Electrical Machine Design

18EE55

5th Sem –

staff: S. M. Inamadar

Question Paper → Feb/Mar 2022

Staff: Prof. S. M. Inamadar

Pages: 1 → 44

CBCS SCHEME

USN 2VD20EE415

18EE55

Fifth Semester B.E. Degree Examination, Feb./Mar.2022
Electrical Machine Design

Time: 3 hrs. Max. Marks: 100

Note:* 1. *Answer any FIVE full questions, choosing ONE full question from each module.
2. *Assume any missing data suitably.*

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. What are the important considerations for the design of electrical machines? Explain in brief and what are its limitations? **(10 Marks)**

b. Mention the desirable properties of electrical insulating materials. Also give the classification of insulating material based on temperature with an example for each. **(10 Marks)**

OR

2 a. What are the desirable properties of magnetic materials? Explain in brief magnetic material and its classification. **(10 Marks)**

b. Write brief note on modern manufacturing techniques in the design of electrical machines. **(10 Marks)**

Module-2

3 a. Discuss the various factors which govern the choice of number of poles in a DC machine. And what are the advantages of choosing larger number of poles. **(10 Marks)**

b. Calculate the diameter and length of armature for a 7.5 kW, 4 pole, 1000 rpm, 220 V shunt motor. Given : Full load efficiency 83%, Maximum gap flux density = 0.9 wb/m^2; Specific electric loading = 30000 ampere conduction per metre ; field form factor = 0.7. Assume that the maximum efficiency occurs at full load and the field current is 2.5% of rated current. The pole face is square. **(10 Marks)**

OR

4 a. The following particulars refer to the shunt field coil for a 440 V, 6 pole, DC generator : MMF per pole = 7000 A, Depth of winding = 50 mm, Length of inner turn = 1.1 m; Length of outer turn = 1.4 m, Loss radiated from outer surface excluding ends = 1400 W/m^2, Space factor = 0.62 ; Resistivity = 0.02 Ω/m and mm^2. Calculate

(i) The diameter of the wire (ii) Length of coil
(iii) Number of turns and (iv) Exciting current **(10 Marks)**

b. Define specific electric and magnetic loadings of a DC machines. What are the merits and demerits of selecting higher value of specific loadings? Mention the factors to be consider during the choice of specific loading. **(10 Marks)**

Module-3

5 a. Derive the output equation of a 3 phase core type transformer and hence deduce an expression for output-emf/turn. **(10 Marks)**

b. Determine the dimension of core and yoke for a 200 KVA, 50 Hz single phase core type transformer. A cruciform core is used with distance between adjacent limbs equal to 1.6 times the width of core laminations. Assume voltage per turn 14 V, maximum flux density 1.1 wb/m^2, windows space factor 0.32, current density 3 A/mm^2 and stacking factor = 0.9. The net iron area is 0.56 d^2 in a cruiciform core where d is diameter of circumscribing circle. Also the width of largest stamping is 0.85 d. **(10 Marks)**

OR

6 a. Explain the procedure to calculate the no load current for a single phase transformer. **(10 Marks)**

b. A 250 KVA, 6600/400 V, 3 phase core type transformer has a total loss of 4800 W at full load. The transformer tanks is 1.25 m in height and $1m \times 0.5m$ in plan. Design a suitable scheme for tubes if the average temperature rise is to be limited to 35°C. The diameter of tubes is 50 mm and are spaced 75 mm from each other. The average height of tubes is 1.05 m. Specific heat dissipation due to radiation and convection is respectively 6 and 6.5 W/m^2 - °C. Assume that convection is improved by 35 percent due to provision of tubes. **(10 Marks)**

Module-4

7 a. Derive expression for rotor bar and end ring current of squirrel cage induction motor. **(10 Marks)**

b. Find the main dimension of a 15 kW, 3 phase, 400 V, 50 Hz, 2810 rpm squirrel cage induction motor having an efficiency of 0.88 and a full load power factor of 0.9.
Assume :
Specific magnetic loading = 0.5 wb/m^2
Specific electric loading = 25000 A/m
Take the rotor peripheral speed as approximately 20 m/s at synchronous speed. **(10 Marks)**

OR

8 a. With usual notations, derive the output equations of a 3 phase induction machine. **(10 Marks)**

b. Discuss the factors to be considered while deciding the length of air gap, number of stator and rotor slots in an induction motor. **(10 Marks)**

