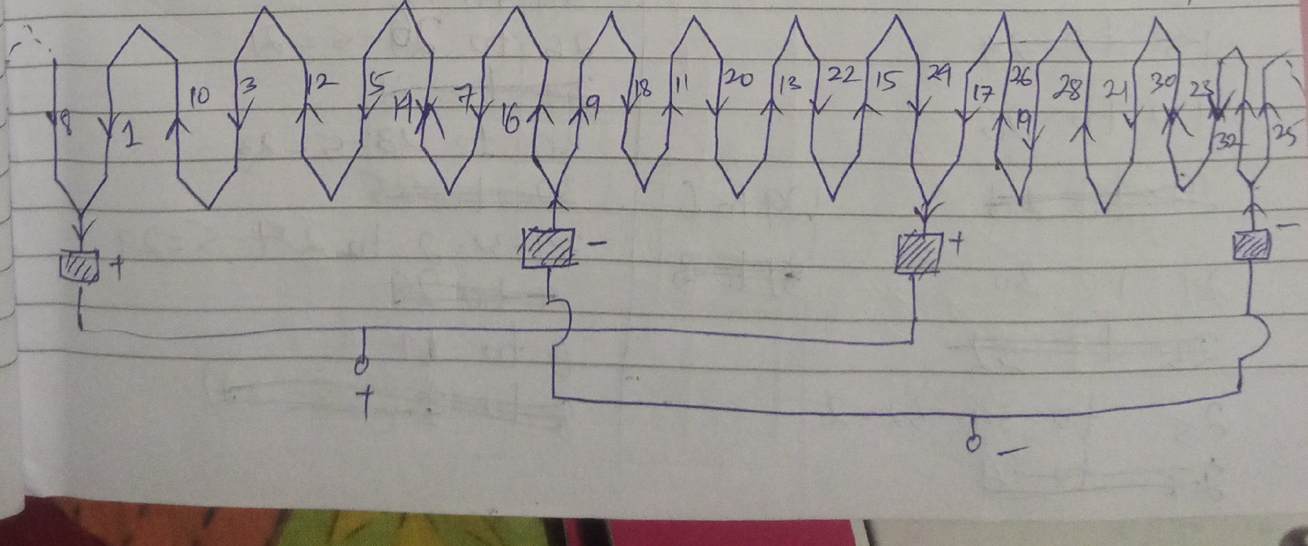
Equivalent L



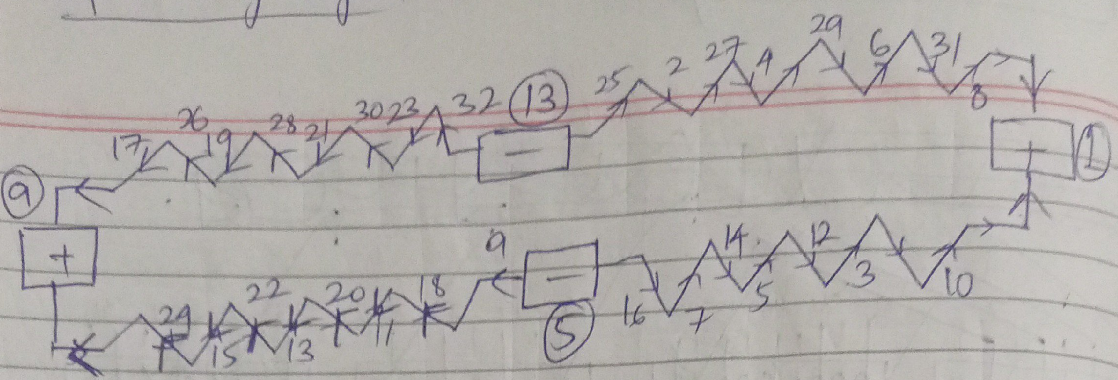
## Equivalent Linear Diagram :







Lap winding diagram –




Q) Design and draw a 2 layer progressive duplex lap winding for a 6 pole DC generator with 24 slots and each slot having two coils side indicating the position of the pole, position of brush and parallel path from there of.

Ans: $y_P = \frac{24 \times 2}{6} = \frac{Z}{P} = 8$.

$9 - 4 = 5$.

$y_B = 8 + 1 = 9$, $y_F = \cancel{8-1=7}$ 4 (winding 1)

**Back End**

$1$ to $1 + Y_B = 1 + 9 = 10$

~~3 to 3+9 = 12~~

5 to 5+9 = 14

~~7 to 7+9 = 16~~

9 to 9+9 = 18

~~11 to 11+9 = 20~~

13 to 22

~~15 to 24~~

17 to 26

~~19 to 24~~

21 to 30

~~23 to 32~~

25 to 34−32 = 2

~~27 to 4~~

29 to 6

~~31 to 8~~

**Front End**

10 to $10 - Y_F$ = 10 − 5 = 5

~~12 to 12−5 = 7~~

14 to 14−5 = 9

~~16 to 16−7 = 9~~

18 to 14−5 = 13

~~20 to 13~~

22 to 22−5 = 17

~~24 to 17~~

26 to 26−5 = 21

~~28 to 21~~

30 to 28−5 = 23

~~32 to 25~~

34−32 = 2 to 34−5 = 29

~~4 to 29~~

6 to 1

~~8 to 1 (33−32)~~.

Win…

Back End

3 to $3 + Y_B = 12$ (9)

