PART-B

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1. Derive the equation of a three phase Induction motor :-

Output Equation of AC Machine :-

The equation of Induced emf frequency current through each conductor on total number of armature conductor of an ac machine are the Induced emf per phase.

$$E_{ph} = 4.44 \phi T_{ph} k_{ws}$$

The Frequency of Induced Emf

$$f = \frac{Pn_s}{2}$$

The current through Each conductor.

$$I_z = \frac{I_{ph}}{a}$$

$$I_z = I_{ph}$$

where I_{ph} - current per phase.

a - no. of. parallel path per phase.

Total no. of. armature conductors.

$$Z = \text{no. of. phase} \times 2T_{ph}$$

Specific Magnetic loading, $B_{av} = P\phi / \pi DL$

Specific Electric Loading $ac = I_z Z / \pi D$

Consider a 3ϕ machine,

$$Q = 3 E_{ph} I_{ph} \times 10^{-3}$$

$$Q = 3 [4.44 f \phi T_{ph} K_{ws}] a I_z \times 10^{-3}$$

$$= 13.32 \frac{P n_s}{2} \phi T_{ph} K_{ws} a I_z \times 10^{-3}$$

$$= 6.66 P n_s \phi T_{ph} K_w a I_z \times 10^{-3}$$

$$= 6.66 P \phi \frac{Z}{6} K_{ws} a I_z \times 10^{-3}$$

$$Q = 1.11 a P \phi I_z \cdot Z n_s K_{ws} \times 10^{-3}$$

$$Q = 1.11 \left\{ [B_{av} \times \pi D L] [a_c \pi D] [n_s K_{ws} . a \times 10^{-3}] \right\}$$

$$Q = 11 B_{av} . a_c . K_{ws} \times 10^{-3} D^2 L n_s$$

where $C^o = 11 B_{av} . a_c . K_{ws} \times 10^{-3}$

$$Q = C^o D^2 L n_s$$

2. Estimate the Stator core dimensions, number of Stator slots and number of Stator conductors per Slot for a 100KW, 3300V, 50Hz, 12 Pole, Star connect-ed slip ring Induction motor. Assume average gap density = 0.4 wb/m², conductors per metre = 25000 A/m Efficiency = 0.9, Power factor = 0.9 and winding Factor = 0.96. Choose main dimensions to give best power Factor.

Solution :-

$$\text{KVA input} = \frac{100}{0.9 \times 0.9} = 123.5$$

$$\text{Synchronous Speed, } n_s = \frac{2 \times 50}{12} = 8.33 \text{ r.p.s}$$

$$\text{Output coefficient, } C_o = 11 \times 0.96 \times 0.4 \times 25{,}000 \times 10^{-3}$$

$$= 105.6$$

$$\therefore \text{Product } D^2L = \frac{123.5}{105.6 \times 8.33} = 140.4 \times 10^{-3} \, m^3$$

For Best power factor $\tau = \sqrt{0.18L}$ (Eqn. 10.63)

(or) $\pi D/12 = \sqrt{0.18L}$

$$D^2 = 2.63L$$

Thus, we have.

$$2.63L^2 = 140.4 \times 10^{-3}$$

$L = 0.23m$ and $D = 0.78m$.

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$$\phi m = 0.4 \times \frac{\pi \times 0.78}{12} \times 0.23$$

$$= 18.8 \times 10^{-3} \, wb$$

Stator voltage per phase,

$$E_S = 3300/\sqrt{3} = 1905V$$

Stator turns per phase,

$$T_S = \frac{1905}{4.44 \times 50 \times 18.8 \times 10^{-3} \times 0.96}$$

$$T_S = 487$$

The total number of stator conductors $= 6 \times 487$
$= 2922$

The slot varies between 15 to 25mm.

The no. of. stator slots S_S lies between.

$$\frac{\pi \times 0.78 \times 10^3}{25} = 98 \quad \text{and} \quad \frac{\pi \times 0.78 \times 10^3}{15} = 163$$

