Benifit & loss

Tertiary Winding Transformer

→ In Addition to primary & Secondary, Third wdg is used Tertiary Winding.

→ Two winding into 3 wdg with extra secondary winding.

Why to use Tertiary wdg

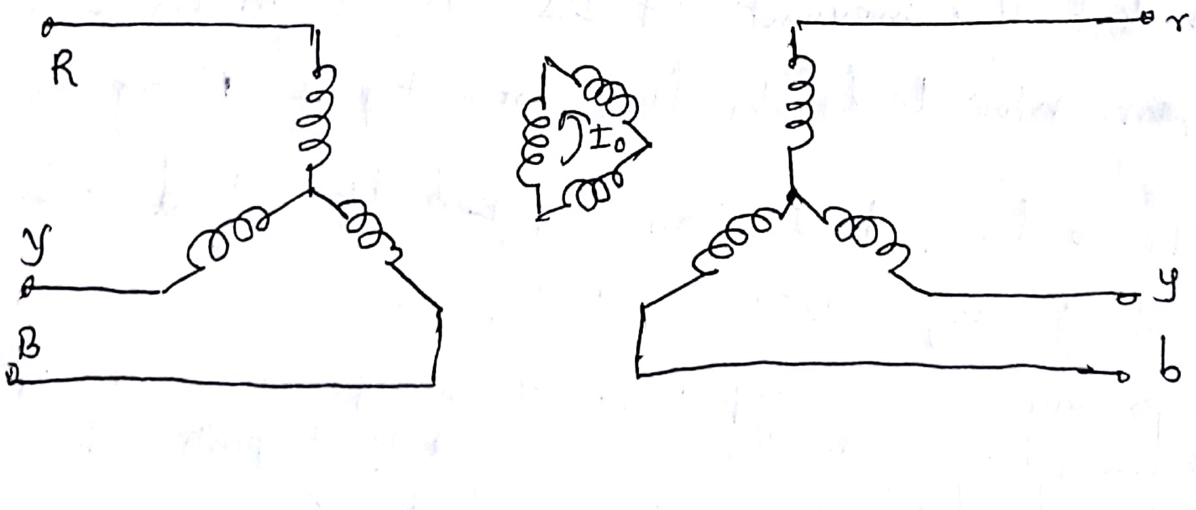
practical Approach

1) If two wdg has to supply additional load
2) The phase compensating devices supplied by 3φ wdg tfr.
3) used as voltage coil in testing transformer.
4) Three supply system operating at different voltages, interconnected using 3 wdg tfr
5) To meet substation requirement (Different voltage)
6)

Tertiary wdg generally connected in delta. Thus when any fault or short circuit occurs on primary or secondary sides, there will be large unbalance of phase voltage which is compensated by large tertiary wdg circulating current with large Reactance

16
×24
640
600
1240
2000
1240
0760

Stabilization due to Tertiary wdg in λ-λ Tfr



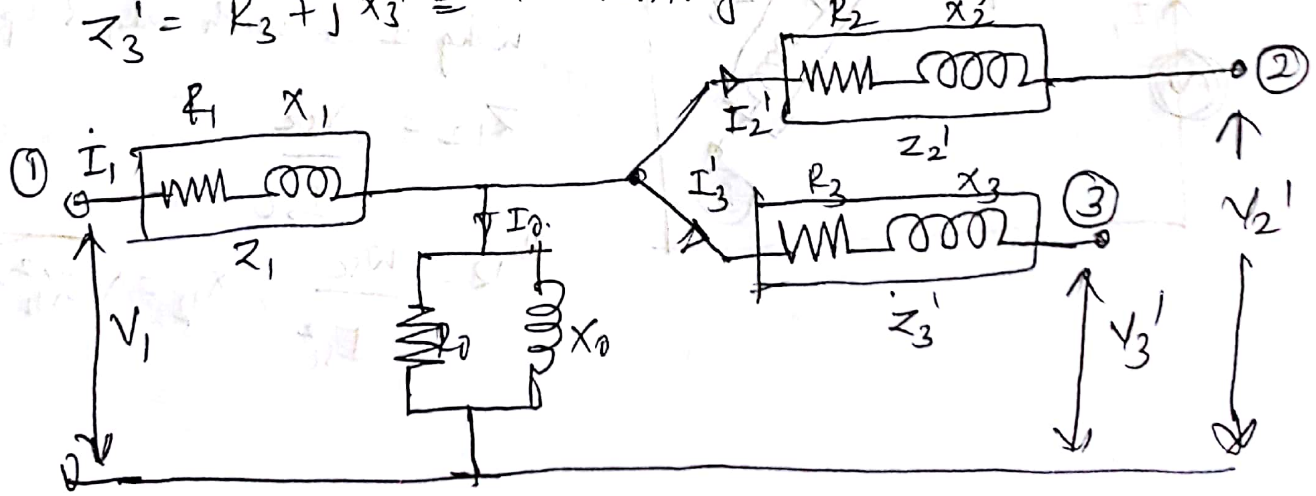
- for unbalanced single phase load, Δ-Δ Connection offers high reactance to flow of current.
- unbalanced load has 3 components viz, positive, negative & zero sequence components.
- zero sequence component on secondary side cannot be balanced by primary currents as zero sequence currents cannot flow in isolated neutral of star connected primary.
- on the secondary side zero sequence current sets up magnetic flux in core. & iron path is available for this flux and impedance offered to zero sequence clu flux is very high.
- But delta connected tertiary wdg permits circulation of zero sequence currents in it.
- So impedance offered to flow of zero sequence currents is lowered.
- For this purpose tertiary winding is <u>stabilizing winding</u>

Equivalent circuit of Tertiary tfr

let $Z_1 = R_1 + jX_1$ = Imp prim wdg

$Z_2' = R_2' + jX_2'$ = " sec " Reff primary

$Z_3' = R_3' + jX_3'$ = " teritiary " Reff prim



Determining the equivalent circuit parameters

Open & short test are performed

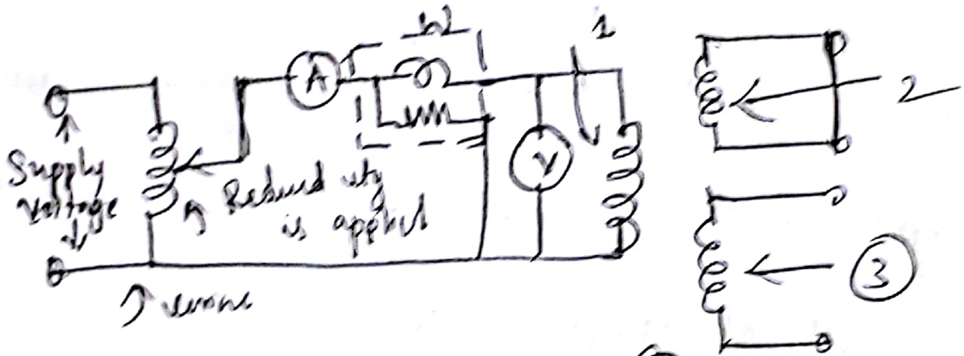
① Open circuit test

It is conducted on any one wdg giving core losses, exciting branch components and turns ratio. The other two windings are kept open when supply is given to any one wdg

