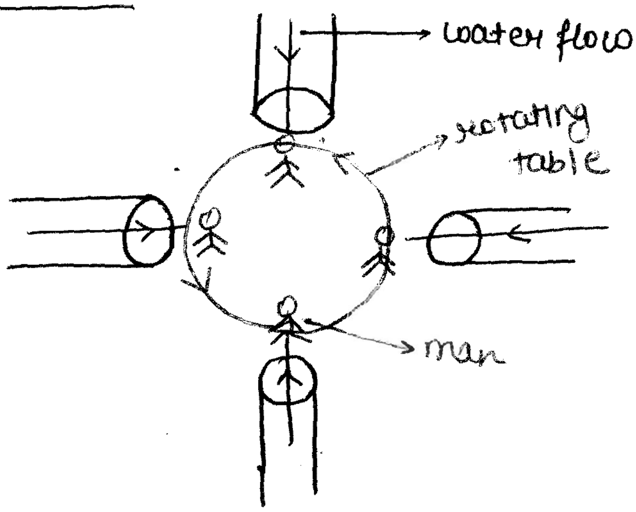
MADE EASY
SYNCHRONOUS MACHINE
By- RAJAN ROY SIR

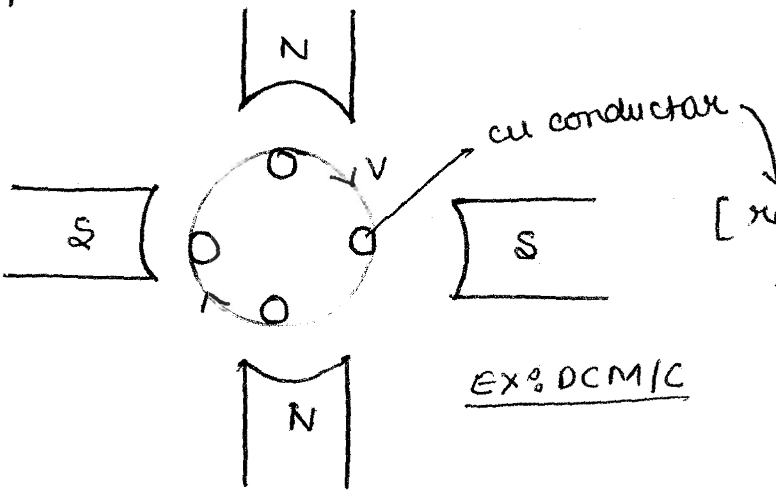
- Theory
- Explanation
- Derivation
- Example
- Shortcuts
- Previous Years Question With Solution

Introduction :-



[we will feel rate of change of water]

similarly



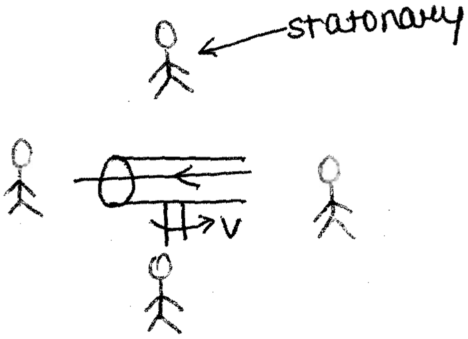
[rate of change of flux linkage]

⇓

EMF ⇒ I

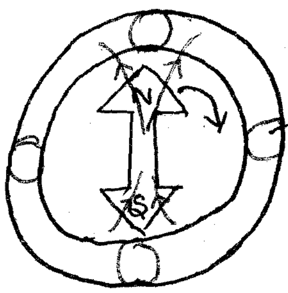
Ex: DC M/C

Ex-:



[we feel rate of change of water]

Analogy : Now conductor is at stationary [cu]



[rate of change of flux linkage]