The total no. of. slots for different number slots per pole per phase is,

stator slots S_S	72	108	144	180
slots/pole/phase q_S	2	3	4	5

Thus we can use either 108 (or) 144 slots

For the stator, $S_S = 108$

Total number of stator conductors, $Z_s = 6T_{ph}$

$= 6 \times 483 = 2898$

iii) Number of slots

Slot pitch varies between 15mm to 25mm;

$$Y_{ss} = \frac{\pi D}{S_s}$$

$$S_s = \frac{\pi D}{Y_{ss}}$$

when $Y_{ss} = 15mm$, $S_s = \dfrac{\pi \times 0.777}{15 \times 10^{-3}} = 163$

$Y_{ss} = 25mm$, $S_s = \dfrac{\pi \times 0.777}{25 \times 10^{-3}} = 98$

If $q=2$, $S_s = 2 \times 12 \times 3 = 72$

$q=3$, $S_s = 3 \times 12 \times 3 = 108$

$q=4$, $S_s = 4 \times 12 \times 3 = 144$

$q=5$, $S_s = 5 \times 12 \times 3 = 180$

Number of slots = 108 (and) 144

case i:-

$S_s = 108$

conductor per slot $Z_{ss} = \dfrac{2898}{108} = 27$

Slot loading $= I_s Z_{ss}$

$$I_s = \frac{Q}{\sqrt{3} \times E \times 10^{-3}} = \frac{123.5}{\sqrt{3} \times 3300 \times 10^{-3}} = 21.6A$$

case ii)

$S_s = 144$

conductor per slot $Z_{ss} = \frac{2898}{144} = 20$

slot loading $= 21.6 \times 20 = 432AC$

with $S_s = 108$ slot loading exceeds maximum specified limit

$S_s = 144$

Total stator conductors $= S_s \times Z_{ss}$

$= 144 \times 20$

$= 2880$

New value of turns per phase.

$T_s = \frac{Z_{ss} S_s}{6}$

$= \frac{20 \times 144}{6} = 480$ turns/ph

$T_s = 480$ turns/ph.

3. Determine the main dimensions, number of radial ventilating ducts, number of stator slots and the number of turns per phase of a 3.7kW, 400 Volt, 3 phase, 4 Pole, 50HZ Squirrel cage Induction motor to be Started by a star delta Starter. work out the winding details. Assume: Average Flux density in the air-gap = 0.45 wb/m^2, Ampere conductors per meter = 23000 ac/m, Efficiency = 0.85 and power factor = 0.84. Machines rated at 3.7kW, 4 Pole are Sold at a competitive price and therefore choose the main dimensions to give a cheap design.

Given data:-

$P = 3.7kW$

$V = 400V, 3\phi$

$P = 4$

$f = 50HZ$

$B_{av} = 0.45 \, wb/m^2$

$ac = 23000 \, ac/m$

$\eta = 0.85$

$p.f = 0.84$

cheap design

$K_{ws} = 0.955$

$S_f = 0.9$

To Find:-

1. D & L
2. n_d
3. S_s
4. T_{ph}

Solution:-

i) KVA rating, $Q = \dfrac{P}{\eta \times p.f} = \dfrac{3.7}{0.85 \times 0.84}$

$= 5.18 KVA$

output coefficient,

$$C_o = 11\, B_{av}\, ac\, K_{ws} \times 10^{-3}$$

$$= 11 \times 0.45 \times 23000 \times 0.955 \times 10^{-3}$$

$$C_o = 108.7$$

Speed,

$$N = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ r.p.m};$$

$$n_s = \frac{N}{60} = \frac{1500}{60} = 25 \text{ r.p.s}$$

$$D^2L = \frac{Q}{C_o n_s} = \frac{5.18}{108.7 \times 25} = 1.906 \times 10^{-3}\, m^3 \longrightarrow (1)$$

For a cheap design, $L/\tau = 1.5$ to 2

Taking $L/\tau = 1.5 \Rightarrow L = 1.5\tau$

$$L = 1.5\, \frac{\pi D}{P} \Rightarrow L = \frac{1.5 \times \pi \times D}{4} = 1.178D \longrightarrow (2)$$

Solving (1) & (2)

$$D^2(1.178D) = 1.906 \times 10^{-3}$$

$$D^3 = \frac{1.906 \times 10^{-3}}{1.178} = 1.617 \times 10^{-3}$$

$$D = 0.117m$$

$$L = 0.178 \times 0.117 = 0.13\, m$$

$$D = 0.117m$$

$$L = 0.13m.$$

Pole pitch, $\tau = \frac{\pi D}{P}$

$$= \frac{\pi \times 0.117}{4} = 0.091m$$

The Length of core is 0.13m and therefore 1 radial duct of 10mm wide is provided.