Module-5

9 a. What is SCR of a synchronous machine? What are the effects of SCR on machine performance? **(10 Marks)**

b. Determine the main dimensions for a 1000 KVA, 50 Hz, 3 phase, 375 rpm alternator. The average air gap flux density is 0.55 wb/m^2 and the ampere conductors per meter are 28000. Use rectangular poles and assume a suitable value for ratio of core length of pole pitch in order that bolted on pole construction is used for which the maximum permissible peripheral speed is 50 m/s. The runaway speed is 1.8 times the synchronous speed. **(10 Marks)**

OR

10 a. The fields coils of a salient pole alternator are wound with a single layer winding of bare copper strip 30 mm deep, with separating insulation 0.15 mm thick. Determine a suitable winding length, number of turns and thickness of conductor to develop an mmf of 12000 A with a potential difference of 5 V per coil and with a loss of 1200 W/m^2 of total coil surface. The mean length of turn is 1.2 m. The resistivity of copper is 0.021 Ω/m and mm^2 **(10 Marks)**

b. Explain the factors to be considered in the selection of number of armature slots of a synchronous machine. **(10 Marks)**

* * * * *

Feb-March 2022

Electrical Machine Design

Module-1

1 a) What are important consideration for design of electrical m/cs? Explain in brief and what are it's limitations? (10 marks)

Answer: Important Considerations for Design of Electrical Machine

1) major considerations are size of m/c cost incurring on design, Durability and Life,
2) Designing Magnetic Circuit for Required Specification of m/c with magnetic materials like Permanent magnets, Ferromagnetic materials,
3) Designing type of winding with copper or aluminium or copper-alloy selecting suitable loading.
4) Designing dielectric and insulation required which is essential and saves Life of m/c.
5) Thermal circuit design, to keep temp within Limits.

6) Mechanical Parts, for Selecting & fixing frame size, bearings to avoid noise and for smooth Running of m/c.

Limitation for Design

1) Saturation — Decides size & type of magnetic material.

2) Temp Rise — Decides m/c performance and should be within limits to avoid Losses

3) Insulation - Good insulation gives better Durability

4) Efficiency - It depends on good design, size & loadings are considered

5) Mechanical Parts — Gives Rigidity to structure.

6) Commutation — To avoid losses

7) Power Factor - Low P.f design yields in poor quality of m/c and incurs Losses

1 b - Mention the desirable properties of electrical insulating materials. Also give classification of insulating material based on temperature with an example of each.
— 10 marks

Ans :

Desirable Properties of Insulating Materials

1) High Dielectric strength - Decides Good insulation ex: Mica - 20-200 KV/mm

2) High Resistivity - unit 10^{-6} ohm-cm
ex: Nichrome, Stainless steel
$R_2/R_1 = (\theta_2 + 235°C)/(\theta_1 + 235°C)$

3) Dielectric Constant - Mica (4 - 8)
Porcelain - 5 - 6.2
- High Melting Point -

4) Low dielectric hysteresis - To avoid vibration in m/c

5) Good Thermal Conductivity
- measure of Ability to Pass heat through it.
unit w/m-Kelvin
ex: Copper - 398 w/m.k.
Silver - 429 w/m.k

6) High Degree of Thermal Stability
- For Good Performance

7) Should not absorb moisture

8) Liquid Insulator Should not Evaporate

9) Low dielectric Loss Angle δ

Classification of Insulating material based on classification

Class - A - 90° ex: cotton, silk - Paper wood

Class - B - 105° - class A + Impregnated with resin cellulose

Class - E - 120°C - Synthetic resin enamels, cotton

Class - B - 130°C - mica, Glass, Fibre

Class - F - 155°C - class B + Bonding Substance

Class - H - 180°C - Glass Fibre, Asbestos with Silicon Resin

Class - C - >180°C - mica, Ceramics with Binder

Depending upon Required Specification Suitable Insulating Material are selected

Normal Temp - 40°C

10% Tolerance

Hot spot & maximum → 200°C

One class of Insulating material healthy LifeTime 20000 Hours.

2(a) What are the desirable Properties of magnetic Materials? Explain in brief magnetic material & it's classification.

(10 marks)

Answer: Desirable Properties of Magnetic Materials

Work Done in one complete one Revolution

= Total Magnetic Loading x Total Electric loading

$= (P\phi) \times I_z\, 2$

Specific Magnetic loading $B_{av} = \frac{P\phi}{\pi D L}$

B_{av} = Flux Per pole / Area under one Pole

= Flux per pole / Pole Pitch x length of Armature

1) Highest Possible Permeability
2) Very high Resistivity
3) Low hysteresis Loss (Narrow loop)
4) High Saturation Index (To Reduce weight, volume of Iron Rock)
5) High Curie Point - beyond Curie point → magnetic material Loses it's properties.

Specific magnetic loading B_{av} should be Reduced to Low iron loss for high Speed and high Frequency AC m/c.