7 to 16

11 to 20

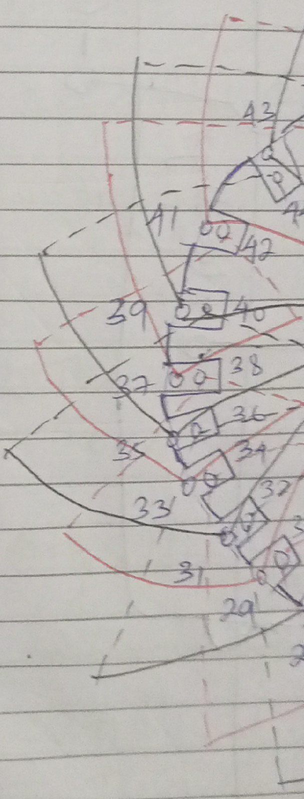
15 to 24

19 to 28

23 to 32

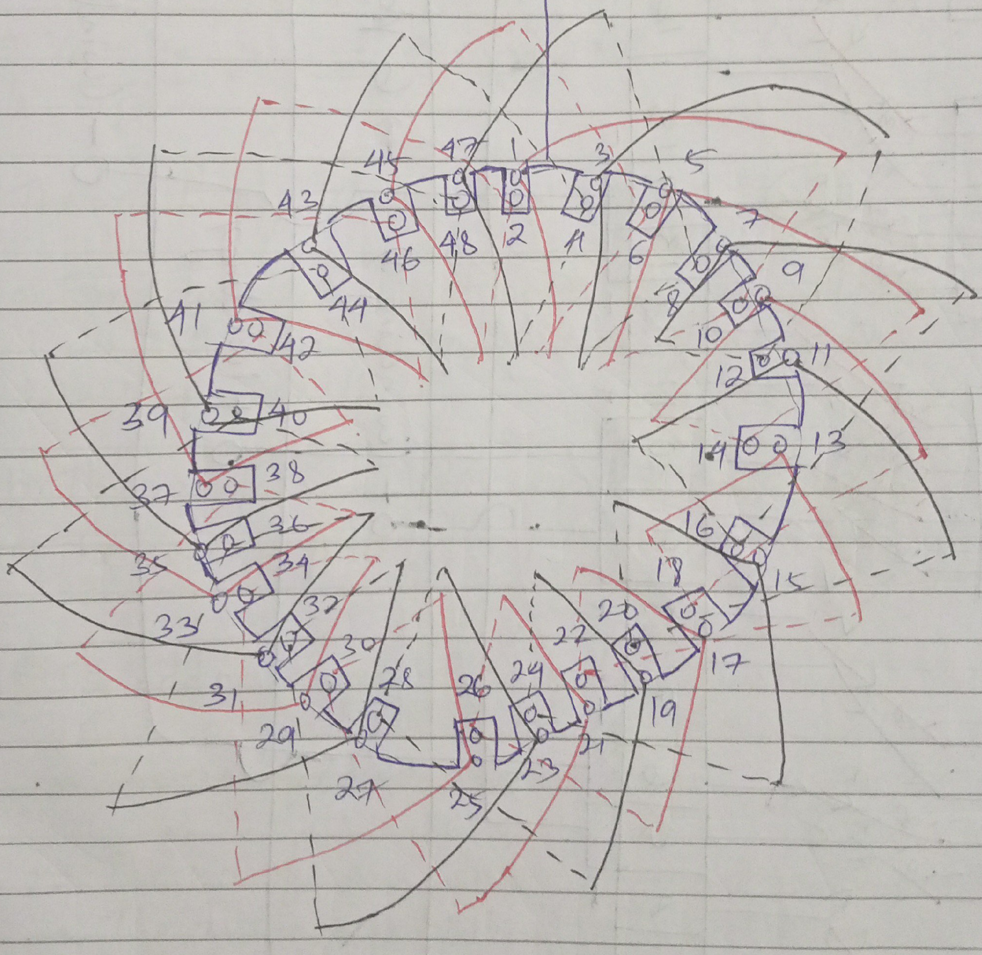
27 to 4 (36−3…

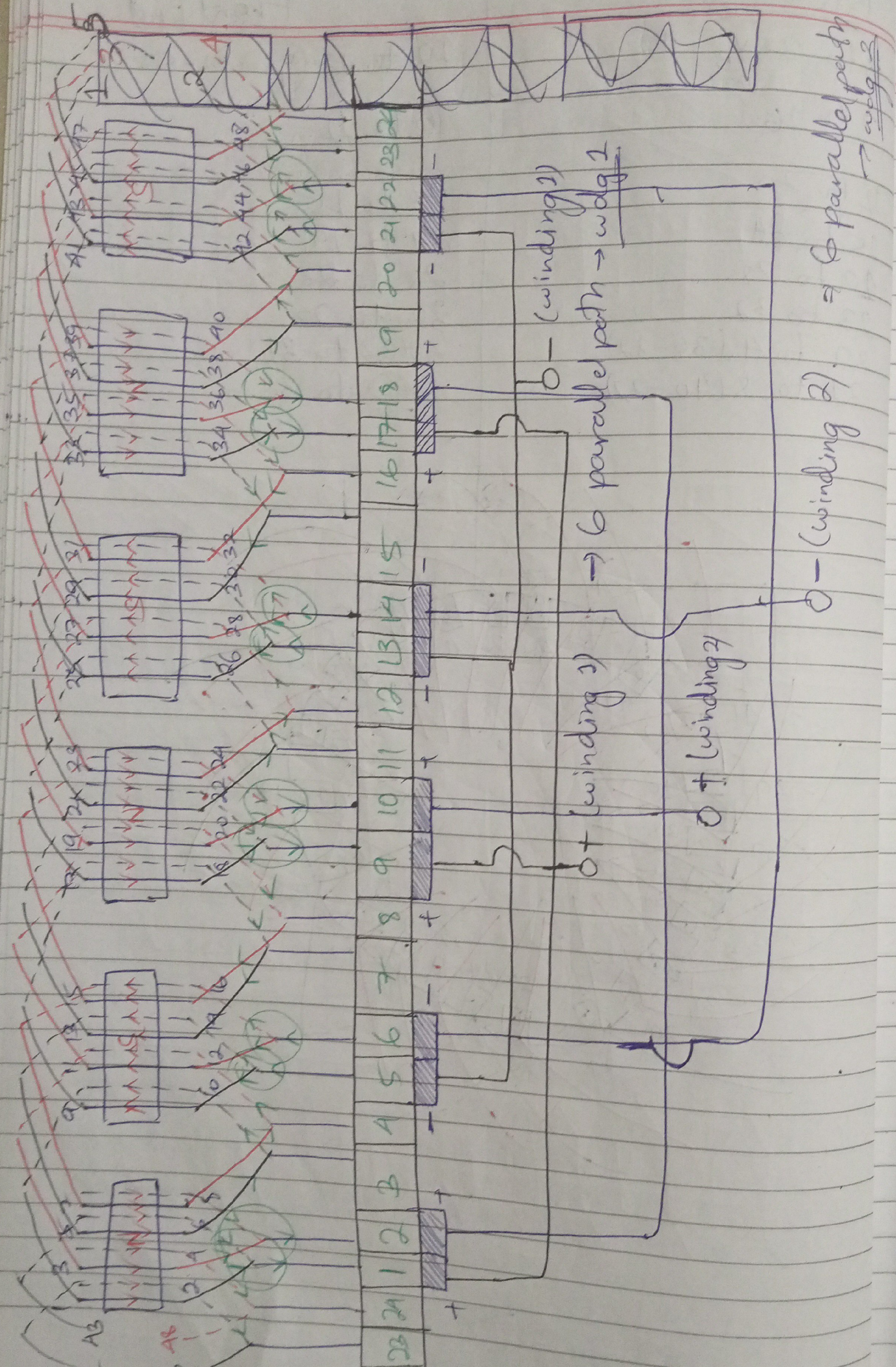
31 to 8 (40−3…



# Winding – II

| Back End | Front End |
|---|---|
| 3 to $3+Y_B = 12$ (9) | 12 to $12-Y_F = 12-5 = 7$ (5) |
| 7 to 16 | 16 to 11 |
| 11 to 20 | 20 to 15 |
| 15 to 24 | 24 to 19 |
| 19 to 28 | 28 to 23 |
| 23 to 32 | 32 to 27 |
| 27 to 4 (36−32) | 4+32 to 31 |
| 31 to 8 (40−32) | 8 (+32 −32) to 3 |






* No. of parallel path

## Wave winding →

**Properties –**

1) Both back and fr
2) Both the back a
   equal to pole pit
   back pitch can be

3) The commutator p

4) The average pit
   must be an intege

$\Rightarrow Y_A = \frac{Y_B + Y_F}{2} = \frac{Z}{}$

5) The resultant pitch

6)(a) For even no. of p
   have 2, 4, 6 pole
   like 15, 17, 19 (odd).