$\therefore$ Net iron Length, $L_i = S_f[L - n_d w_d]$

$$L_i = 0.9[0.13 - 1 \times 10 \times 10^{-3}] = 0.108m.$$

3) Number of slots:-

Slot pitch, $Y_{ss} = 10mm$ to $15mm$ (For small machine)

$$Y_{ss} = \frac{\pi D}{S_s}$$

$$S_s = \frac{\pi D}{S_s}$$

When $Y_{ss} = 10mm$, $S_s = \frac{\pi D}{Y_{ss}} = \frac{\pi \times 0.117}{10 \times 10^{-3}} = 37$

$Y_{ss} = 15mm$, $S_s = \frac{\pi \times 0.117}{15 \times 10^{-3}} = 24$

$S_s = 24, 26, 28, 30, 32, 34, 36.$

$q \rightarrow$ slots per pole per phase.

$S_s = q \times$ Number of poles $\times$ Number of phases.

If $q = 2$, $S_s = 2 \times 4 \times 3 = 24$

$q = 3$, $S_s = 3 \times 4 \times 3 = 36$

$q = 4$, $S_s = 4 \times 4 \times 3 = 48$

$S_s = 36$ is selected.

4) Turns per phase

$$T_{ph} = \frac{E_{ph}}{4.44 f \phi_m K_{ws}}$$

$$\phi_m = \frac{B_{av} \pi D L}{P} = \frac{0.45 \times \pi \times 0.117 \times 0.13}{4}$$

$$\phi_m = 5.37 \times 10^{-3} \text{ wb.}$$

$E_{ph} = V = 400V$ [∵ Delta connected]

$$T_{ph} = \frac{400}{4.44 \times 50 \times 5.37 \times 10^{-3} \times 0.955}$$

$T_{ph} = 351$ turns

Number of conductors, $Z_s = 6T_{ph}$

$= 6 \times 351$

$Z_s = 2108$

conductor per slot, $Z_{ss} = \frac{Z_s}{S_s} = \frac{2108}{36} = 58.5$

∴ Actual number of turns per phase,

$$T_s = \frac{S_s \times Z_{ss}}{6} = \frac{36 \times 58.5}{6}$$

$T_s = 351$ turns.

conductor per slot $Z_{SS} = \frac{2922}{108} = 27$

Stator current per phase $I_S = \frac{100 \times 10^3}{\sqrt{3} \times 3300 \times 0.9 \times 0.9}$

$= 21.6A$

slot loading, $= I_{SS} Z_S = 21.6 \times 37 = 583$ Ampere conductors

This exceeds the maximum specified limit of 500 Ampere conductors and, therefore we cannot use 108 slots.

with

$S_S = 144$

conductors per slot $Z_{SS} = 2922/144 = 20$

Slot loading $= 216 \times 20 = 432$ Ampere conductors

This is below the maximum specified limit.

We use 144 slots with 20 conductors per slot.

4. Determine the approximate diameter and length of core and no. of. stator conductor for a 11KW, 400V, 3ϕ, 4 Pole, 1425 rpm, D connected IM. $B_{av} = 0.45 \, Wb/m^2$. $ac = 23,000 \, ac/m$. Full load Efficiency is 0.85. PF=0.88, $L/\tau = 1$

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Given Data =

$P = 11KW$ | Pole $= 4$

$V = 400V$ | $N = 1425$ rpm

$ac = 23,000$ ac/m | $PF = 0.88$

$\eta_{Full} = 0.85$ | $Bav = 0.45$ wb/m^2

$L/\tau = 1$

To Find :-

D, L, no. of. stator slots (S_s) and no. of. stator conductors (Z_s)

Formula :-

$Z_s = 6T_s/S_s$

$S_s = \pi D/y_{ss}$

$Q = 11\ B_{av} ac\ K_{ws} \times 10^{-3} D^2 L n_s$

Solution :-

$$Q = \frac{11}{\eta \times pf} = \frac{11}{0.85 \times 0.88} = 14.7 KVA$$

$n_s = 2f/p$

$$= \frac{2 \times 50}{4} = 25$$

$K_{ws} = 0.955$ (Assume)

$14.7 = 11 \times 0.45 \times 23,000 \times 0.955 \times 10^{-3} \times D^2 L \times 25$

$5.4 \times 10^{-3} = D^2 L$

$D^2 L = 0.0054 m^3$

$L/\tau = 1$

$L = \tau = L = \pi D/p$

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$L = 0.785D$

$D^2(0.785D) = 0.0054$

$0.785D^3 = 0.0054$

$D = 0.19\,m$

$L = 0.149$

$L = 0.15$

$T_s = \frac{E_s}{4.44 f \phi K_{ws}}$ $\Rightarrow \frac{P\phi}{\pi DL} = B_{av}$