Classification of Magnetic Material

1) Diamagnetic material - very weak
   No magnetic moment - Insert Gases

2) Paramagnetic material - Less Magnetic
   Random orientfly Magnetic moment
   ex: Rare earth Metals

3) Ferro Magnetic material - Good Magnetic
   Iron, Nickel, Cobalt, - Parallel Aligned
   Soft or Hard, Carbon steel -
   Cast iron, - yokes, poles in D.C mile
   Rotor of Turbo - Alternator

4) Anti Ferromagnetic material -
   Aligned in Reverse Direction
   Antiparallel Fe, ⊗

5) Ferri Magnetic Materials -
   - Mixed Parallel and Anti
   Parallel Magnetic material
   moment.
   Fe_3O_4 - oxide of Iron

2 b - Write a brief note on modern manufacturing Techniques in the design of Electrical m/cs.

— 10 Mark

Ans: Modern Manufacturing Technique in Electrical m/cs

- 1) Design in Single Unit
2) Use of Software for Simulation
   ex: Auto Cad,
3) Automated or Semi Automation from Industries for Design of m/c
4) Attaining Required Ratings by Selecting Good Conducting, Magnetic and Insulating material
5) Verifying Performance Parameters Load Tests Automatic Winding.
6) Design Good Mechanical Parts by using brazing, process.
7) Designer first uses Analysis method for m/c Dimensions material and construction. alters data for Required Performance
8) Synthesis method - Hardware verification.
9) Reduce size, Loss by Design at best.

Module - 2

3) (a) Discuss the various factors which govern the choice of no of poles in D.C m/c. And what are advantages of choosing large no of poles — (10 Marks)

Ans: Factors Governing Choice of Poles in D.C m/c

1) $B_{av} = \frac{P\phi}{\pi D L}$ ∴ $P = \frac{B_{av} \pi D L}{\phi}$

Length (L) of m/c and Armature Diameter (D)

2) Hysteresis Losses

3) Frequency 25 Hz to 50 Hz

4) Current per parallel path Limited to 200 A

5) Current per brush Arm should not be more than 400 A

6) Weight of Copper ⇒ Less to Reduce Size

7) Length of Commutator — more conductor, more pole

8) Flash over →, Labour Charges

9) Distortion of field form -

Advantages of Large No of Poles

1) Weight of Armature Core and Yoke

2) Cost of Armature and Yoke

3) Overall length and Diameter

4) Length of Commutator

5) Distortion of field form under D, Cont Load

3b - Calculate the diameter and length of armature for 7.5 kw, 4 pole 1000 r.p.m, 220 V shunt motor Full load efficiency is 98%. Maximum Gap density = 0.9 wb/m², specific electric loading = 3000 ac/m : Field form factor = 0.7. Assume that maximum efficiency occurs at full load and field current is 2.5% of rated current. The pole face is square. (- 10 marks)

Ans: Given Data

D.C motor 7.5 KW - 220V, 4 pole 1000 Rpm

Full load η = 83% B_{av} = 0.9 wb/m²

q or (ac) = 3000 ampere conductor/m

Field form factor = 0.7

Maximum efficiency at F.L

I_f = 2.5% of I_{rated}

Face of pole = Square pole

Power i/p = $\frac{P}{\eta} = \frac{7500}{0.83}$ = 9040 w

Input = output + Losses

Losses = 9040 w - 7500
= 1540 w

Constant losses = $\frac{1540}{2}$ = 770 w

$I_{F.L}$ = Motor Current at F.L

= $\frac{7500}{0.83 \times 200}$ = 41.1 A

I_f = Field Current = 0.025 × 41.1
= 1.03 A

Friction & windage = 770 - 227
= 543 W

$B_{av} = K_f B_g = 0.7 \times 0.9 = 0.6346$ wb/m²

$C_0 = \pi^2 B_{av} \times q \times 10^{-3}$
$= \pi^2 \times 0.63 \times 3000 \times 10^{-3}$
= 186.5

Speed $n = \frac{1000}{60}$ (r.p.m) = 16.67 r.p.s

$D^2 L = \frac{P_a}{C_0 n} \Rightarrow P_a = \left(\frac{1 + 2\eta}{3\eta}\right) P$