(b) The no. of comm

(c) The average pitch

(d) For odd no. of pa
   the no. of coil m
   ~~→ The no. of com~~

→ The no. of com

→ The average
   but must be e

* No. of parallel path = mp, Differ by 2m

## Wave winding →

### Properties –

1) Both back and front pitch must be odd.
2) Both the back and and front pitch must be nearly equal to pole pitch. (Here sometimes front pitch and back pitch can be equa). ($Y_F = Y_B \pm 2m$)
3) The commutator pitch $Y_C = \frac{C \pm 1}{P/2} = Y_A$, C = No. of coils. $C = \frac{Z}{2} \rightarrow$ (No. of conductor)
4) The average pitch must be an integer.

$$\Rightarrow Y_A = \frac{Y_B + Y_F}{2} = \frac{Z \pm 2}{P} \qquad \left(Y_B = \frac{2C}{P} \pm k\right)$$

5) The resultant pitch $Y_R = 2Y_P = Y_B + Y_F$
6) (a) For even no. of pair of pole, i.e., the machine which have 2, 4, 6 pole (even), the no. of coil must be odd like 15, 17, 19 (odd).

(b) The no. of commutator segment must be odd.

(c) The average pitch, i.e., $Y_A = \frac{Y_B + Y_F}{2}$ may be odd or even

(b) For odd no. of pair of poles (Machine have 3, 5 and 7 poles the no. of coil must be odd or even

~~The no. of commutator~~

→ The no. of commutator segment can be odd or even
→ The average pitch must be odd for even no. of coil but must be even for odd no. of coils.

0 – (winding 2). ⇒ parallel path → wdg 3

6.2.25

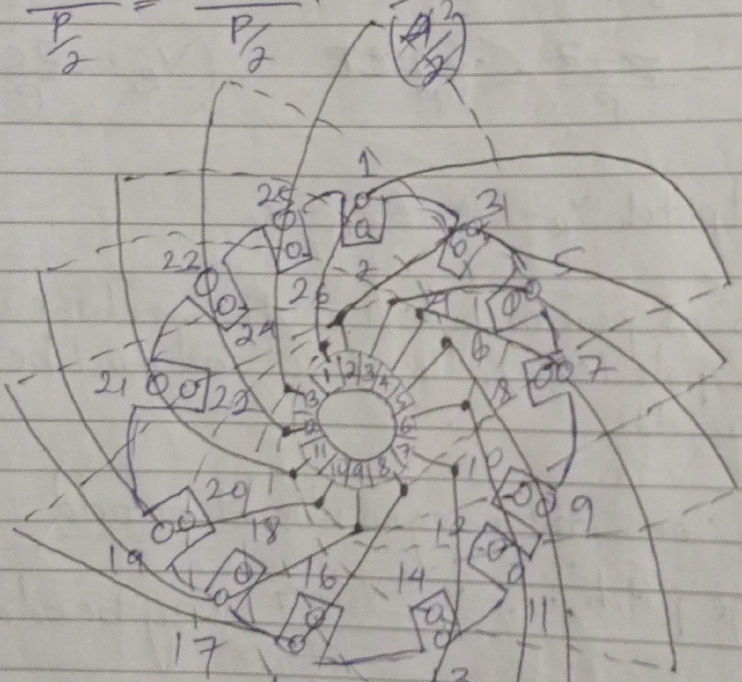
Q) Develop a wave winding for 4-pole simplex 13 slots wave connected DC generator with a commutator having 13 segment. No. of coil side/slot = 2 indicating the pos$^n$ of the brush

$\boxed{C = 13}$

Ans: $y_p = \frac{Z}{P} = \frac{13+1}{}$

$y_F = 7, \; y_B = 7.$

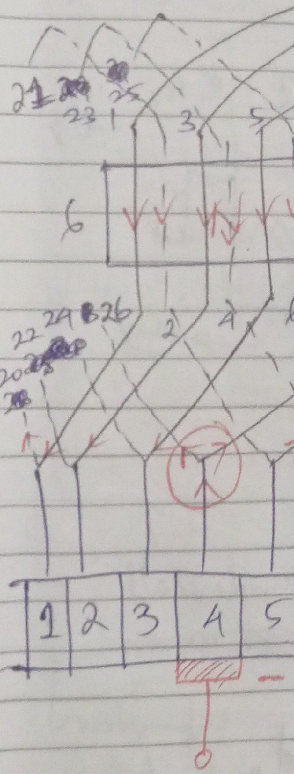
$y_C = \frac{C \pm 1}{\frac{P}{2}} = \frac{13+1}{\frac{P}{2}} = \frac{14}{\cancel{4}^{2}/\cancel{2}} = 7.$




* Downward → current towards Observer.
Upward → current ~~toward~~ away observer.

~~Front~~
Back En

| |
|---|
| 1 → 8 |
| 15 → 22 |
| 3 → 10 |
| 17 → 24 |
| 5 → 12 |
| 19 → 26 |
| 7 → 14 |
| 21 → 2 |
| 9 → 16 |
| 23 → 4 |
| 11 → 18 |
| 25 → 6 |
| 13 → 20 |