$\phi = B_{av} . \pi DL / p$

$= \frac{0.45 \times \pi \times 0.19 \times 0.15}{4}$

$\phi = 0.01006$

$T_s = \frac{400}{4.44 \times 50 \times 0.01006 \times 0.955}$

$T_s = 187.55$

S_s = No. of. phase × pole × q

$q = 1$

$q = 2$ (Assume)

For $q = 1$ $S_s = 12$

$q = 2$ $S_s = 24$

$q = 3$ $S_s = 36$

$q = 4$ $S_s = 48$

$q = 5$ $S_s = 60$

$$Y_s = \frac{\pi D}{S_s} = \frac{\pi \times 0.19}{0.36} = 0.0165 = 16mm$$

therefore Y_s lies between 15 to 25

$$S_s = 36$$

Let,

$$Z_{ss} = \frac{6T_s}{S_s} = \frac{6 \times 187.55}{36} \approx 32$$

Z_{ss} should be an even Integer,

$$Z_{ss} = 32$$

Total no. of. conductors, $S_s \times Z_{ss}$

$$= 1152$$

$$\text{Turns/ph} = \frac{1152}{6} = 192.$$

5. Estimate the stator core dimensions, number of stator slots and the no. of. stator conductors per slot for a 100KW, 3300V, 50HZ, 12 pole, star connected slip ring Induction motor. Assume $B_{av} = 0.4\ Wb/m^2$, $ac = 25000\ A/m$, Efficiency $= 0.9$, power factor $= 0.9$ and winding factor $= 0.96$, choose the dimensions to give best power factor. The slot loading should not exceed 500 Ampere conductors.

DESIGN OF ROTOR BARS :-

ROTOR BAR CURRENT :-

For a Induction motor, the rotor bar current is given by the Equation.

Rotor bar current, $I_b = \frac{2 m K_{ws} T_{ph}}{S_r} I_s \cos\phi$

where,

m - No. of. phases.

K_{ws} - Stator winding Factor

T_{ph} - No. of. turns per phase

S_r - No. of. rotor slots

I_s - Stator current

For 3-ϕ $m=3$

$$I_b = \frac{6 T_s I_s}{S_r} K_{ws} \cos\phi$$

Rotor mmf = 85% of Stator mmf.

$$I_b = 0.85 \times \frac{6 T_s I_s}{S_r}$$

AREA OF ROTOR BARS :-

The area of each rotor bar can be expressed as,

$$a_b = \frac{I_b}{S_b}$$

where,

a_b - Area of each rotor bar, mm^2

I_b - Rotor bar current, A

δ_b - current density in rotor bar, A/mm^2

$\delta_b = 4 \text{ to } 7 \; A/mm^2$

DESIGN OF ENDRINGS:-

END RING CURRENT:-

In a 3-ϕ Induction motor, the stator has 3-ϕ distributed winding. If a 3-ϕ supply is given to the stator winding, a rotating magnetic field is produced. this rotating magnetic field may be considered as sinusoidally distributed in space as the harmonics as small.

Let

I_b - Rotor bar current, A

$I_{b(max)}$ - maximum value of current in each rotor bar, A

$I_{b(Avg)}$ - Avg. value of current in rotor bar, A

I_e - Endring current, A

$I_{e(max)}$ - maximum value of current in the end ring, A

S_r - No. of. stator slots

P - No. of. poles.

$$I_{e(max)} = \frac{\text{No. of. rotor bars}}{2} \times \left[\text{Maximum current in rotor bar}\right]$$