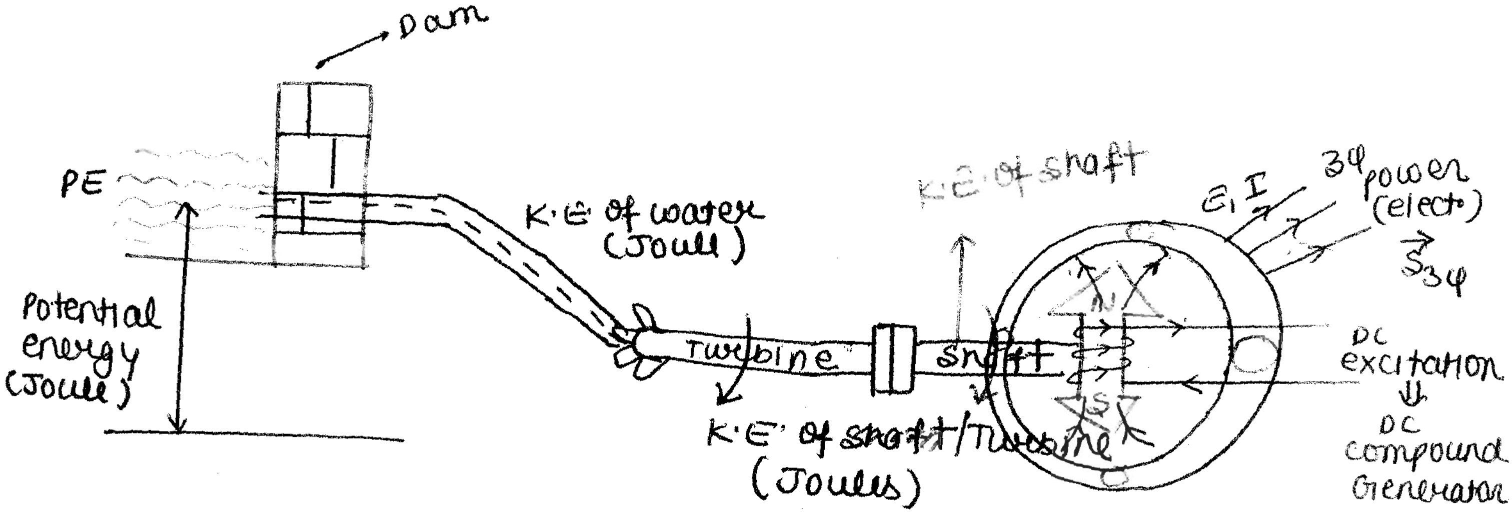
Ex-: synchronous M/C

weight ↑ ⟶ stationary (knife + vegetable)   weight ↓ ⟶ movement (Arman spoon + vegetable)

m/c rating ↓ (600V) then conductor weight ↓. then movement will be done of conductor in DC M/C.

In S/M rating ↑ then weight of conductor ↑ then conductor will be stationary.

Shimla



$\vec{S}_{3\varphi} = P + jQ$

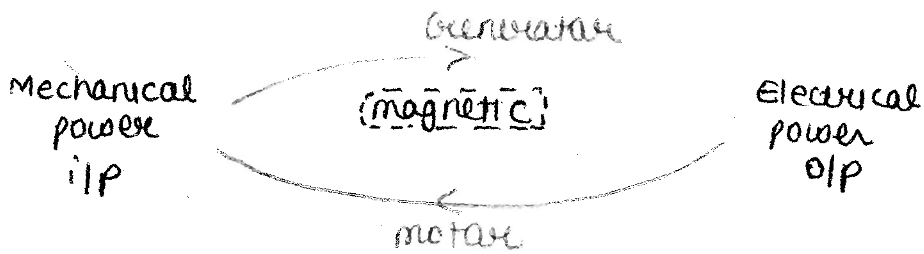
P → Real; Q → Imaginary

P (Real power) ⇒ watt or Joule/sec

magnet ⟶ conductor relation with flux lines which is imaginary.

DC excitation is used for flux setup in S/M.

Active power ⟶ Mechanical power ⟶ Electric power with the help of flux only.



Synchronous M/C

Stationary	Rotating
→ Stator	→ Rotor
→ Armature winding on Stator.	→ Field winding (DC) on Rotor.
→ Armature winding in which load current flows.	→ with the help of field windg to set up flux.