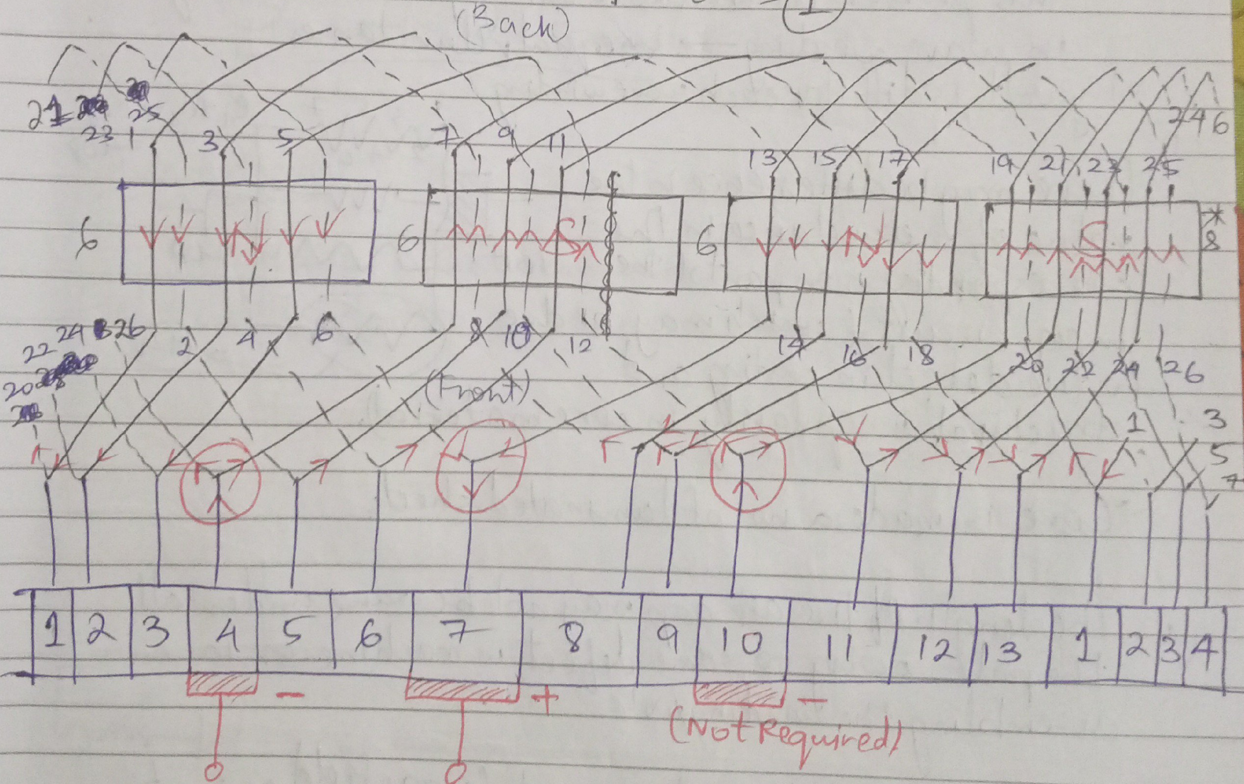



No. of pa
Cond. p

dex 13 slots
mutator
icating

= 13

| ~~Front~~ Back End | Front End |
|---|---|
| 1 → 8 | 8 → 15 |
| 15 → 22 | 22 → 3 |
| 3 → 10 | 10 → 17 |
| 17 → 24 | 24 → 5 |
| 5 → 12 | 12 → 19 |
| 19 → 26 | 26 → 7 |
| 7 → 14 | 14 → 21 |
| 21 → 2 | 2 → 9 |
| 9 → 16 | 16 → 23 |
| 23 → 4 | 4 → 11 |
| 11 → 18 | 18 → 25 |
| 25 → 6 | 6 → 13 |
| 13 → 20 | 20 → 1 |




No. of paralel path = 2
Cond. per parrallel path = 13

# Disadvantages of Armature Winding :-

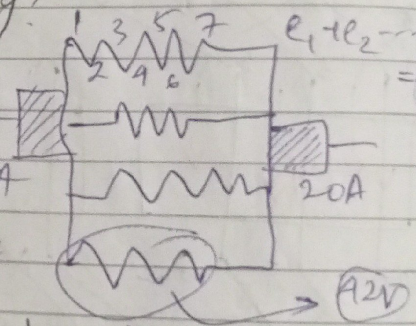
1) In lap winding, no. of parallel path $= P \times m$ (is more) and each & every path there is a conductor, more no. of parallel connection.

→ Dissimilar voltage induced in wave winding, leading to circulating current in arm. winding. This leads to diff. in current flow in brush, leading to overloading.

→ This problem occurs due to air gap non-uniformity in wave winding → unequal reluctances

Why volt. is diff. for each wave winding?

(i) ∴ There may be difference in the value of reluctance in the corresponding iron part of the mag. circuit, (which may be due to the defect in casting and structural irregularity in core material).




↳ Core is made a no. of laminated sheets

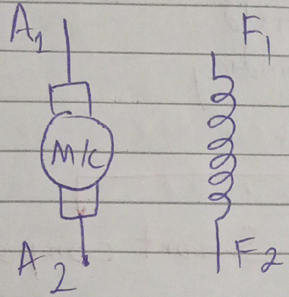
(ii) The length of the air gap may not be same under all the pole, owing to some defect in machine or in assembling the winding/pole.

(iii) Core may be different strength (mag. field owing to error in putting the field winding). Therefore the unequal amt. of emf generated in diff. parallel path give rise to resultant emf which act across the armature winding.

→ Due to this resultant emf, a large circulating current will flow through the armature winding and at the same time, this amt. of current will flow through brush. As a result, there is considerable inequality of brush-arm current, and due to this heavy current, we need to incorporate $I^2R$ loss at no-load condⁿ of the generator and motor.

- Further due to the heavy current, there is a sparking or over-heating of brush contact surface, so to free this heavy current, some conductor is required and this conductor is called <u>equiliser ring</u>.

~~Equaliser Ring~~




A → Armature Terminal
F → Field Terminal

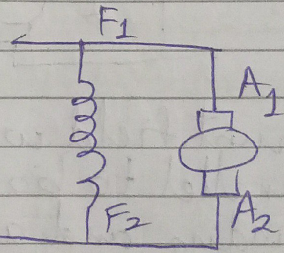
Terminal of DC M/C = 4.

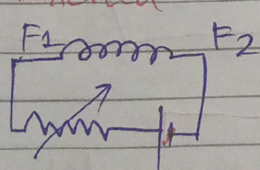
## Excitation:

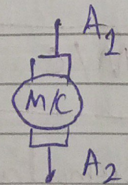
Excitation is the phenomenon of process by which mag. field will be developed in the DC Machine.

### Type of DC M/C

- Separately Excited
- Self Excited



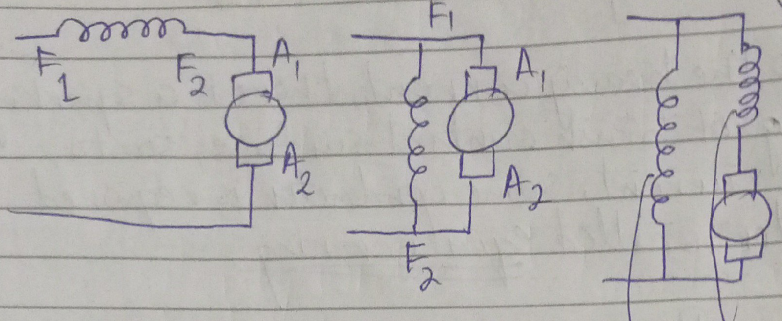

① In separately excited, the field and armature terminals are not internally connected.

② In self excited, the field and armature terminals are internally connected.

③ The voltage drop for self excited DC machines is more compared to separately excited ones.

Self-excited

Series M/C — Shunt M/C — Compound M/C

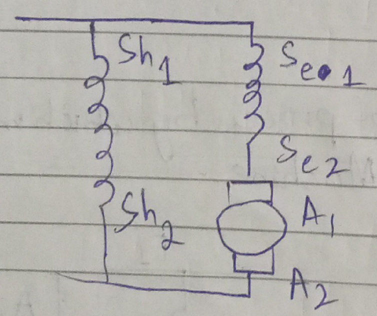



Compound M/C → Same position connected in series with the armature and remaining position is parallel to the armature

Classifications:

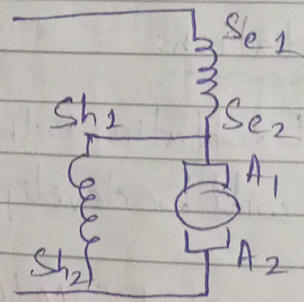
① Compound M/C

Long compounded




Shunt field winding is parallel to both series winding and armature.

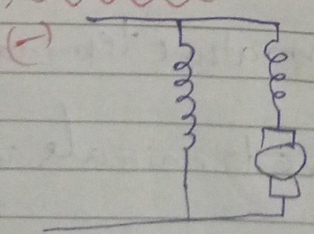
Short compounded




Shunt field winding is parallel only to armature winding.

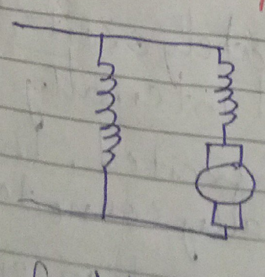
② Compound M/C

Differential Compounded (−)



Series field flux oppose the shunt field flux

Cumulative Compounded (+)



Series field flux helps/add in the shunt field flux.

Shunt → More resistance, Series → Less resistance

14.2.25

→ The patter... the magnet... the air bac... produced by... winding, dep...

1) The windin...

2) The nature... current fl... through the...

3) The magnet... configurat... machine su...

• In the figur... conductor a...

→ According... acting on an... current enc...