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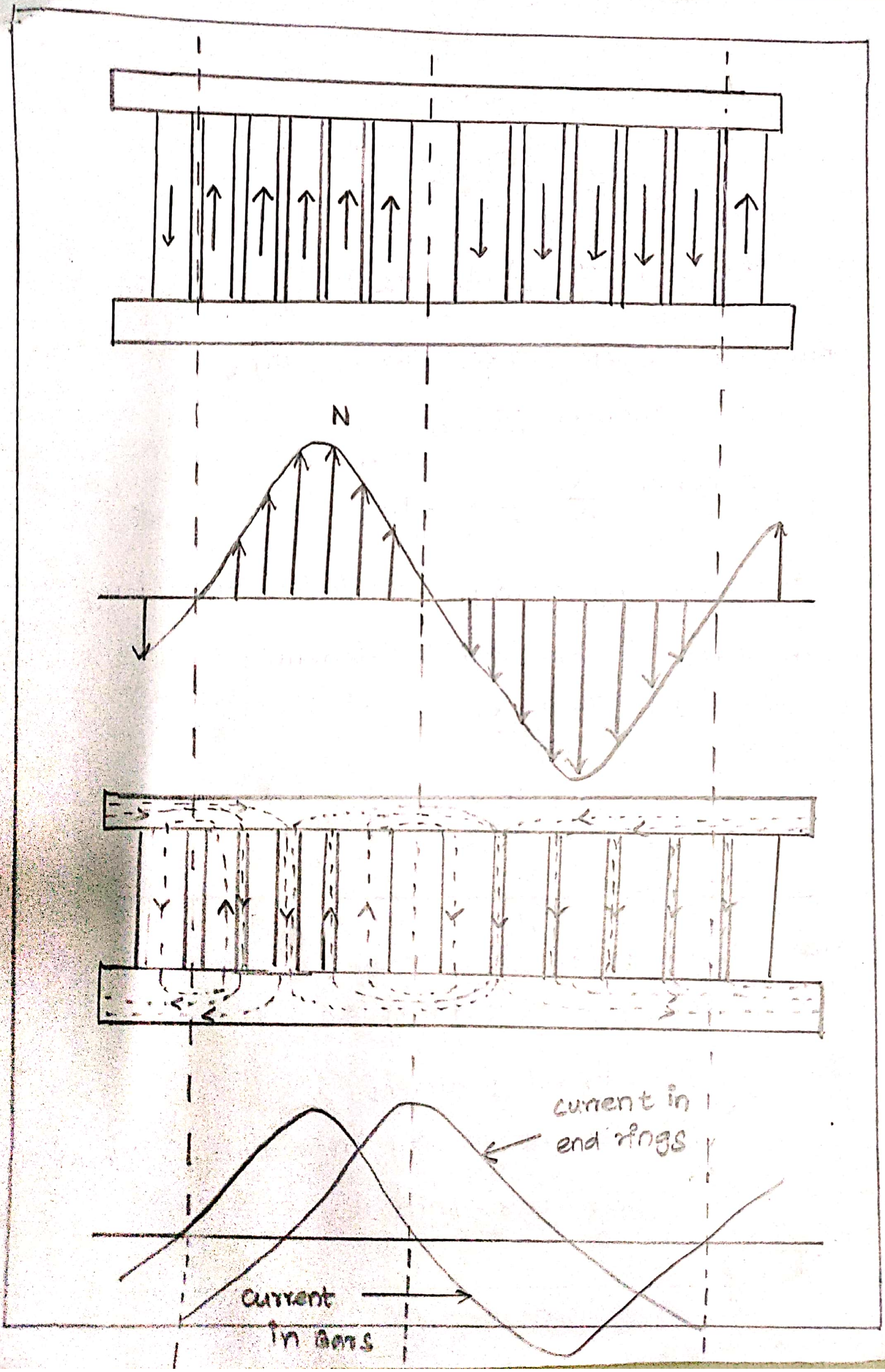

N
current in
end rings
Current
in Bars

$$I_{e(max)} = \frac{S_r}{2p} \times I_{b(avg)}$$

$$= \frac{S_r}{2p} \times \frac{I_{b(max)}}{\pi/2}$$

$$I_{e(max)} = \frac{S_r}{2p} \times \frac{2}{\pi} (I_{b(max)})$$

But bar current varies sinusoidally

$$I_{b(max)} = \sqrt{2} \times I_b$$

$$I_{e(max)} = \frac{S_r}{2p} \times \frac{2}{\pi} \times \sqrt{2} I_b$$

The end ring current also varies sinusoidally

The R.M.S. value of end ring current,

$$I_e = \frac{I_{e(max)}}{\sqrt{2}}$$

$$= \frac{1}{\sqrt{2}} \times \frac{S_r}{2p} \times \frac{2}{\pi} \times \sqrt{2} I_b$$

$$I_e = \frac{S_r I_b}{\pi p}$$

Area of End ring :-

Area of each end ring, $a_e = I_e / \delta_e$

I_e – End ring current, A

δ_e – current density in end ring, A/mm^2

$\delta_e = 5$ to 8 A/mm^2.