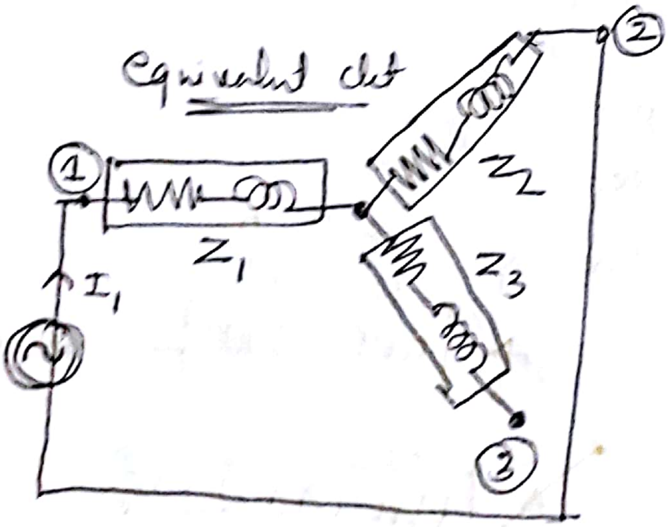
$$N_{12} = \frac{V_2}{V_1}, \quad N_{23} = \frac{V_3}{V_2}, \quad N_{13} = \frac{V_3}{V_1}$$

② Short circuit test

Stage 1 :- Reduced supply vtg is given to winding 1 till the Rated cu flows in ② & ③ open



Equivalent ckt



$Z_{12} = Z_1 + Z_2$ — (9)

Short circuit Impedance of wdg 1 & with wdg 3 open

$$Z_{12} = \frac{V_{sc}}{I_{sc}}$$

$$R_{12} = \frac{W_{sc}}{I_{sc}^2}, \quad X_{12} = \sqrt{Z_{12}^2 - R_{12}^2}$$

In Stage 2

Supply to 1, 2 is open, 3 is shorted

$Z_{13} = Z_1 + Z_3$ — (b)

In Stage 3

Supply to 2, 1 is open, 3 is shorted

$Z_{23} = Z_2 + Z_3$ — (c)

$Z_{12} - Z_{23} = Z_1 - Z_3$ and add to Z_{13} $(+Z_{13})$

$= Z_1 - Z_3 + Z_1 + Z_3 = 2Z_1$

$$Z_1 = \frac{1}{2}\left[Z_{12} + Z_{13} - Z_{23}\right].$$

$$Z_2 = \frac{1}{2}\left[Z_{23} + Z_{12} - Z_{13}\right]$$

$$Z_3 = \frac{1}{2}\left[Z_{13} + Z_{23} - Z_{12}\right]$$

Voltage Regulation

Step 1 :- $S_1 = \dfrac{\text{Actual primary kVA loading}}{\text{Base kVA}}$.

$S_2 =$ " $S_3 =$ "

Step 2 :- $\cos\phi_1, \phi_2, \phi_3$ operating p.f & $V_{R1}, V_{X1}, V_{R2}, V_{X2}, V_{R3}$ & V_{X3} pu resistive & reactive drop

Setp 3 : per unit Regulation

$E_1 = S_1 (V_{R1}\cos\phi_1 + V_{X1}\sin\phi_1)$

$E_2 = S_2 (V_{R2}\cos\phi_2 + V_{X2}\sin\phi_2)$

$E_3 = S_3$ (")

Step 4: If regulation for only pair is reqr

$E_{12} = E_1 + E_2$

Rating of teritiary wdg

Rating of one third (35%) of rating of main wdg

* primary, Secondary & tertiary wdgs of 50Hz, 1ϕ, 3 winding tfr are rated at 3.35kV, 5MVA, 1.8kV, 2.5MVA & 440V, 2.5 MVA Respectively. Three short ckt test on this tfr gave following results.

a) primary excited, Secondary shorted 300V, 746.26V.

b) " , Tertiary " .700V, 746.26V.

c) Secondary " Tertiary " 250V, 1388.8 V.

Resistance are ignored

Find the pu values of equivalent impedance of tfr on a 5 MVA, rated voltage Base.

→ 5 MVA be base.

For primary wdg, let $V_{Base} = 3.35$ kV.

$$I_{base} = \frac{\text{Base MVA}}{V_{base}} = \frac{5000}{3.35} = 1492.53\,A.$$

Secondary wdg, $V_{Base} = 1.8$ kV

Embedded, In

$$I_{base} - \frac{5000}{1.8} = 2777.77\,A$$

Cumulative unlomentum & renewb (Solar Sun.)

(1) $V_{pu} = \frac{0.300}{3.35} = 0.895$ pu, $I_{pu} = \frac{746.26}{1492.53} = 0.5$ pu

$Z_{12} = \frac{V_{pu}}{I_{pu}} = \frac{0.0895}{0.5} = 0.179$ pu.

(2) $V_{pu} = \frac{0.700}{3.35} = 0.2089$ pu, $I_{pu} = \frac{746.26}{1492.53} = 0.5$ pu

$Z_{13} = \frac{0.2089}{0.5} = 0.4179$ pu

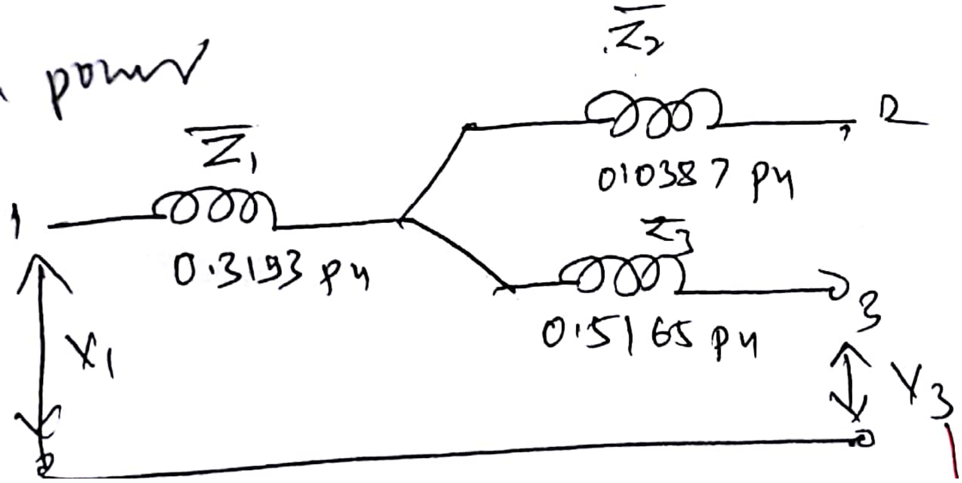
(3) $V_{pu} = \frac{0.250}{1.8} = 0.1388$ pu

$I_{pu} = \frac{1388.8}{2777.7} = 0.5$ pu.

$Z_{23} = \frac{0.1388}{0.5} = 0.2776$ pu.

$\bar{Z}_1 = 0.3193$ pu $\bar{Z}_2 = 0.0387$ pu, $\bar{Z}_3 = 0.5165$ pu

High power



wed
7, 4, 10, 12, 16,
25, 27, 28, 29,
34, 37, 38, 43,
47, 49, 51, 52,

wed
12, 20, 23, 34, 43,

mo
2, 4, 9, 11
17, 19, 22, 2
31, 32, 34
42, 43, 4
49, 50,
53, 54,

Tue (Afternoon)

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DC Generator

Posting

Review of Basic Concept

electrical machine which converts mechanical energy into an electrical energy called generator. A generator producing DC voltage is called a d.c generator.