$P_a = \left(\frac{1 + 2(0.83)}{3(0.83)}\right) \times 7.5$
= 8.012 kW

$\therefore D^2 L = 8.1 / 186.5 \times (16.67)$
$= 2.59 \times 10^{-3}$ m³

Since Square pole = $L / \tau = 1$

$L = 0.7 \times \frac{\pi D}{4} = 0.55 D$

$D^3 \; 0.55 = 2.59 \times 10^{-3}$

D = 0.17 m

L = 0.55 × 0.17 m

L = 0.09 m

4 (a) The following particulars refer to the shunt field coil for 440V, 6 pole; D.C Generator. mmf per pole = 7000 A. Depth of winding = 50 mm, Length of inner Turn = 1.1 m. Length of Outer Turn = 1.4 m. Loss radiated from outside surface excluding ends = 1400 W/m^2. Space Factor = 0.62. Resistivity = 0.02 Ω/m. Find

1) Diameter of wire 2) Length of coil
3) No of Turns 4) Exciting current

— 10 marks

Ans: Given Data

D.C Generator, 440V, 6 pole, mmf/pole = 7000 A

Depth of Winding = 50 mm

Lmt = Length of Mean Turn (inner Turn) = 1.1 m

Length of Outer Turn = 1.4 m

Loss = 1400 W/m^2

Space Factor = 0.62

Resistivity = 0.02 Ω/m m and mm^2

Voltage Across Shunt field Winding
= 0.8 × Rated Voltage = 0.8 × 440
= 352 V

$$L_{mt} = \frac{L_o + L_i}{2} = \frac{1.4 + 1.1}{2} = \frac{2.5}{2} = 1.25 \text{ m}$$

Area of Field Conductor = af

$= \frac{ATf \times Lmt}{Ef} = \frac{700 \times 1.25}{58.2} = 2.98$ mm^2

Diameter of Bare Conductor d = 1.85 mm

No of Turns $Tf = \frac{Sf\, hf\, df}{Ef} \times 10^2$

$= \frac{0.62 \times hf \times 50}{58.2} \times 10^2\, hf$

$= 1.04 \times 10^4\, hf$

Area of Outer Surface = Lo hf

= 1.4 hf

Permissible Loss = 1400 w/m^2

$If = \frac{\text{Permissible Loss}}{\sigma f}$

$= 33.4\, hf$

$AT_f = If\, Tf = 33.4\, hf\, Tf$

= 7000

$Tf = \left(\frac{700}{33.4}\right) hf = 210/hf$

$1.04 \times 10^4 \times hf =$

$Tf^2 = 1.04 \times 10^4\, hf \times \frac{210}{hf}$

$= 21.84\, 10^6$

Tf = 1405

$R_f = 12.4 \Omega$

$I_f = 4.73 A$

$h_f = \frac{I_f}{1.04 \times 10^4} = 0.142 m$

4 b Define specific loading of Electrical and magnetic for D.C machines. What are the merits and demerits of selecting higher value of specific loadings? Mention the factors to be considered during choice of specific Loadings?

– 10 Marks

Ans:

Specific Magnetic Loading:

It is defined as Total Flux per unit area over the surface of armature periphery

$B_{av} = \frac{P\phi}{\pi D L}$

It is determined by
max Flux Density in iron parts
Magnetizing Current 5.0 T
Core losses D.C m/c 0.4 to 0.8

Specific Electric Loading;

$$ac \text{ or } q = \frac{I_2 Z}{\pi D}$$

It is defined as no of armature conductors per meter of armature periphery at the Air Gap
$q = 15000$ to 5000

Merits of higher S.m.L and S.E.L

1) High q increases temp, Losses,
2) Higher q increases armature Reaction
3) Higher q increases conduction & Temp leads to sparking
4) Higher Bav core loss increases
5) Higher Bav, mmf for magnetic
6) increases, cost of m/c Increases
7) Bav Higher mmf Increases
8) So Bav Range is 0.45 to 0.75
9) q Range 15000 to 5000 ac/m
10)

Factors considered During choice of specific loading.