→ For the pa... is (3I). a... as shown i...

→ For the pa...

→ For the pa...

Therefore, t... linear, whi...

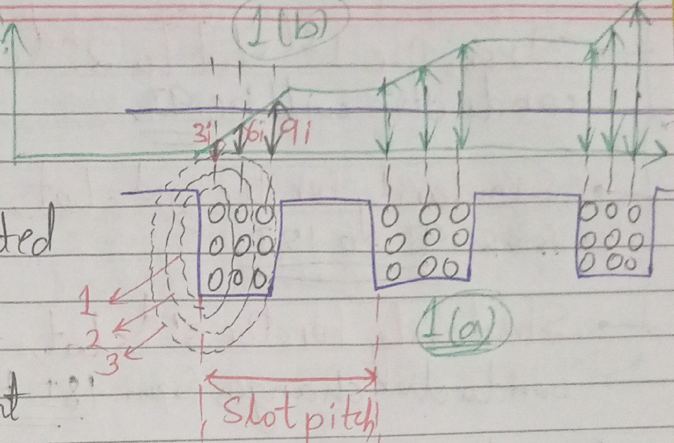
→ This m.m.f... machine

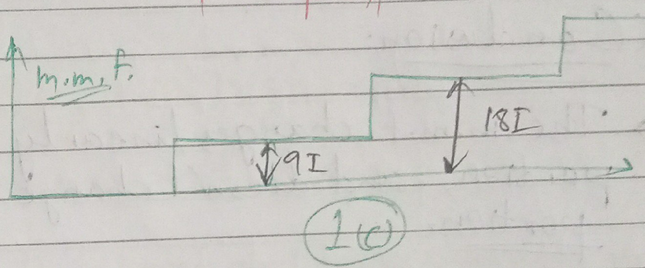
14.2.25

# M.M.F. produced by distributed winding :-

→ The pattern of the magnetic field along the air back periphery produced by the distributed winding, dependupon:

1) The winding arrangement
2) The nature of the current flowing through the winding
3) The magnetic circuit configuration of the machine such as air gap length, slot opening, etc.




- In the figure 1(a), each slot is assumed to contain 9 conductor and each conductor carry a current (I).

→ According to the Ampere's circuital law, the m.m.f acting on any closed path is equal to the total ~~closed~~ current enclosed by that path

→ For the path 1, the ampere conductor enclosed is (3I), and this is therefore the m.m.f. change as shown in the figure 1(b)

→ For the path 2, the ampere conductor enclosed is 6I.
→ For the path 3, the ampere conductor enclosed is 9I.

Therefore, the m.m.f. changed from path 1 to 3 is linear, which is shown in Fig 1(b).

→ This m.m.f. 0 to 9I over the slot portion of the machine (slot width).

→ From the 1st slot to 2nd slot total ampere conductor will be 9I.

→ Similarily for the 2nd slot, total ampere conductor changes from 9I to 18I.

→ Similarily for the 3rd slot, total ampere conductor changes from 18I to 27I.

## * Conclusion:

→ The m.m.f. changes linearly over the slot portion, and doesn't change over the Tooth/Tip portion.

→ In order to make analysis simple, the change in m.m.f over the slot portion is taken as stepped at the middle of the slot with.

* In other words, the total change of m.m.f., i.e, 9I over the slot portion is taken to occur at the centre of the slot as shown in the figure 1(c).

→ Therefore nature of the m.m.f. as a waveform is a step-rectangular.

## * M.M.F. of a coil:

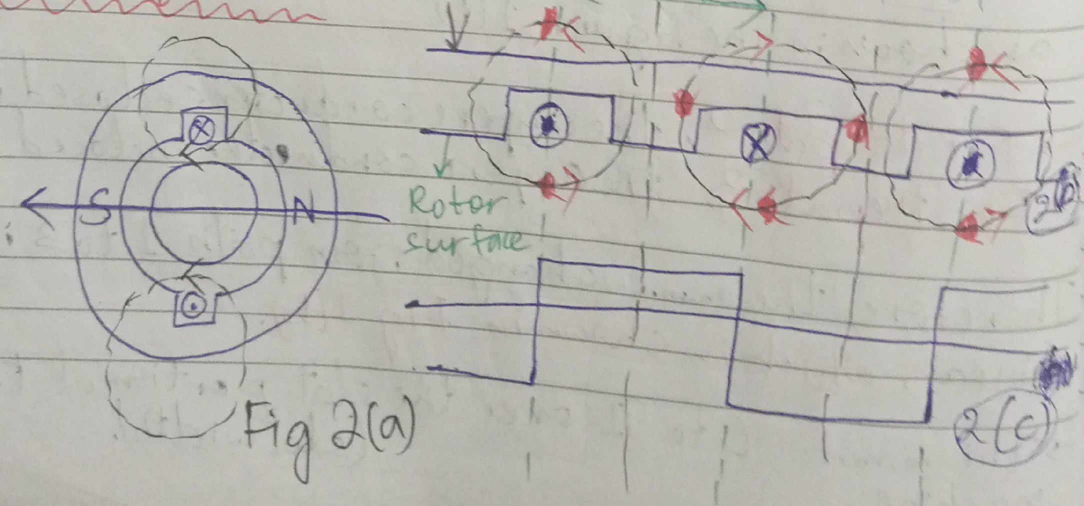



Fig 2(a)

ollow cylindrical → inner

tal ampere

conductor
mpere changes

mpere

the slot
the Tooth/Tip

the change in
s stepped at

nt, i.e, 9I
cur at the
gure 1(c).

waveform

2(b)

2(c)

→ Consider 1 full-pitch coil on the stator on a 2-pole uniform air-gap machine as shown Fig 2(a).

→ The coil consists of n-turn and each turn carry a current of (I). The direction of the current of two coil sides is indicated by a cross & dot notation

→ The mag. flux setup by this coil current is shown in the dotted line of Fig 2(a).

The developed view of Fig 2(a) is shown in the Fig 2(b).
• In order to determine the coil mmf
the following assumptions are to be made:-

1) The permeability of the stator and rotor Iron is much higher than that of air. In view of this, it may be assumed that the stator and rotor have infinite permeability. This means that the reluctance of the mag. field flux is offered by the air gap only.

2) The mag. flux line are assumed to cross the air-gap radially. This assumption is permissible because the air gap is much smaller is comparison to the pole pitch.

3) The total ampere turn produced by the coil is NI. Thus, if the total ampere turn is NI, then half the m.m.f is req. to create flux from rotor to stator in the air gap, where half is required to create m.m.f. is req. to create flux from stator to rotor in the air gap.

4) The flux line radially cross the air gap between the rotor and stator twice,

→ Accd. to Fig 2(b), the m.m.f and the flux radially upward from rotor to stator is assumed positive ~~while that from stator to rotor is assumed negative~~

→ Thus the m.m.f distribution is step-wise giving a rectangular waveform.