Advantages of stationary armature winding :-

245 MVA, 3φ, 15.75 kV (Armature windg)
DC winding : 310 V, 2600 DC current

(i) Easier to insulate high voltage winding.
(ii) No centrifugal force on stationary armature.
(iii) 3-φ power can be directly tapped from alternator through solid conductors i.e; no slip rings and brushes are required hence losses are reduced
(iv) Cooling of armature is easier.

Advantages of Rotating winding :-

(i) As power required for field winding is less as compared to armature winding so size will be less & hence inertia will be lesser and easy to rotate at high speed.
(ii) In DC supply only two slip ring are require.

Main reason of stationary armature is high current
Explanation :- As current ↑ ⇒ Heating ↑ ⇒ conductor + insulator get expand.

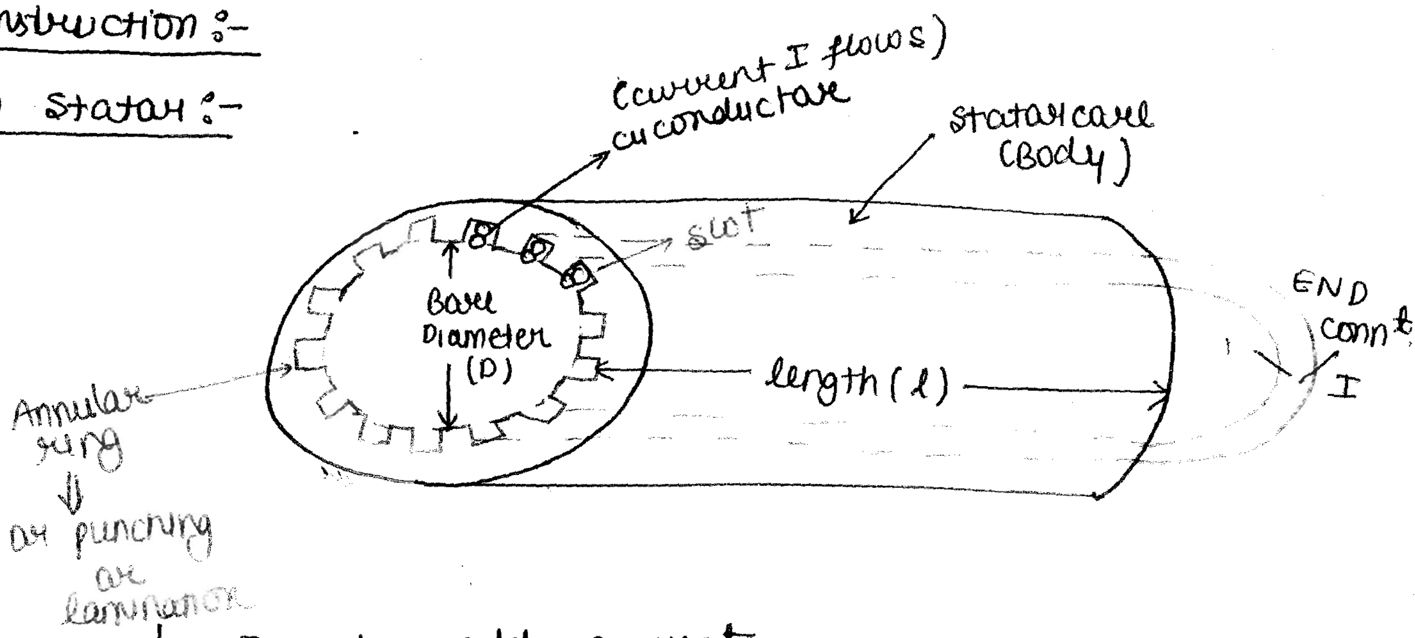
As current ↓ ⇒ Heating ↓ ⇒ conductor contracts but insulation will not contracts with same rate.
⇓
There is air gap b/w conductors and insulator

if conductor rotates then due to centrifugal force this gap increases and become non-uniform. Hence flux waveform becomes distorted. ⇒ EMF full of harmonics
⇓
Harmonic current
⇓
Heating (RMS value)
⇓
Rating ↓ ⇐ equipment Temperature rise ↑

So, stationary armature is require.