Principle operation of a DC generator

Dynamically induced emf (principle)

Faraday's law of electromagnetic Induction (principle)

- → Faraday's law of magnetic lines of
- → Statement "whenever the number of magnetic lines of force i,e flux linking with a conductor or a coil changes, an electromotive force is set up in that conductor or coil.
- → Change in flux is present when relative motion betw cond^n & flux.
- → Relative motion achieved by moving coil (flux or flux (cond^n). So emf gets generated in cond^n
- → Such an induced emf is dynamically induced emf.
- → generating action requires following component
  - i) The cond or coil
  - ii) flux
  - iii) Relative motion betw cond^n & flux.

→ In practical generator, cond^c are rotated to cut magnetic flux keeping flux stationary.

→ To have large vtg as output, no of cond^c are connected together in specific manner to form winding (Armature winding).

→ part on which it is kept armature

→ cond^c on Armature are rotated by external device prime mover. (diesel engine, steam engines, steam turbines, water turbines).

→ necessary φ produced by current carrying wdg is field winding

→ Direction of emf induced (Fleming Right hand Rule).

Construction

1) yoke :- outermost cover, mechanical support.
2) poles :- carry field wdg, pole core & pole shoe
3) field winding :- to produce flux for generating action, made up of conducting (copper)

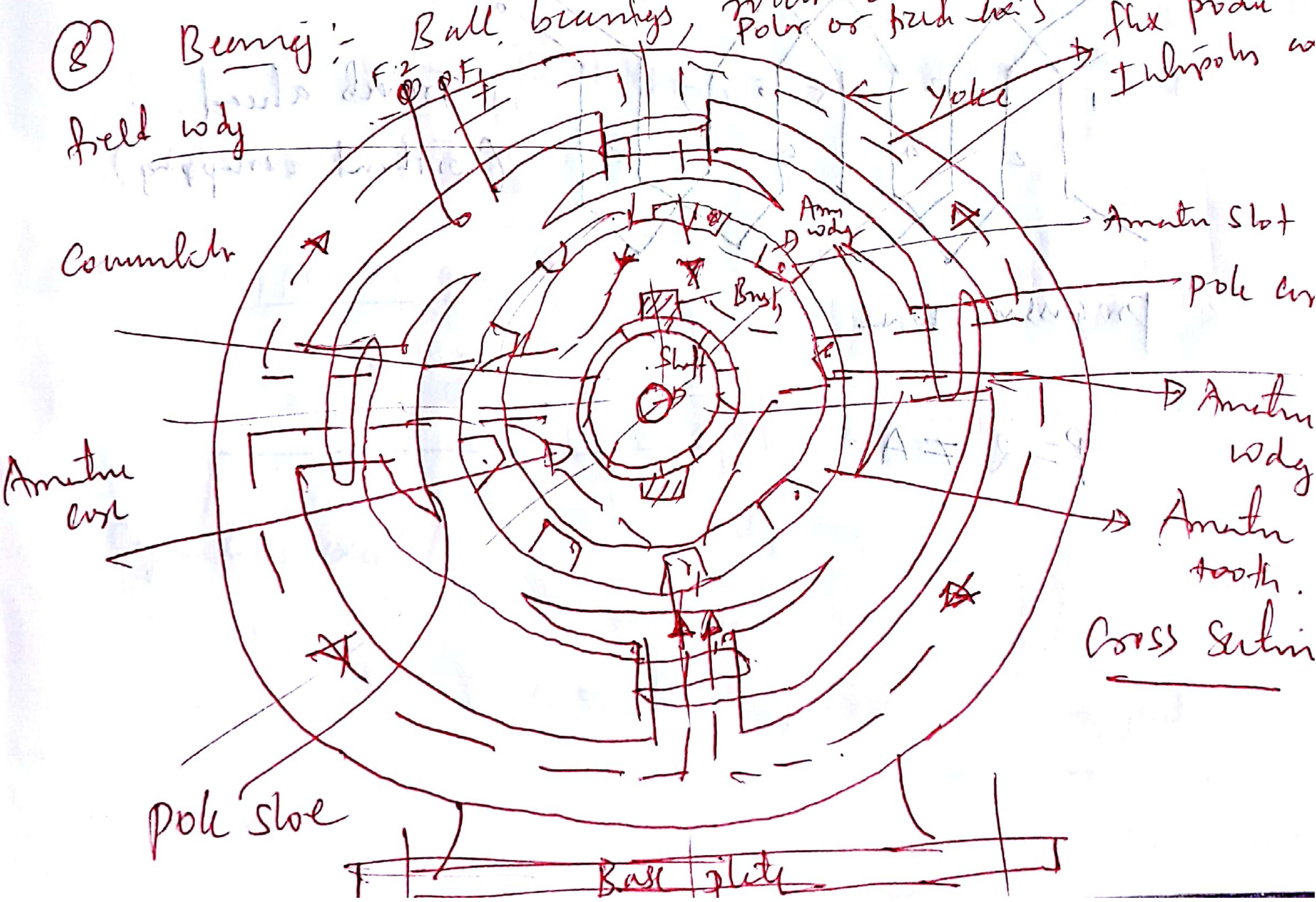
4) Armature core :- Cylindrical & rotating part mounted on shaft. Consists slots on its periphery to hold cond^c. air ducts to provide cooling. Laminations.

(5) Commutator :- Basic nature of emf is alternating, AC to dc. Copper segments & along rotates with armature

(6) Armature winding :- placed in slots, generation of emf takes place in this.

(7) Brushes :- Stationary & resting on surface of commutator collects current, carbon.

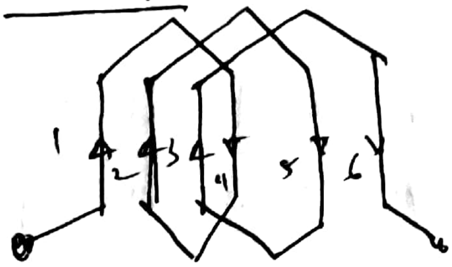
(8) Bearing :- Ball bearings, roller bearing.



Cross Section

Armature wdg

a) lap b) wave



1-start 1-finish (overlapping)

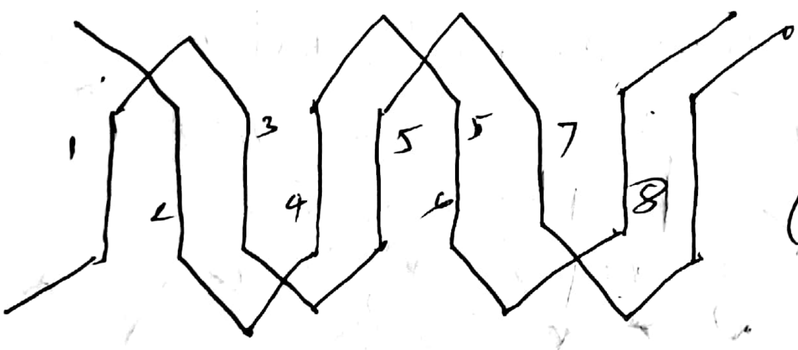
Due to such connection, total no of cond^c gets divided into

'p' no of parallel paths, P = no of poles in m/c.

↓

large → high cur capacity → high cur rating generator

Wave



Travels ahead. (without overlapping).