→ The m.m.f $+\frac{1}{2}NI$ is used to setting flux from rotor to stator in the air gap. No mmf required for the iron path

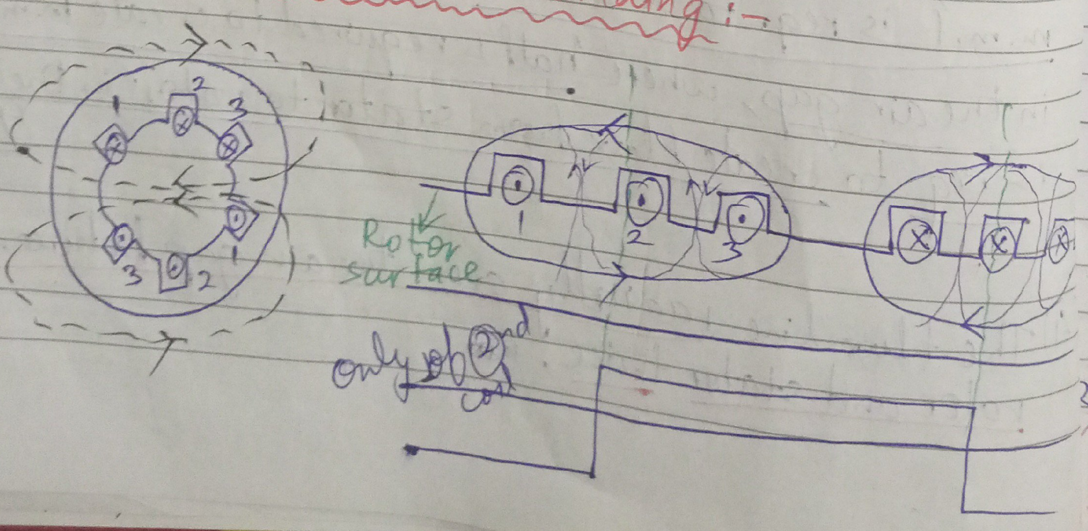
→ Similarly, the m.m.f $-\frac{1}{2}NI$ is used to setting flux from stator to rotor in the air gap. No mmf required here also for iron path.

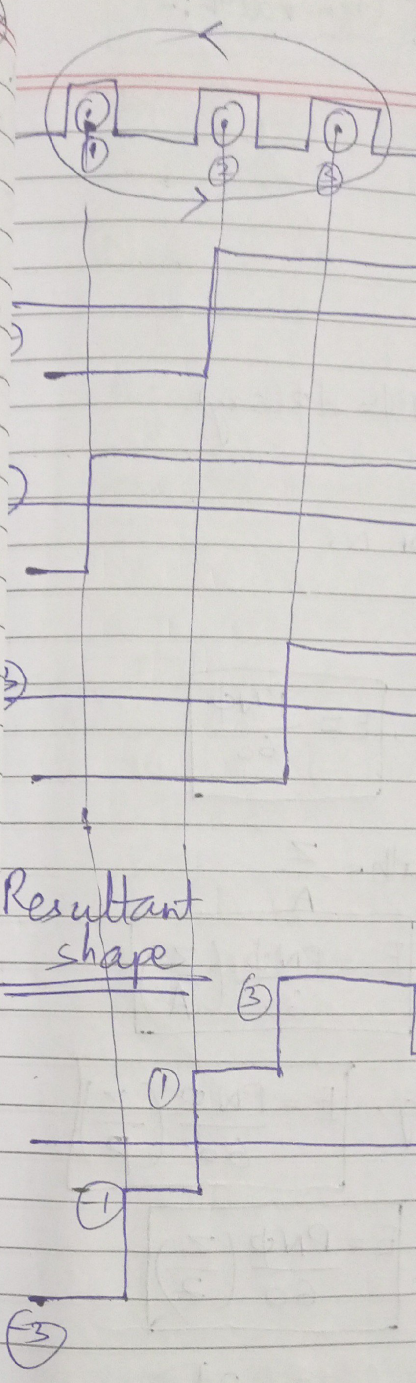
→ It is seen that the air gap m.m.f wave as any instant is rectangular in nature.

→ If the coil current is DC, the magnitude of the m.m.f doesn't vary with time and space, which is required in 3-$\phi$ Induction motor.

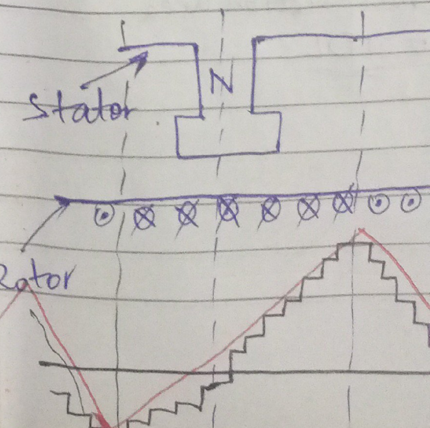
→ For AC, the amplitude of m.m.f wave varies with time, not space, i.e., the air gap mmf wave is time-variant but space invariant.