Construction :-

(i) Statar :-

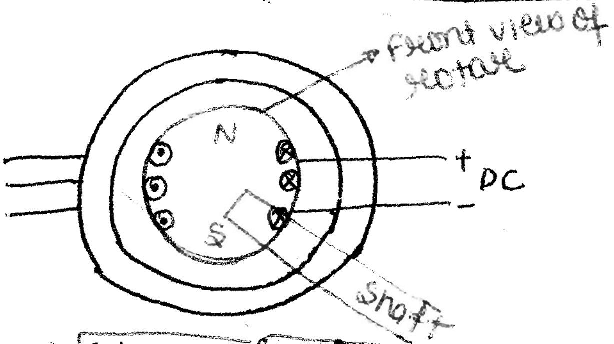
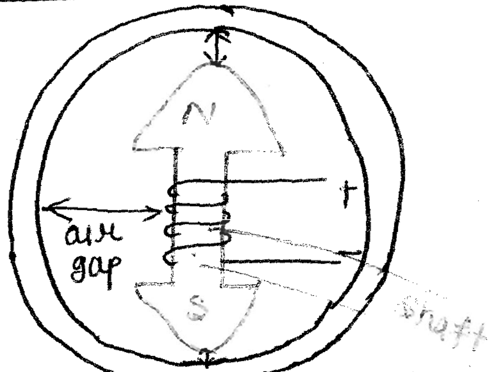


└→ To reduce eddy current

Statar core ⇒ cold rolled non-grain oriented Si - steel lamination
⇓
because amount of φ is more in S/M

A statar core consist of a stack of slotted ring shape lamination. When these laminations are stacked and bolted together, a cylindrical core results with axial slots on its inner surface.

(ii) Rotar :-

cylindrical rotar	Salient pole rotar (project outward)
(i)  → air gap uniform	(i)  → air gap is non-uniform
(ii) High speed alternatar. Ex :- Turbo alternatar ⇓ Steam power plant (High energy then High speed)	(ii) Low or medium speed alternatar. Ex :- Hydro alternatar ⇓ Water (less energy then less speed)

(iii) N_S = synchronous speed

$$\uparrow_{(a)} N_S = \frac{120 f}{P \downarrow_{(b)}} \text{ rpm}$$

f = frequency of supply

P = poles on m/c

(iv) P↓ then ⇒ Diameter ↓ ⇓ length ↑

$$\text{power} \propto \downarrow_{(a)} D^2 \, l \uparrow_{(b)} N_S$$

→ To maintain power

(v) N_S ↑ ⇒ the material which is used is used solid steel (Ni + Cr + Mo) [To sustain the higher speed]

eddy current ↑↑

(vi) Rotor winding is distributed ($\frac{2}{3}$ rd space) so less space left ($\frac{1}{3}$ rd).

Hence no damper winding is used. [due to less space]

So, eddy current damping is used to eliminate hunting.

(iii) $$\downarrow_{(a)} N_S = \frac{120 f}{P \uparrow_{(b)}}$$

(iv) P↑ then ⇒ Diameter ↑ ⇓ length ↓

$$\text{power} \propto \uparrow_{(a)} D^2 \, l \downarrow_{(b)} N_S$$

→ To maintain power

(v) N_S ↓ ⇒ the material which used is steel (laminations) eddy current ↓

(vi) Damper winding is used in rotor pole. To reduce effect of hunting and stabilizes rotor. Rotor winding is concentrated.

Q.N:- For generation sinusoidal shape (cosine function) is preferred?

Answer:- Two reason:-

(i) Revolving magnetic field by sinusoidal wave shape, w

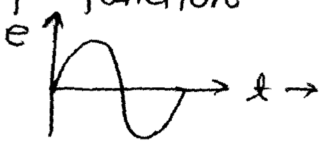
(ii) It can be represented by Phasor. Hence easy to analyse

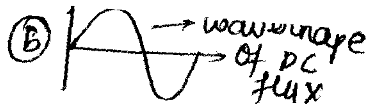
NOTE-:

$E \propto \frac{d\varphi}{dt}$ → then it will be also cosine function.