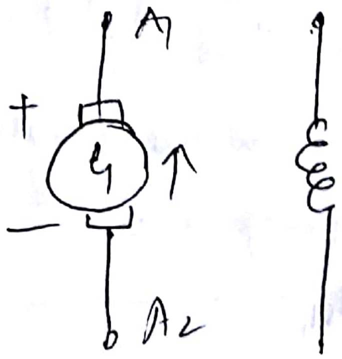
Progressive wave

$P = 2 \neq A$.

Emf equation

$$E = \frac{\phi Z N P}{60 A} \quad (A = P) \; (A = 2)$$

Symbolic Representation of generator

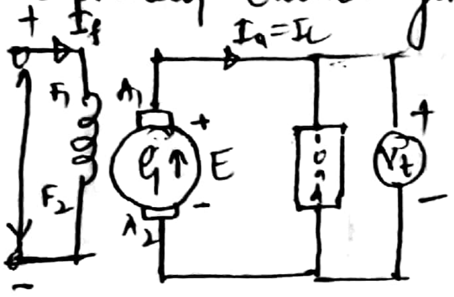
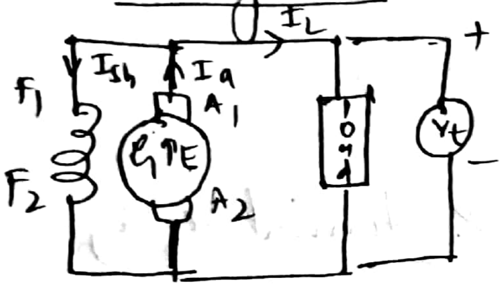
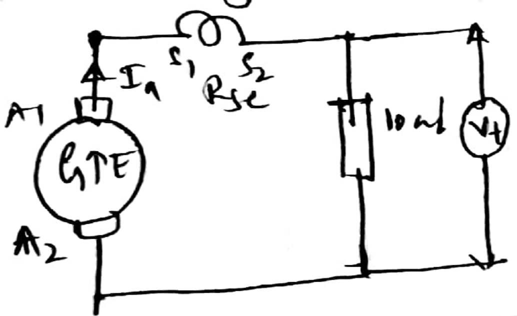
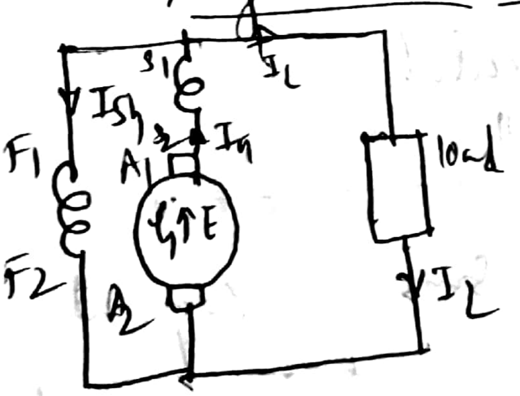


Relation betw no load & terminal voltage

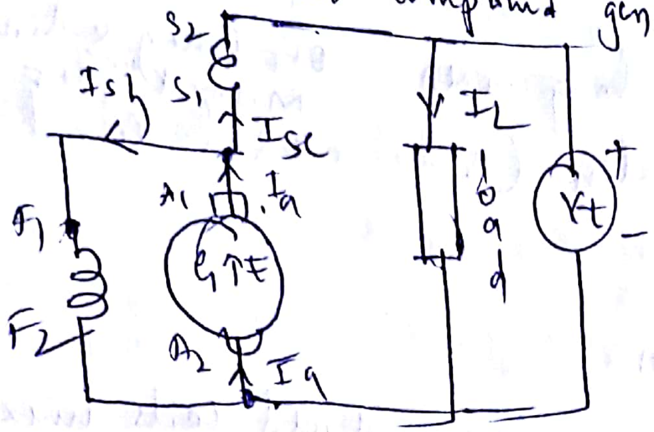
$E = V_t + I_a R_a + V_{brush}$ // — Voltage eqn of dc gen. (Type of gen).

Types of generator

DC gen
- Separately excited
- Self excited
  - Shunt
  - Series
  - Compound
    - long shunt
    - Short shunt

Sr. No	Type of dc generator	Voltage & C/n equations
1)	Separately excited gen 	$I_a = I_L$ $E = V_t + I_a R_a + V_{brush}$
2)	Shunt generator 	$I_a = I_L + I_{sh}$ $I_{sh} = V_t / R_{sh}$ $E = V_t + I_a R_a + V_b$
3)	Series generator 	$I_a = I_{se} = I_L$ $E = V_t + I_a (R_a + R_{se}) + V_b$
4)	long shunt compound gen 	$I_a = I_L + I_{sh}$, $I_a = I_{se}$ $I_{sh} = V_t / R_{sh}$ $E = V_t + I_a (R_a + R_{se}) + V_b$.

5) Short shunt compound gen



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

$$I_{sh} = \frac{E - I_a R_a}{R_{sh}} = \frac{V_t + I_L R_{se}}{R_{sh}}$$

$$E = V_t + I_a R_a + I_L R_{se} + V_b.$$

Power developed in armature $= E I_a$ W

load power $= V_t I_L$ W.

{4, 12, 22, 33, 38, 43, 48, 49, 52, 53,

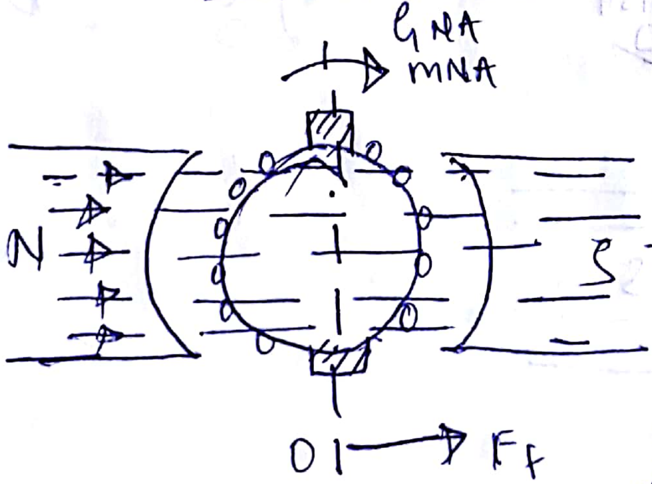
Introduction to Armature Reaction

→ Field flux & Armature flux (load)

→ The effect of Armature flux on distribution of main field flux is called Armature Reaction

Armature flux —
- weakens main flux — Reduce generated
- distort main flux — Sparking at Brushes

Concept of Armature Reaction



→ There is no current in armature conductors.

→ Polar axis
left to Right (flux)
parallel to field axis.

- MNA (no emf induced axis)
- GNA (axis of symmetry b/w poles)

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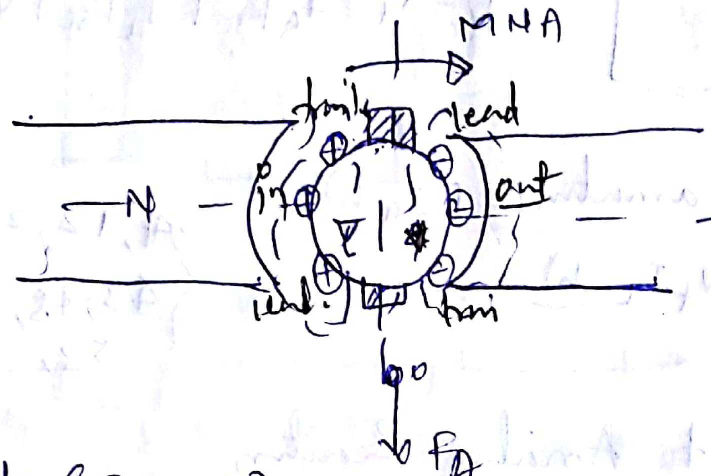
→ Brushes always kept along MNA. Field mmf OFF (mag & direction)
MNA ⊥er OFF

→ MNA — axis of commutation (since reversal current takes place along the axis)



Field coils unexcited armature carry current.