1) Maximum Flux Density }
2) magnetizing Current } S.m.L
3) Core Losses }

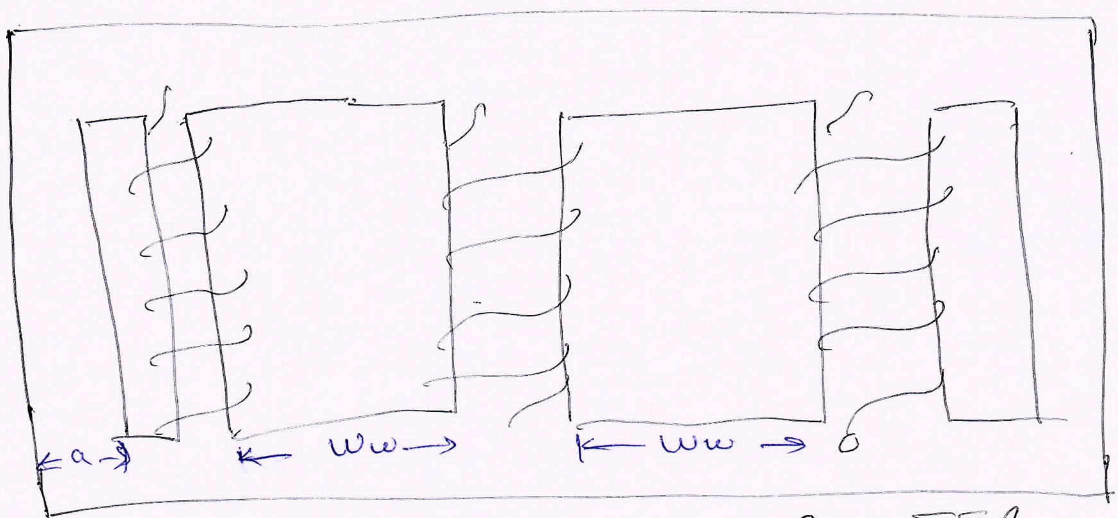
4) Permissible Temp Rise }
5) Voltage Rating of m/c }
6) Size of m/c } S.E.L
7) Current Density of m/c }

Module - 3

5 a - Derive the Output Equation of 3ϕ, Core type Transformer and hence deduce an expression for output Emf / Turn

(— 10 marks)

Ans: Output Equation of 3ϕ Core Type of Transformer



Five Limb 3ϕ Core TFR

Rating of Transformer $KVA = V_1 I_1 \times 10^{-3}$

$= E_1 I_1 \times 10^{-3}$

E_1 = Induced emf $= 3 \times 4.44 f \phi_m T_1 \times I_1 \times 10^{-3}$ — eqn (a)

In 3ϕ Transformer, each leg carries LV & HV windings of one phase each window carries LV & HV winding of two phases

So Copper Area available for winding

$$A_{cu} = (a_1 T_1 + a_2 T_2) + (a_1 T_1 + a_2 T_2)$$

$$= 2(a_1 T_1 + a_2 T_2)$$

$$= 2\left(\frac{I_1 T_1}{\delta} + \frac{I_2 T_2}{\delta}\right)$$

Assuming $\Rightarrow I_1 T_1 = I_2 T_2$

$$A_{cu} = 2 \times \frac{2 I_1 T_1}{\delta}$$

$$= A_w K_w$$

K_w = Window space factor

$$I_1 T_1 = \frac{A_w K_w \delta}{4} \Rightarrow \text{eqn B}$$

So substituting eqn B in eqn A

$$KVA = 3 \times 4.44\, A_i B_m f \times \frac{A_w K_w \delta}{2} \times 10^{-3}$$

$$\boxed{KVA = 3.33 f \delta A_i B_m A_w K_w \times 10^{-3}}$$

Volt / Turn Eqn

Voltage / Turn $= E_t = 4.44 f \phi_m$

$$\frac{\phi_m}{I_1 T_1} = \frac{\text{magnetic loading}}{\text{electric loading}}$$

$$= K_t$$

$$\boxed{I_1 T_1 = \phi_m / K_t}$$

$$KVA/phase = 4.44 \phi_m f \left(\frac{\phi_m}{K_t}\right) \times 10^{-3}$$

$$\phi_m = \sqrt{\frac{K_t \times (KVA)/phase}{4.44 f \times 10^{-3}}}$$

$$E_t = 4.44 \phi_m f T_1$$

$$E_t = 4.44 f \sqrt{\frac{K_t \times KVA/phase}{4.44 f \times 10^{-3}}}$$

$$= \sqrt{4.44 f \times 10^{-3} \times K_t \times KVA/phase}$$

$$= K \sqrt{KVA}$$

$$K = 4.44 f \times 10^{-3} \times K_t$$

K depends Type of TRF

1.0 to 1.2 → 1ϕ Shell Type

1.3 → 3ϕ Shell "

(0.75 to 0.85) 1ϕ Core Type

(0.6 to 0.7) 3ϕ Core Type

0.45 for 3ϕ Core Type (Distribution)

Module - 3

5 b - Determine the dimension of core and yoke for a 200 KVA, 50 Hz single phase core type Transformer. A cruciform core is used with distance between adjacent limbs equal to 1.6 times the width of core lamination. Assume voltage per turn 14V, maximum flux density 1.1 wb/m², window space factor 0.32, current density 3 A/mm² and stacking factor = 0.9. The net iron area is 0.56 d² in cruciform core. Also width of largest stamping is 0.85 d [d - Diameter of circumscribing circle.]