↓

cosine function





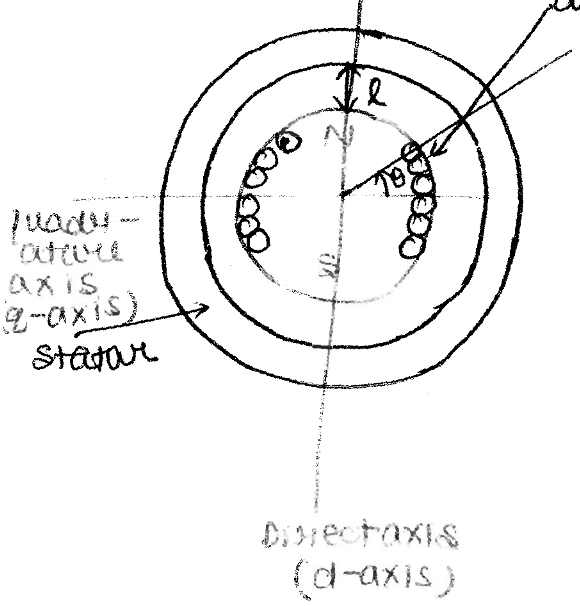
But in rotor we give DC supply in S/M. [so w.r.t. flux will not change]

Then how we get (B) waveform waveshape.

How as flux in rotor produces sinusoidal dc waveshape in air gap.?

⇒ For cylindrical rotor :-

$\varphi = \varphi_m \sin\theta$ where θ = angle in space



$$\varphi = \frac{mmf}{Reluctance} = \frac{N I_{dc}}{(1/\mu)\frac{l}{a}}$$

N = No. of turns in rotor winding = constant

I_{dc} = constant

l = constant } reluctance constant

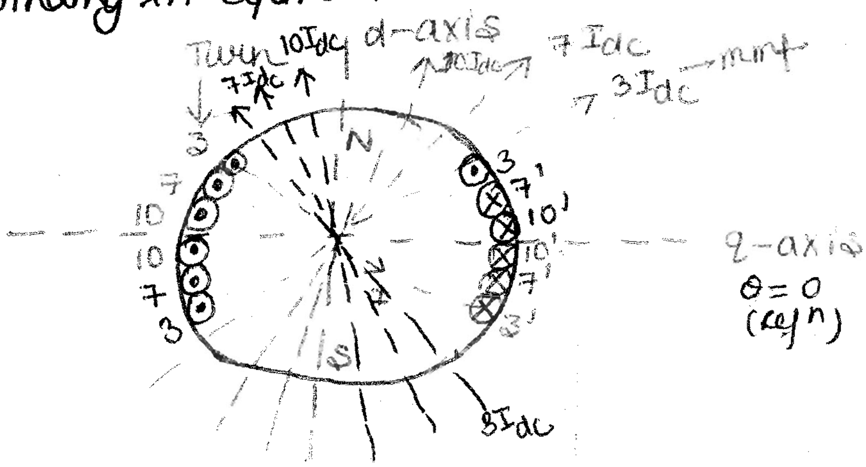
a = Area = constant

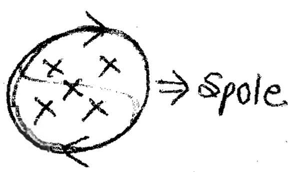
then φ = constant but we need cosine waveshape.

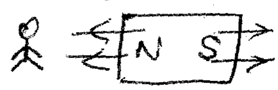
so, to get sinusoidal dc waveform in space, as $\varphi \propto N I_{dc}$ because Reluctance & I_{dc} = constant

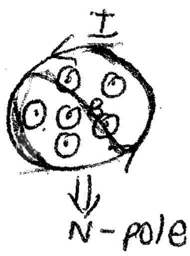
Now, $\varphi \propto N$ so, we are in distributed winding.