→ Current (FRHR)

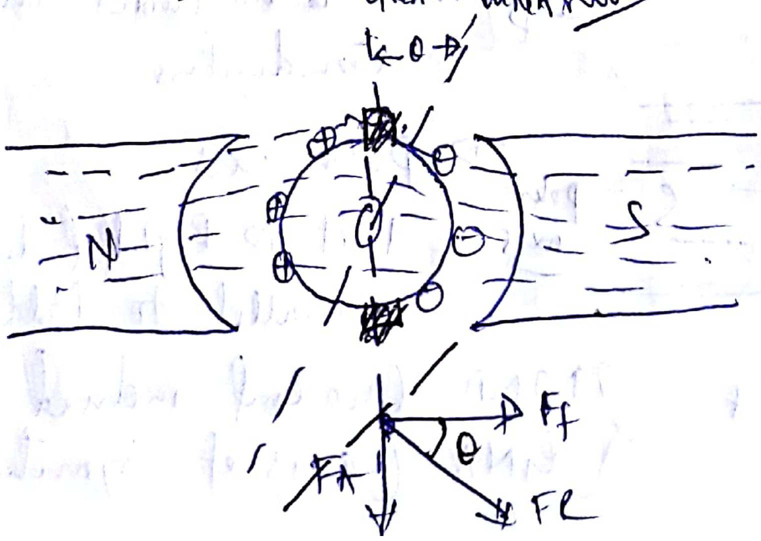
N pole (c/n downwards), S pole (c/n upwards).

→ flux direction downwards (symmetrical along brush axis)

try to magnetise core along brush axis (OFA).

→ This mmf depends on magnitude of armature c/n. Armature mmf (mag & direction)

→ field mmf & armature mmf exists simultaneously (OFA & OFf).



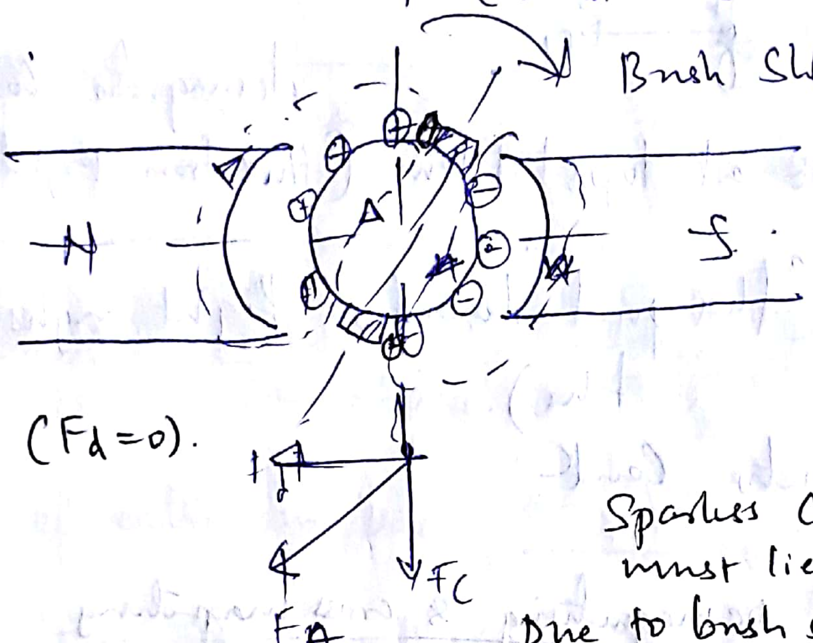
→ flux through armature is not uniform & symmetrical gets distorted. Due to interaction

→ flux crowded at trailing pole tips (Counter rotation) but weakened at leading pole tips.

→ Resultant mmf OF_R — OF_f & OF_A

→ new position of MNA ⊥^r to OF_R (θ) brushes

→ Due to brush shift (cond^c as well as Chg is redistributed)



$\theta = 0$ ($F_d = 0$).

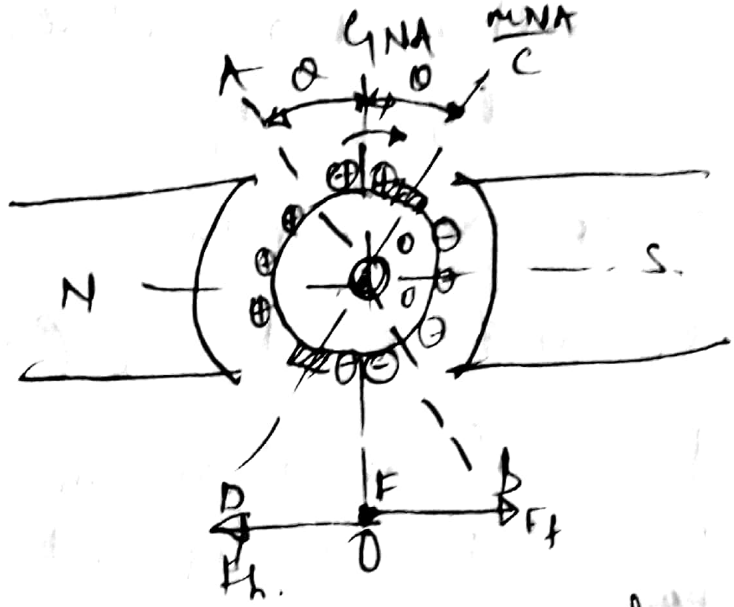
Sparkless commutation brush must lie on MNA.

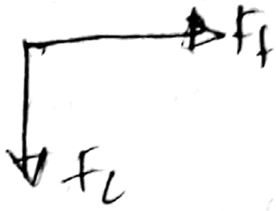
Due to brush shift (mmf F_A) Becoz some of cond^c change

→ Armature mmf is along New MNA (Inclined at θ) vertical.

→ OF_A → OF_d (→ demagnetising — Reduce total flux; OF_C — Crossmagnetising — distortion ↑ I_a.

Demagnetising & cross magnetising Cond





demagnetis cond"

AOC = BOD = 2θ at top & bottom (Flux from Right to left)

AOD & BOD (flux point downwards Right angles to main flux).