(— 10 marks)

Ans: Given Data

200 KVA, 50 Hz 1φ Core Type

Cruciform Core

Distance between adjacent limbs = 1.6 × width of core lamination

E_t = Voltage / Turn = 14 V

B_m = 1.1 wb/m²

K_w = 0.32 δ = 3 A/mm²

Stacking Factor = 0.9

$A_i = 0.56 d^2$

$KVA = 2.22 f \delta A_i B_m A_w K_w \times 10^{-3}$

$200 = 2.22 \times 50 \times 3 \times A_i \times 1.1 A_w K_w$

$\phi_m = \frac{Et}{4.44 \times 50} = \frac{14}{4.44 \times 50} = 0.0630$

$A_i = \frac{\phi_m}{B_m} = \frac{0.0630}{1.1} = 0.0572$

$= 0.0572\ m^2$

let $K_w = 0.9$

$A_w = \frac{200}{2.22 \times 50 \times 3 \times (0.0572) \times 1.1 \times 0.9 \times 10^{-3}}$

$A_w = 200/18.85 = 10.61$

$A_w = \frac{10.61}{10^3} = (0.0106)\ m^2$

diameter $= d = \sqrt{\frac{A_i}{0.56}} = \sqrt{\frac{0.0572}{0.56}}$

$d = 0.32\ m$

width of Largest Stamping

$a = 0.85 d = 0.85 \times 0.32$

$a = 0.272\ m$

Distance between Core Centre

$D = 1.6\ a = 1.6 \times 0.272$

$= 0.435\ m$

Width of window $= D - d = 0.115\ m$

$A_w = H_w \times W_w$

$H_w = \frac{0.0106}{0.115} = 0.092\ m$

$W_w = 0.115\ m$

For 1Ø core

$D_y = a \qquad H = H_w + 2H_y$

$W = D + a$

$D_y = a = 0.272\ m$

$H_y = 0.272\ m$

$H = 0.092 + 2 \times 0.272$

$H = 0.636$

$W = D + a$

$W = 0.435 + 0.272$

$W = 0.732\ m$

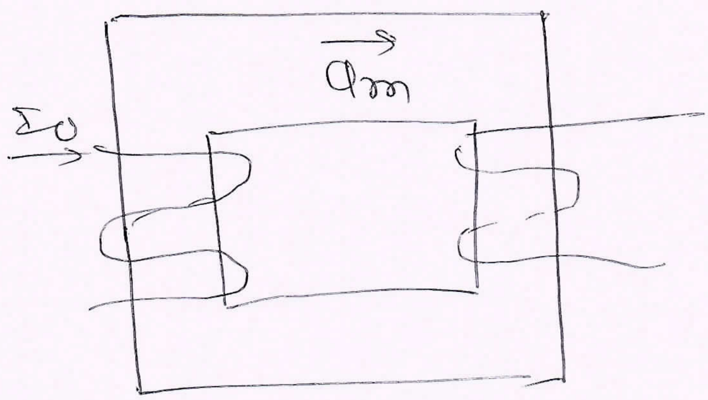
Module - 3

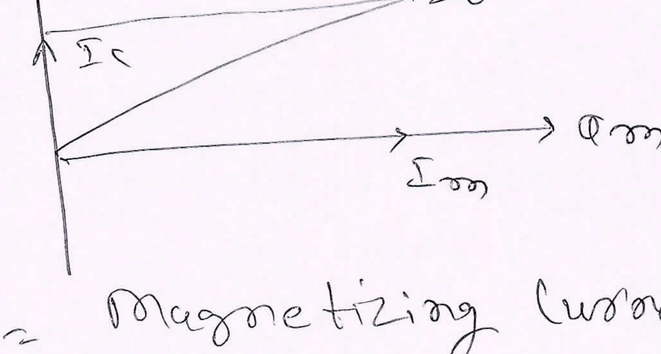
6 a - Explain the procedure to calculate No load current for Single phase Transformer.

(→ 10 Marks)

Ans:

let I_0 = No load current of Transformer. It is vector sum of I_m and I_c





I_m = Magnetizing Current

I_c = Working Component Current

$$I_0 = \sqrt{I_c^2 + I_m^2}$$

No load I/p to TRF/phase $= V_1 I_0 \cos\phi_0$
$= V_1 I_c$

I_c = Core Loss / V_1, 1φ TFR

I_c = Core loss / 3 V_1 3φ TFR

Magnetic Circuit = Iron Path + Air Path

AT_0 = AT for iron + $800000 \, l_g B_m$

$$I_m = \frac{\text{AT for iron} + 800000 \, l_g B_m}{\sqrt{2} \, T_1}$$

Normal TFR Design

$I_0 \le 2\%$ of I_{FL}

No load Power Factor = $\cos\phi_0 = \frac{I_c}{I_0}$ = Around 0.2

l_g = length of Air Gap

6 b - A 250 kVA, 6600/400V, 3ϕ Core Type Transformer has a total Loss of 4800 W at Full load. Transformer Tank is 1.25 m in height and 1m X 0.5m in plan. Design a suitable scheme for Tubes average Temp Rise not to exceed 35°C. Diameter of Tube is 50 mm and 75 mm apart from each other. Average height of tubes is 1.05 m. Specific heat dissipation by radiation and convection is 6 and 6.5 W/m^2. Convection is improved by 35%.. (-10 marks)