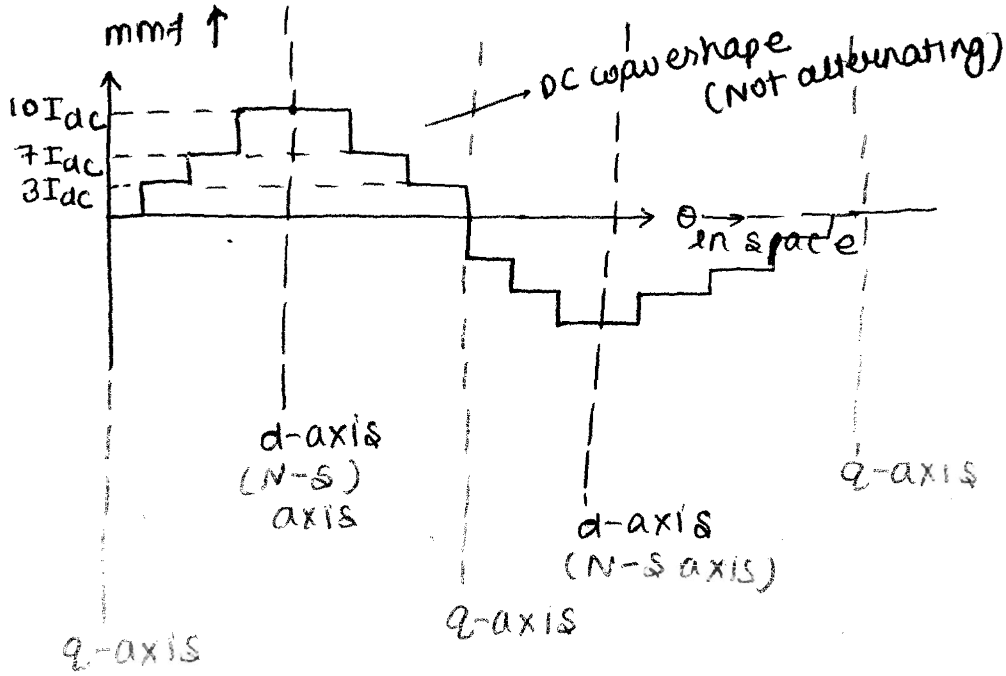
Distributed winding in cylindrical rotor :- $\varphi \propto N$





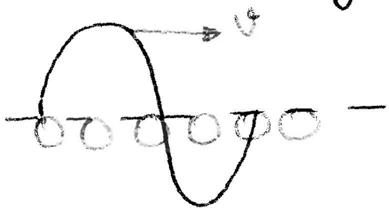


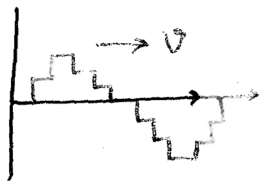




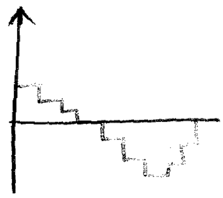
जलेबी
↳ sinusoid wavesh but no alterna

when rotor start rotating then we get alternating mmf then e = sin. wave





@ t=0 ⇒ mmf=0



at t=0 ⇒ mmf = peak w.r.t. stator conductor

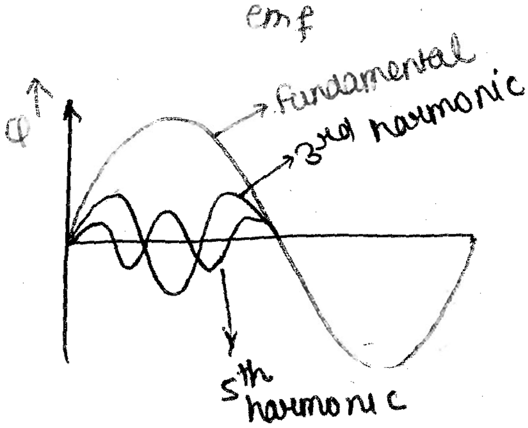
mmf wave : odd + Half wave symmetric
then all sine term with odd harmonic.

$$\text{mmf} \Rightarrow \varphi \text{ in space} = \varphi_1 \sin\omega t + \varphi_3 \sin 3\omega t + \varphi_5 \sin 5\omega t + \cdots$$