Cross magnetis Cond

Calculation of Demagnetising & cross magnetising

∴ total no of arm Cond lying in Angles (AOC & BOD) $= \frac{4\theta_m}{360} \times Z$

total no of turns in these Angles $= \frac{1}{2}\,\frac{4\theta_m}{360}\,Z = \frac{2\theta_m}{360} \times Z$

Demagnetising amp-turns $= \frac{2\theta_m}{360} \times IZ$

(D) " /pole $= \frac{\theta_m}{360} \times IZ$

$$AT_d / pole = ZI \times \frac{\theta_m}{360}$$

Total arm - cond^c / pole = Z/p

Demag cond^c / pole = $\frac{2\theta_m}{360} \times Z$

Cross magnetizing cond^c / pole = $\frac{Z}{P} - Z\frac{2\theta_m}{360} = \left[\frac{1}{P} - \frac{2\theta_m}{360}\right] Z$

" Amp " = $ZI\left[\frac{1}{P} - \frac{2\theta_m}{360}\right]$

Indigo

666 AT_c (∵ Amp-turns) / pole = $ZI\left[\frac{1}{2P} - \frac{\theta_m}{360}\right]$

$$\theta_{mech} = \frac{\theta_{elect}}{\text{pair of pole}} = \frac{\theta_{elec}}{P/2} = \frac{2\theta_e}{P}$$

No of extra turn / pole = $\frac{AT_d \lambda}{I}$ λ = leakage coeffien

I = Arm cond^c $Cl_n = I_{sh}$, $I = I_g$

By adding in field wdg

Problems

A 8 pole wave wound dc gen has 480 arm cond^c. The armature current is 200 A. Find the Armature reaction demagnetizing and cross magnetizing amp turns / pole if i) brushes are on GNA ii) brushes are shifted 6° elec from GNA

1) $\theta_m = 0$ AT_d / pole = 0, AT_c / pole = 3000

2) $\theta_m = 1.5°$, " = 200 " = 280

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* The brushes of lap connected 400 kW, 6 pole gen are given a lead of 21 elec. Calculate

i) ATd/pole (2187.5) ii) ATc/pole (7187.5) iii) series turns required to balance demagnetizing component → 4.08 = 4

The F.L Cu is 750A & Z = 900 & λ = 1.4.

Ia

i)

* ~~Z = 480, I~~

* A 6 pole, 148A ds shunt gen has 480 Cond^c & is wave wound. If field Cu is 2A.

find ATd/pole & ATc/pole at F.L ~~ff~~. Ia = 150A; I = 75A

i) Brushes at GNA

ii) " from GNA 5° elec

iii) from GNA 5° mech

4, 12, 14, 33,

Expression

Expression of Reactance voltage

emf induced

W_b = brush width, W_m = width of mica insulation

V = peripheral velocity of commutator segment.

$$T_c = \frac{W_b - W_m}{V}$$ (time reqr for commutation).

Self Induced voltage = Coefficient of self inductance × Rate of change of Cu.

Self Induced voltage $= L \times \frac{2I}{T_c}$ (Linear commutation)

Self Induced voltage $= 1.11 \times L \times \frac{2I}{T_c}$ (Sinusoidal commutation)

L = coefficient of self Inductance

T_c = Time of commutation

if W_b is given in cm & commutator Dia D_c is given in cm then velocity V is obtained in cm/s

as $V = \frac{\pi D_c N}{60}$ cm/s

* A 4 pole lap wound armature running at 1500 rpm. delivers a current of 150A and has 64 commutator segments. The brush spans 1.2 segments and inductance of each armature coil is 0.05 mH. Calculate the value of reactance voltage Assuming i) linear Commutation ii) Sinusoidal Commutation neglect mica thickness

→ $I = 150A$, $N = 1500$ rpm, $\omega_b = 1.2$ seg, $\omega_m = 0$

$L = 0.05mH$, 64 seg

total 64 segment.

Calculate peripheral speed in seg/sec as ω_b in seg

$$n_s = \frac{1500}{60} = 25 \text{ rps}$$

In one revolution, 64 seg get covered,

V = peripheral speed in seg/second

= No of revolution per sec x total seg on commutator

$= 25 \times 64 = 1600$ seg/sc

$$T_C = \frac{\omega_b - \omega_m}{V} = \frac{1.2 - 0}{1600} = 7.5 \times 10^{-4} \text{ sec}$$

$$I = \frac{I_L}{A} = \frac{150}{4} = 37.5 \text{ A}$$

linear, $E = L \times \frac{2I}{T_C} = 0.05 \times 10^{-3} \times \frac{2 \times 37.5}{7.5 \times 10^{-4}} = 5V$

Sinusoidal, $E = 1.11 \, L \times \frac{2I}{T_C} = 1.11 \times E = 5.53V$

Scanned by CamScanner

* Calculate E_R : $N = 900$ rpm, No of commutator seg = 55, $W_b = 1.74$, coefficient of self induction = 153 μH, Assume linear commutation & neglect mica thickness. Current in each coil = 27 amps.

→ $N = 900$ rpm, $L = 153\ \mu H$, $I = 27A$, $W_b = 1.74$

V = peripheral speed in seg/sec

= (Rev/sec) × commutator seg

$= \frac{900}{60} \times 55 = 825$ seg/sec

$T_C = \frac{W_b - W_m}{V} = \frac{1.74}{825} = 2.109$ ms

$E = L \times \frac{2I}{T_C} = \frac{153 \times 10^{-6} \times 2 \times 27}{2.109 \times 10^{-3}} = 3.91175\ V$

True
2, 4, 7, 9, 10, 11, 12, 17, 28, 30, 34, 37, 39, 41, 42, 43, 46, 47, 48, 49, 51, 52, 55

* Determine E_R (linear commutation)

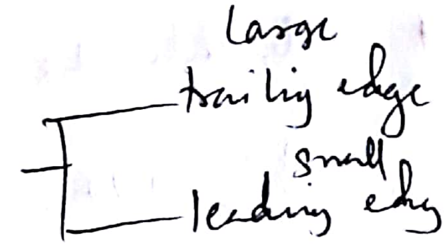
$L = 0.15$ mH, $I = 40$ (per conductor), Brush span: 3 seg, No of commutator seg = 50, $N = 600$ rpm

2V.

True (After)
1, 2, 9, 10, 11, 12, 16, 18, 25, 28, 30, 34, 37, 40, 43, 48, 49, 51, 53, 55

Non-linear commutation

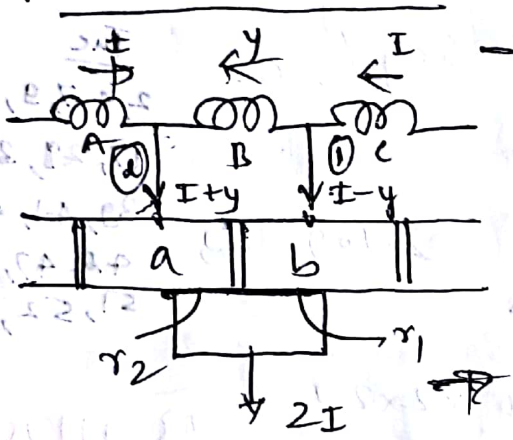
→ Retarded commutation — Cu density



accelerating commutation — " "

Sinusoidal commutation —— It is desirable to retard the commutation during initial moments and to accelerate it at later stage (sinusoidal curve)

Resistance commutation



$r \propto 1/a$

→ low resistance cu brushes are replaced by high resistive carbon brushes

→ Cu I from 'c' two paths (b) & (B & a)

→ low resistive cu brush the Cu will not prefer second path as it will prefer (1) path. (low resistance). $r_1 \simeq r_2$

→ As using carbon brush Cu will select second path $r_1 > r_2$ $(a_1 < a_2)$

→ quick reversal of Cu.

Advantage

1) self lubricating and polish commutator

2) Damage to commutator will be less

Disadvantages

1) loss of 2 volts
2) commutator made longer for heat dissipation

Synchronous generator

3, 10, 12, 16, 33, 43, 46, 48, 49.