(Given Data) 250 kVA 3ϕ Core

6600/400 V

Total loss = 4800 W

H_t = Height of Tank = 1.25 m

L_t = Length of Tank = 1 m

W_t = 0.5 m

θ = 35°C

d_t = 50 mm

spacing = 75 mm

height of Tubes = 1.05 m

Convection Improved by 35% after installing Tubes

Heat Dissipating surface of Tank

S_t = Total Area of Vertical side

$= 2H_T (L_T + W_T)$

$= 2 \times 1.25 (1m + 0.5)$

$= 2 \times 1.25 (1.5)$

$S_t = 3.75 \; m^2$

Loss Dissipated by Tank walls by Radiation and Convection

$= (6 + 6.5) S_t = 12.5 S_t$

let Heat Dissipating surface of Tubes $= X S_t$

Loss Dissipation by Cooling Tubes due to Convection

$= 6.5 \times \frac{135}{100} \times X S_t$

$= 8.8 X S_t$

Total Loss Dissipated by Tank & Tubes

$= 12.5 S_t + 8.8 S_t X$

$= S_t (12.5 + 8.8 X)$

$\theta = \frac{\text{Total Loss}}{\text{Loss Dissipated}}$

$$\theta = \frac{4800}{S_t(12.5 + 8.8x)}$$

$$(12.5 + 8.8x) = \frac{4800}{\theta}$$

$$x = \frac{1}{8.8}\left[\frac{4800}{35 \times 3.75} - 12.5\right]$$

$$x = 2.7354$$

Total Area of Cooling Tubes

$= x S_t = 2.73 \times 3.75$

$= 10.2528 \, m^2$

Area of Cooling Tubes $= \pi d_t l_t$

$= \pi \times 50 \times 10^{-3} \times 1.05$

$= 0.1649 \, m^2$

No of Cooling Tubes $= n_t$

$$= \frac{\text{Total Area of Tube}}{\text{Area of Each Tube}}$$

$$n_t = \frac{10.2528}{0.1649}$$

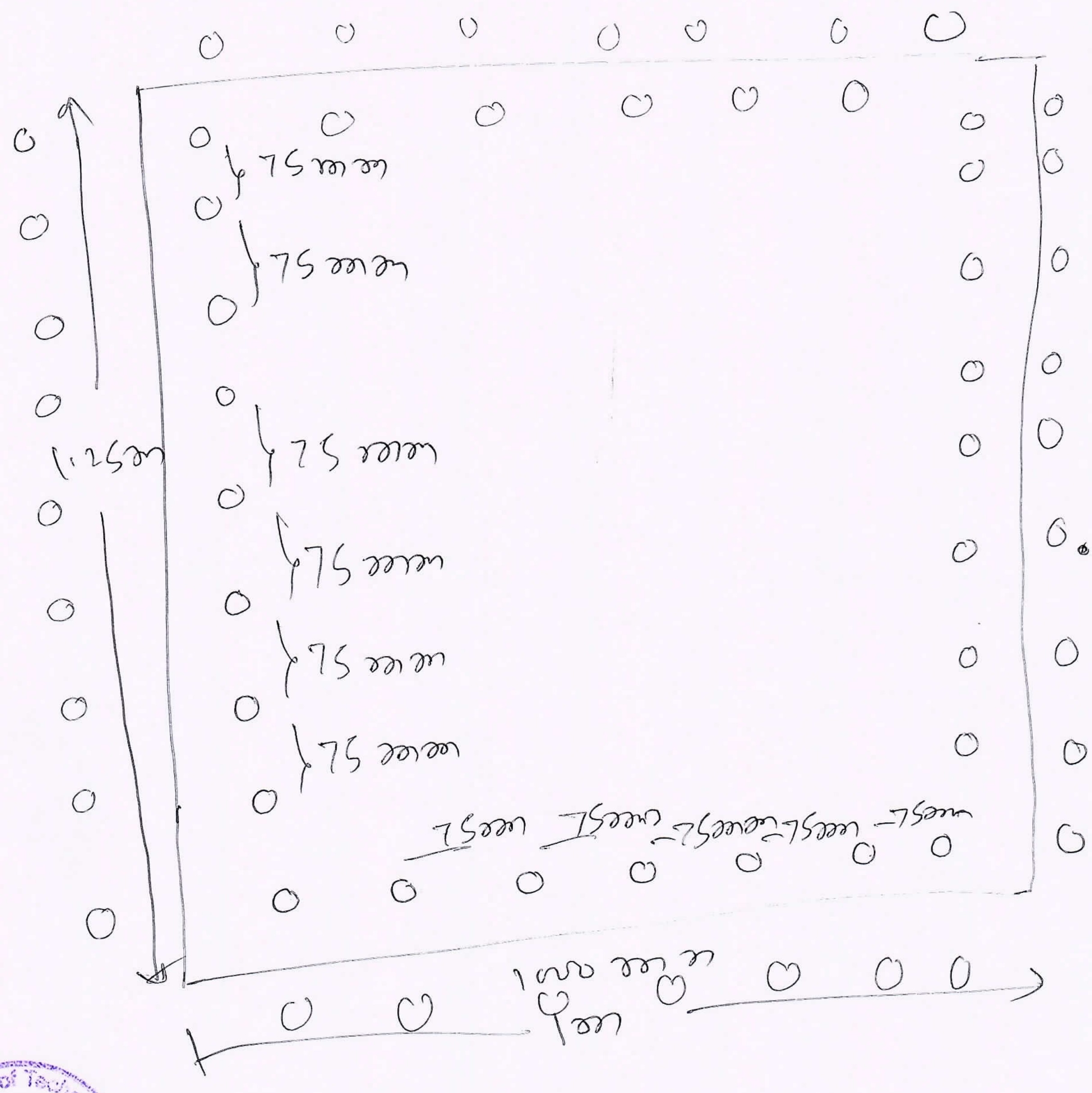
$= 62$

1m = 1000 mm/75 = 13.33

1.25 m = 1250/75 = 17

lengthwise = 13 Tubes

Heightwise = 17 Tubes



G2 = 7 in length wise

⇒ 9 in height wise

So G2+1 = 63 Tubes installed

Module - 4

7a - Derive Expression for rotor Bar and End Ring current of squirrel cage Induction motor.

(10 marks)

Ans: Squirrel Cage I.M consists of bars of copper and aluminium accommodated in Rotor slots.