$\varphi_1 \sin\omega t$ ⇓ Fundamental; $\varphi_3 \sin 3\omega t$ ⇓ 3rd harmonic; $\varphi_5 \sin 5\omega t$ ⇓ 5th harmonic

$$E \propto \frac{d\varphi}{dt} = E_1 + E_3 + E_5 + E_7 + \cdots$$

E_1 ↓ Fundamental emf; $E_3 + E_5 + E_7 + \cdots$ ↓ harmonic in emf



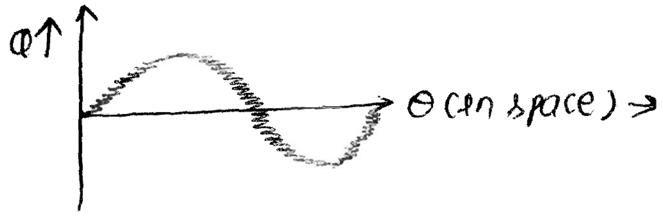
NOTE :- order of harmonic ↑ ⇒ ω ↑ & magnitude (amplitude) ↓

n = 1, (3, 5, 7), 9 - - - → Higher order harmonic

1 → Fundamental

(3, 5, 7) → Dominant harmonic

Along with fundamental, harmonics are also present in flux which can cause harmonics in induced emf also. To reduce these harmonics in flux no. of steps should be more. In ideal case it should be infinite which is not possible. Hence we reduce harmonics in induced emf but not in flux.



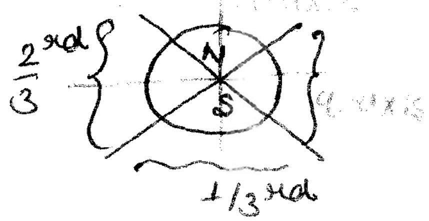
Distribution ↑ ⇒ step ↑
⇓
sinusoidal
i.e, Harmonics ↓

⇒ No. of turns in rotor is maximum near quadrature axis.

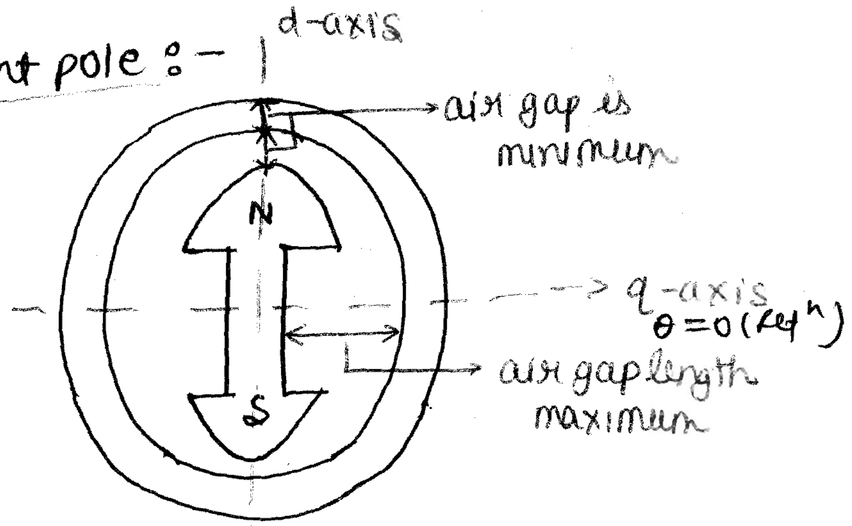
⇒ No. of turns is zero at direct axis.

⇒ winding in rotor lies in $\frac{2}{3}$rd area

⇒ Poles (N & S) are lies in $\frac{1}{3}$rd area



⇒ For salient pole :-



$$\varphi = \frac{mmf}{Reluctance}$$

$$\varphi = \frac{N I_{dc}}{\frac{1}{\mu}\frac{\ell}{a}}$$

$$\varphi \propto \frac{1}{\ell}$$

φ → To get cosine function

$\frac{1}{\ell}$ → So, By profiling face of rotor pole vary air gap length so that flux will have cosine function.