(I) Review of synchronous generator
a) Advantage of Rotating field
b) Construction

(II) Working principle
a) Mech and Electrical Angle
b) frequency of induced emf
c) Synchronous Speed (Ns)

(III) Three phase Armature winding in Synchronous generator
a) winding terminologies
b)

(IV) Types of Armature windings ✓
a) Single & double layer wdgs
b) full pitch and Short pitch winding
1) Coil span
2) Advantages of short pitch Coils
c) Concentrated & distributed windings

(V) Emf Equation of Alternator ✓
a) pitch factor or coil span factor (k_c)
b) Distribution factor (k_d)
1) Derivation of Distribution factor

(~~VI~~) - ~~Harmonics~~
c) Generalised Expression of Emf Eqn of Alternator

28

e) line value of Induced EMF

(VI) Harmonics

a) Slot Harmonics

b) Harmonic minimization

(VII) Effect of Harmonic Components on Induced Emf

a) Effect of Harmonic Component on Kp

b) " on Kd

c) Total Emf generated due to Harmonic components

(VIII) Parameter of Armature winding

(IX) Armature Resistance

(X) Armature leakage Reactance

(XI) Armature Reaction

a) upf load

b) zero lag p.f load

c) zero lead p.f load

d) Armature Reaction Reactance (Xar)

(XII) Concept of synchronous Reactance & Impedance

(XIII) Equivalent ckt of Alternator

Scanned by CamScanner

12, 33, 39, 52, 53, (55)

(A) ac m/c syn gen, Difference betn DC & AC gen

(a) large emf developed in armature (space, condn, insulatn)

b) protected from mech and electrical stresses

c) easier to collect large heavy ckt

d) problem of sparking get avoided at slip Ring

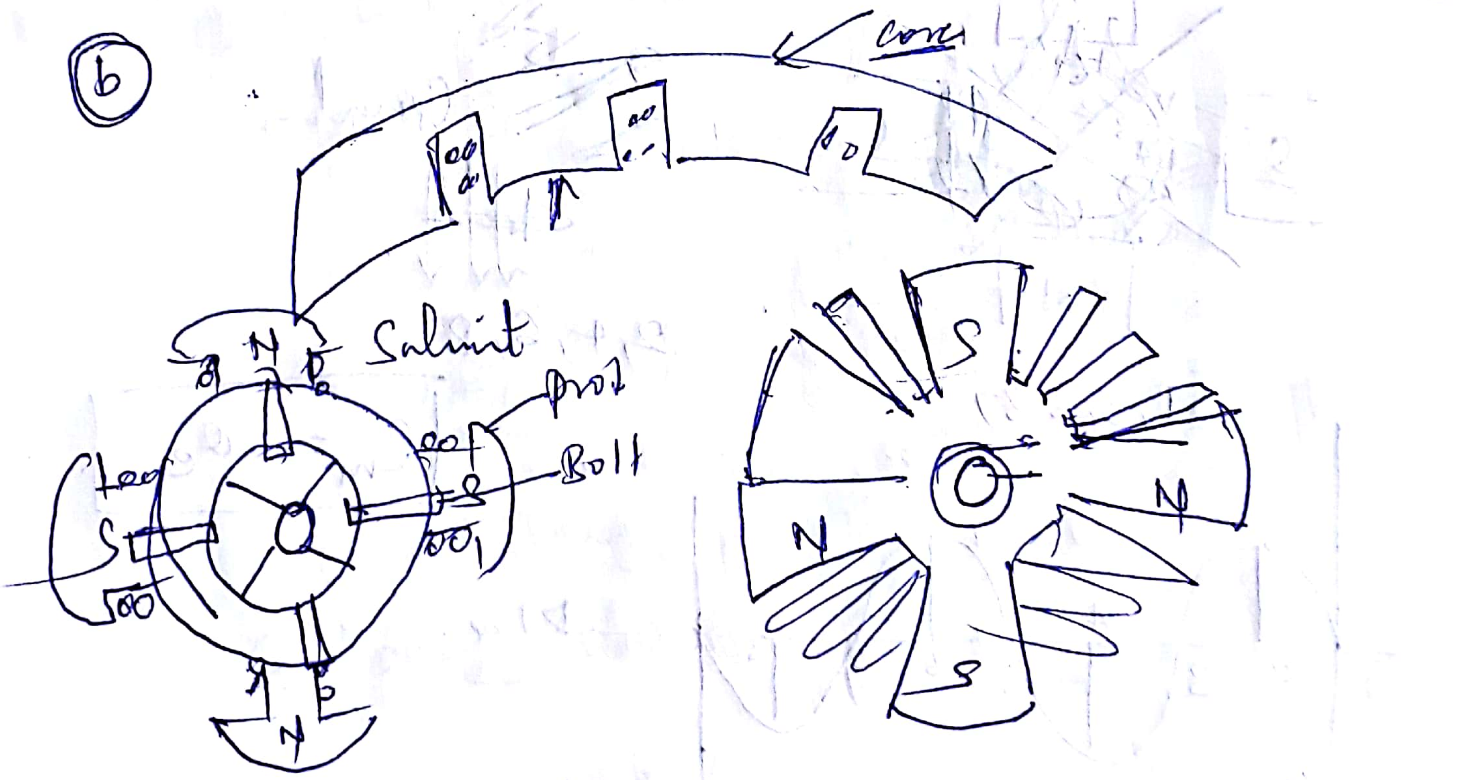
e) field low inertia circuit easy to rotate

f) overall construction is simple armature stationary

g) only two slip Rings are needed for field

h) ventillation improves due to stationary armature

(b)

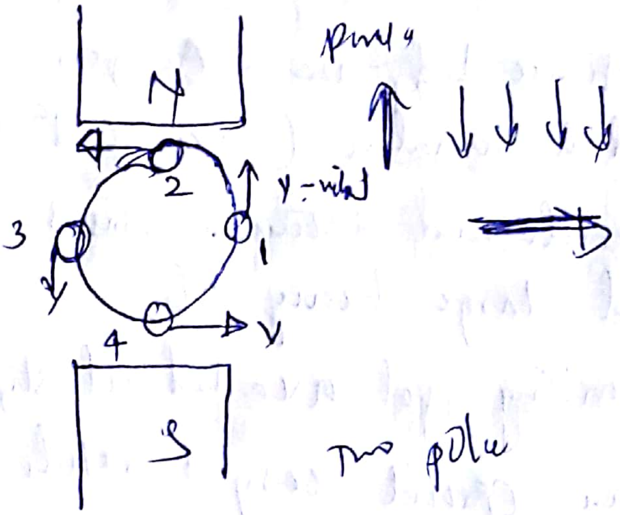


Salient → large dia & short axial length, low speed alternator

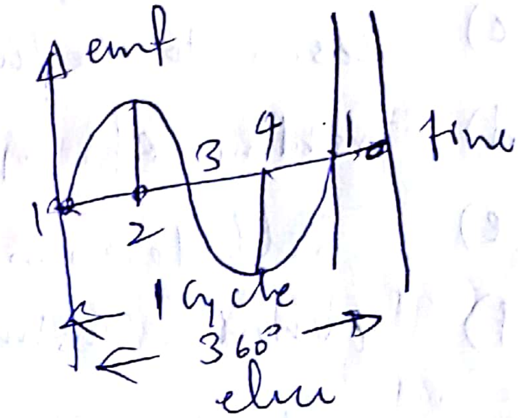
30

Non-salient → small dia & " high.