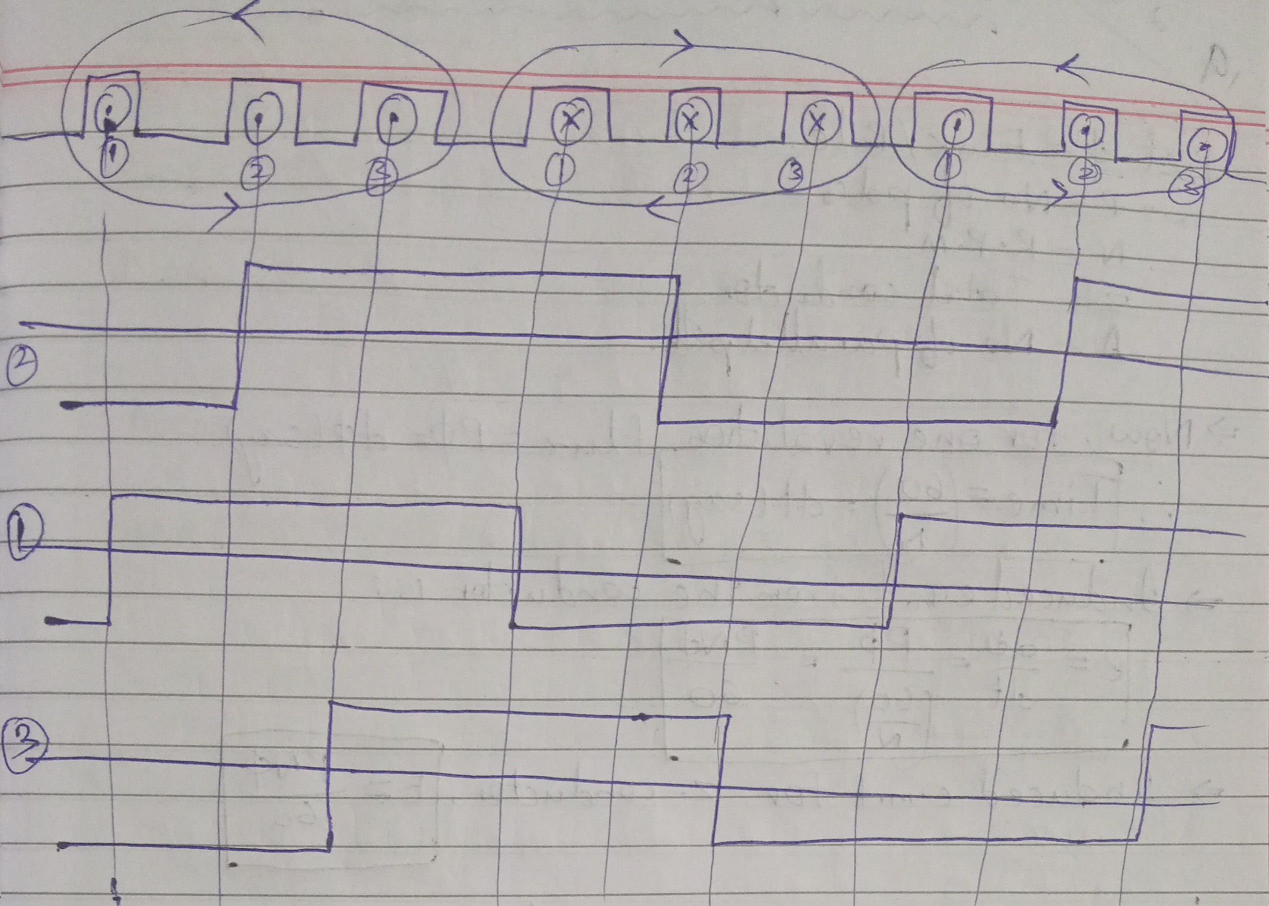
→ M.M.F. of Distributed winding :-



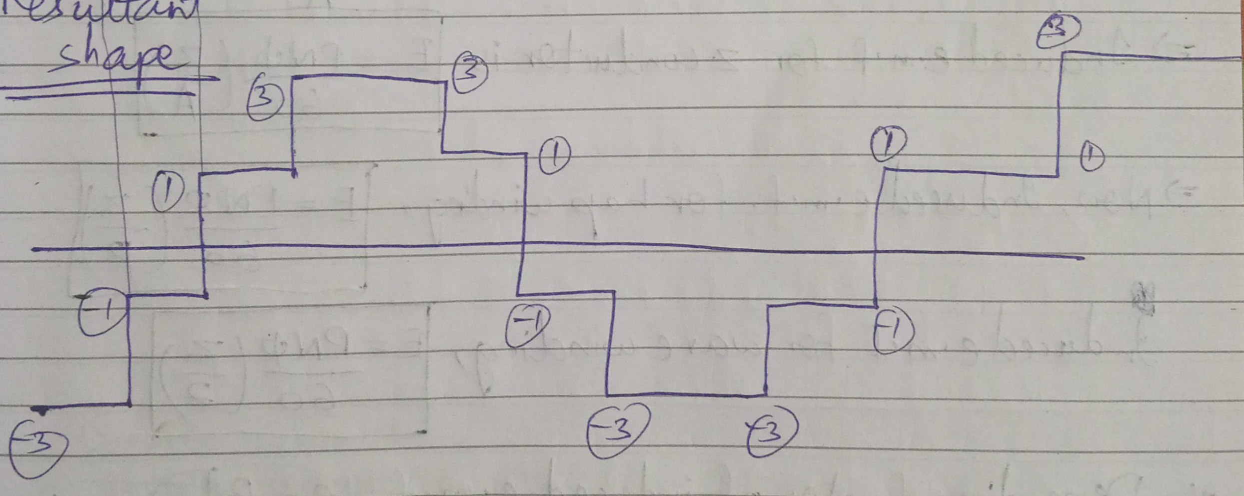




Armature M.M.F.

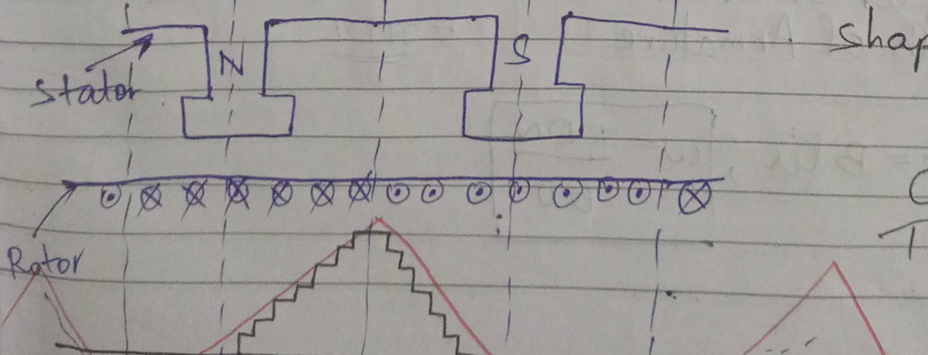




Resultant shape



## Armature M.M.F. of DC M/C :-




Lot of step-up shape → Trapezoid shape.
↓
Converts into Triangular shape

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# E.M.F Equation of DC Generator:-

Let $\phi$ = Flux/Pole
$P$ = No. of poles
$N$ = R.P.M
$Z$ = Total conductor
$A$ = No. of parallel path.

⇒ Now, for one revolution, flux $= P\phi = d\phi$ (say).

∴ $\boxed{\text{Time} = \left(\frac{60}{N}\right) = dt \text{ (say)}}$

⇒ Induced e.m.f from the conductor is:

$$\boxed{e = \frac{d\phi}{dt} = \frac{P\phi}{\left(\frac{60}{N}\right)} = \frac{PN\phi}{60}}$$

⇒ Induced e.m.f for Z-conductor, $\boxed{E = \frac{PN\phi}{60}}$

∴ Now effective conductor/parallel path $= \frac{Z}{A}$

⇒ Induced e.m.f for Z-conductor is $\boxed{E = \frac{PN\phi}{60}\left(\frac{Z}{A}\right)}$

⇒ Now, Induced e.m.f. for Lap winding, $\boxed{E = \frac{PN\phi}{60}\left(\frac{Z}{P}\right)}$

Induced e.m.f for wave winding, $\boxed{E = \frac{PN\phi}{60}\left(\frac{Z}{2}\right)}$.

* Depending factor of induced e.m.f, $e = Blu$

D = Diameter of Armature
L = Length of Armature

* Cross-section area $= \pi DL$

$\boxed{B = \frac{P\phi}{\pi DL}}$, $e = Blu$, $\boxed{\omega = \frac{\pi DN}{60}}$

$$\boxed{E = \frac{PN\phi}{60}\left(\frac{Z}{A}\right)}$$

Here; P, Z and A are constants.

$\Rightarrow E = KN\phi$

$\Rightarrow$ (i) $E \propto \phi$ 

(ii) $E \propto N$

Again $\phi \propto I_f$

$\Rightarrow E \propto I_f$

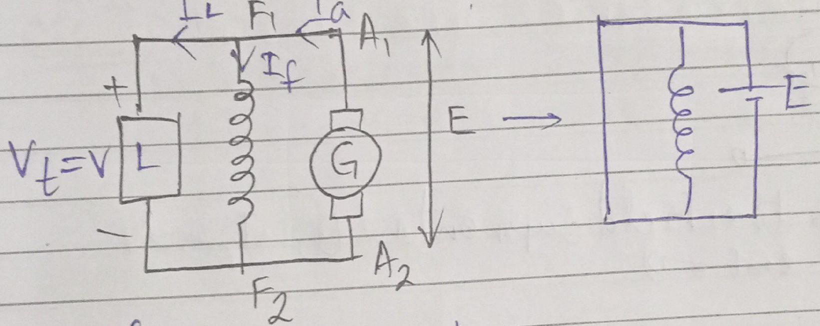
Now, for $N_1, \phi_1 \Rightarrow E_1 = KN_1\phi_1$