(II)



velocity ⊥er to flux

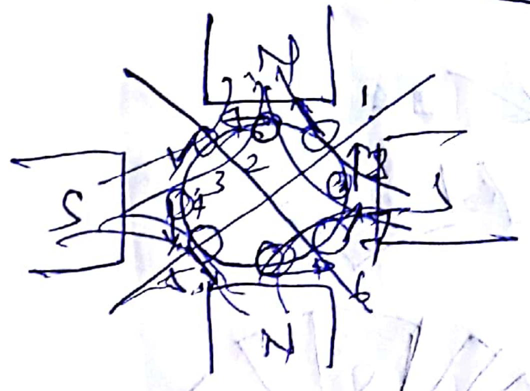


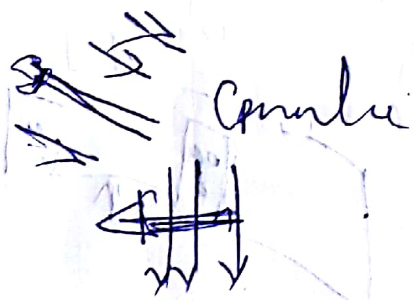
$360° \text{ mech} = 360° \text{ elect} \times \frac{P}{2} \text{ elec}$

$1° \text{ mech} = (P/2)° \text{ elec}$

Alternating nature of emf induced

(a)

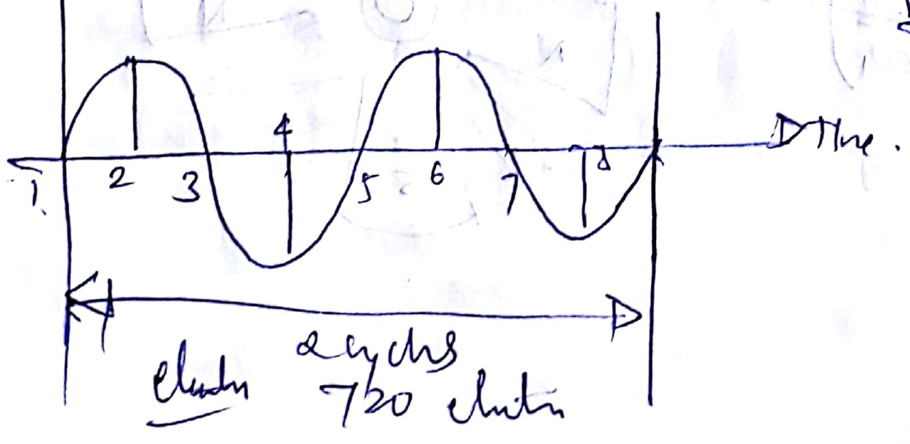




2, 4, 6, 8

1, 3, 5 & 7

$\theta_m = 2\theta_e$



(b)

freq = Cycles/sec C/R × R/sec

= No of cycles per rev × No of rev per sec

$= \left(\frac{P}{2}\right) \times \frac{N}{60} = \frac{PN}{120}$ IIIy cycles/sec

(c) $N_s = \frac{120 f}{P}$ → std

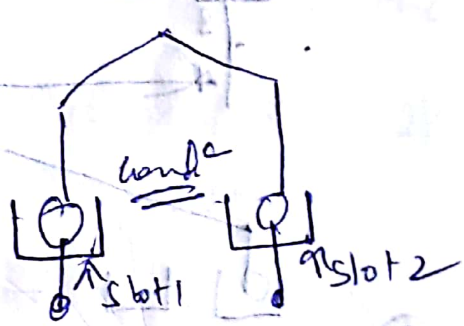
2 - - - - 24

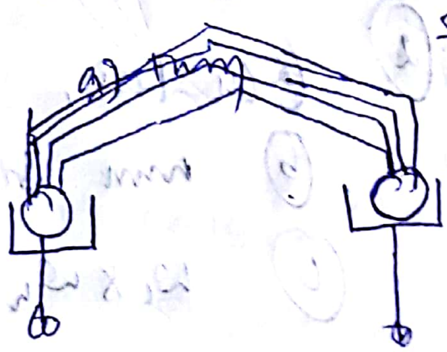
1,2,14,23,40, ~~47, 48~~, 49, 53, (3000) — min — 250

III $e_R = E_m \sin \omega t$, $e_y = E_m \sin(\omega t - 120°)$, $e_B = E_m \sin(\omega t - 240°)$

E_{ph}, (Coils each phase helps emf) → sums

(a) ① Conductor
② Turn
③ coil
④ coil side
⑤ pole pitch



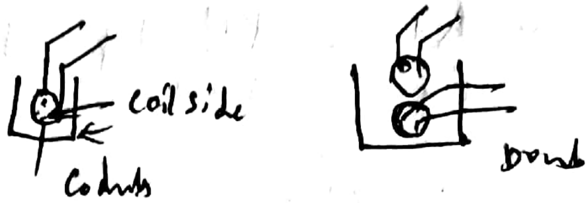


η = slots/pole = 180° elec = η.

32 (6) Slot angle (β)

$$\beta = \frac{180^\circ}{n}$$

(14) (a)

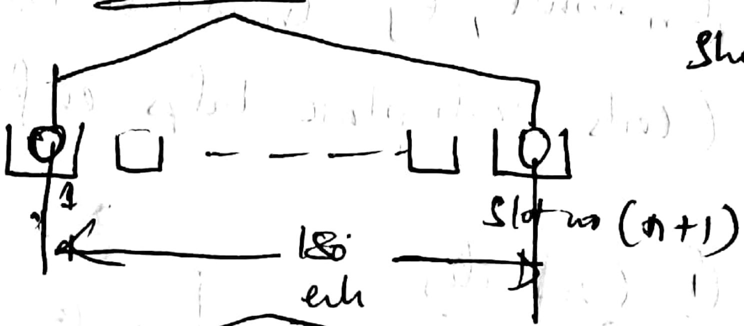


Space wasted in single layer   Double layer used

(b) 2 pole, 18 slots, $n = \frac{18}{2} = 9$. (1 to 10)

$\Rightarrow 180^\circ$

(i) coil span



Short pitch or fractional pitch coil

(2) (a) Cu less, economical

(b) non sinusoidal

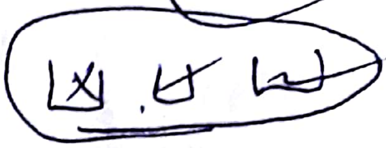
(c) weaker reduces, $\eta \uparrow$.

① Slots per phase per pole (m) =

$m = n/p = n/3$ · $18/2 = 9$

$m = 3$

× Conductors



Sinusoidal, heat dissipation poor

② **Emf eqn**

consider one cond^n in slot

$e_{avg} = d\phi/dt$

for one revolution $e_{avg} = \frac{\text{flux cut}}{\text{time taken}} = \frac{P \times \phi}{60/N_s}$

$= \phi \times \frac{P N_s}{60} = 2f\phi$

$e_{avg}(\text{cond}) = 2f\phi$ V.

full pitch $e_{avg}(\text{turn}) = 2 \times (2f\phi) = 4f\phi$.

Concentrating, $E_{ph} = T_{ph} \times e_{avg}(\text{turn})$ $T_{ph} = \frac{Z_{ph}}{2}$

$K_f = \frac{\text{Rms}}{\text{avg}} = 1.11$

Basic emf eqn for avg [illegible]

$E_{ph}(\text{rms}) = 1.11 \times 4 f\phi T_{ph} = 4.44 f\phi T_{ph}$