$N_2, \phi_2 \Rightarrow E_2 = KN_2\phi_2$

$$\frac{E_1}{E_2} = \frac{N_1\phi_1}{N_2\phi_2}$$

Again, if $\phi_1 = \phi_2 = \phi = \text{constant} \Rightarrow \boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2}}$

## Some other equation for Generator:




(Shunt Generator)

Here, $I_a = I_A$

$\boxed{I_a = I_e + I_f}$ — (i)

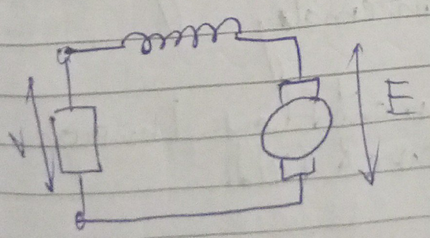
$I_f = I_{sh}$

**In KVL equation:-**

$E = I_a R_a + \underbrace{I_L Z_L}_{V}$, $\boxed{E - I_a R_a = V}$ — (ii)

$\boxed{V = I_f R_f}$ — (iii)

**(Series Generator)**



# Characteristics of DC Generator:

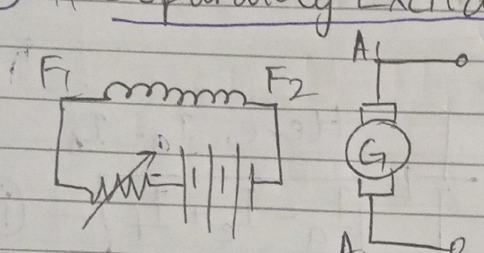
1. No-load or Open-circuit Characteristics
2. External or Load Characteristics
3. Internal characteristics.

## # No-load →

$\Rightarrow E = KN\phi \quad \Rightarrow E \propto \phi$ for const. N.

But $\phi \propto I_f \quad \Rightarrow E \propto I_f$

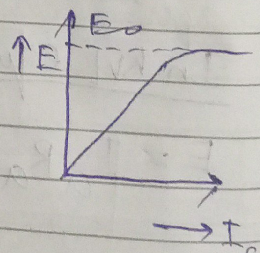
## 1. # Separately Excited Generator →




Case I: When the field current is 0, $I_f = 0$
$\therefore E = 0$ (ind. emf = 0)

Case II: When the field current ($I_f$) increases, $\phi (\uparrow)$
'E' also increases ($E \uparrow$)

Case III: When the field current ($I_f$) decreases,
$\phi (\downarrow)$, 'E' also decreases ($E \downarrow$).

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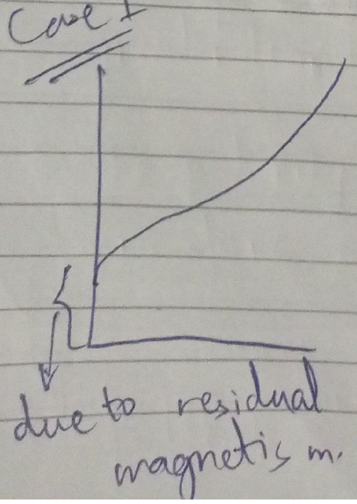


→ Armature wdg & field wdg are connected internaly

→ So, same current flows through both armature & field.

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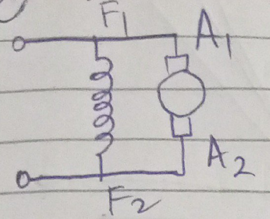
## ② # Shunt Generator




We know that $E = kN\phi$.

$\therefore$ For emf N, $E \propto \phi$

but $\phi \propto I_f \Rightarrow E \propto I_f$.

Case I: When $I_f = 0 \Rightarrow E = 0$ (ind. emf = 0) ✗

(emf. is directly prod.).

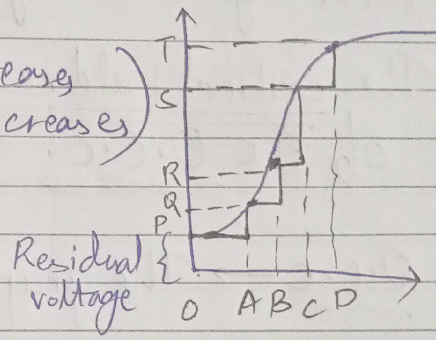
Initially generator has some induced e.m.f., which is possible when residual magnetism.

Case II: (value of Mag. field increases when excitation current increases)

(ind. current increases)

(emf. increases)

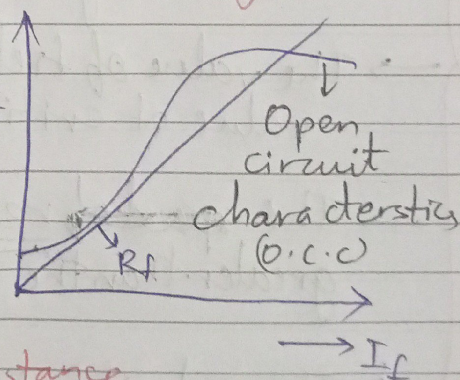
upto saturation point.




→ When dipoles all are aligned perfectly, no more magnetisation increase happen → saturation occurs at some point.

Condition: Some residual volt. is req. at the beginning to make some induced e.m.f and operate the generator.

$\frac{E}{I_f}$ = Appox. value of field resistance + (val. of arm resistance).



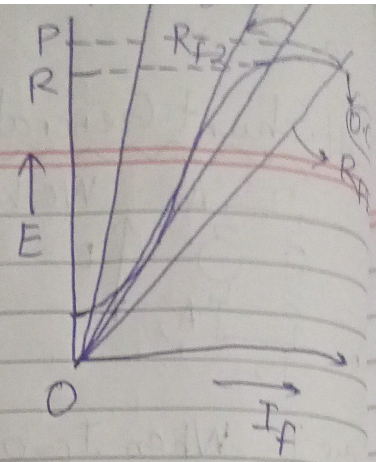

Note: For a particular generator the field resistance is always lower than O.C.C resistance.

## Effect of Field Resistor :-

Consider two field resistance $R_{f1}$ and $R_{f2}$.

$R_{f_1} \rightarrow$ Original field resistance

$R_{f_4} > R_{f_3} > R_{f_2} > R_{f_1}$



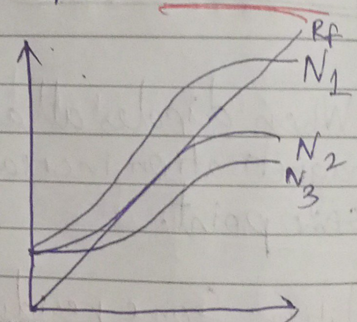

## * Critical Field Resistance

→ The maximum value of the field resistance can build up the voltage.

If the value of field resistance > Critical resistance it can't generate any voltage

· This critical field resistance is the tangent of the O.C.C.

* O.C.C → The graph of E vs. $I_f$ for const. N.




$N_1 > N_2 > N_3$

## * Condition of Voltage Building :-

→ There must be a residual magnetism.

→ The value of field resistance must be less than value of critical field resistance.

→ The ~~speed of~~ rotation of the armature must be greater than the critical speed.

→ The polarity of the field and rotation of the armature must be in proper sequence.

if oppo. polarity → Then it destroys the residual magnetism present.

?. Process of volt. buildup → (O.C.C) explanation

Justify for shunt gen. there must be resid. mag. (O.C.C) explanation