Rotor bar current in rotor is determined by comparing mmf developed in rotor and stator.

I_b = current per Rotor Bar

$$= \frac{(K_{ws} \times S_s \times Z_s') \times I_r'}{(K_{wr} \times S_r \times Z_r')}$$

K_{ws} = winding Factor for stator

K_{wr} = winding Factor for Rotor

S_s = Stator slots

S_r = Rotor slots

Z_s' = No of Conductors / stator slots

Z_r' = No of Conductor / Rotor slots

$I_r' = 0.85\, I_s$

I_s = stator current / phase

Suitable value of Current Density is Assumed

δ_b = Current Density in Rotor bar

= 4 - 7 A/mm²

$A_b = \frac{I_b}{\delta_b}$ mm²

Cross section Area of Bar = A_b

Length of Rotor bar l_b = L + Allowance for skewing

Rotor Bar Resistance (r_b) = $0.021 \times \frac{l_b}{A_b}$

Copper Loss in Rotor bars = $I_b^2 \times r_b \times S_r$

End Ring Equation

All Rotor Bars are short Circuited by Two endings of End Rings.

EMF in Rotor Bar = Sinusoidal over one pole pitch

Under one pole pitch, 50% of Rotor bars and End ring carry current in one direction and other half in another Direction.

$I_e(max)$ = Maximum End Ring Current

$= \frac{1}{2}$ (No of Rotor bars/pole) $I_b(av)$

$$I_e(max) = \frac{1}{2} \times \frac{S_r}{P} \times I_b/1.11$$

$$I_e(r.m.s) = \frac{1}{2} \times \sqrt{2} \times \frac{S_r}{P} \times \frac{I_b}{1.11}$$

$$= \frac{1}{\sqrt{2}} \frac{S_r}{P} \times \frac{I_b}{1.11}$$

Assuming Suitable Current Density in end Rings (4.5 to 7.5) A/mm²

Area of Each End Ring

$$A_e = I_e / \delta_e \quad mm^2$$

D_{me} = Mean Diameter of End Ring

$$\simeq D_r - (4 \text{ to } 6)(cms)$$

$$= (\text{Diameter of Rotor}) - (4 \text{ to } 6)\ cm$$

l_{me} = Mean length of current path

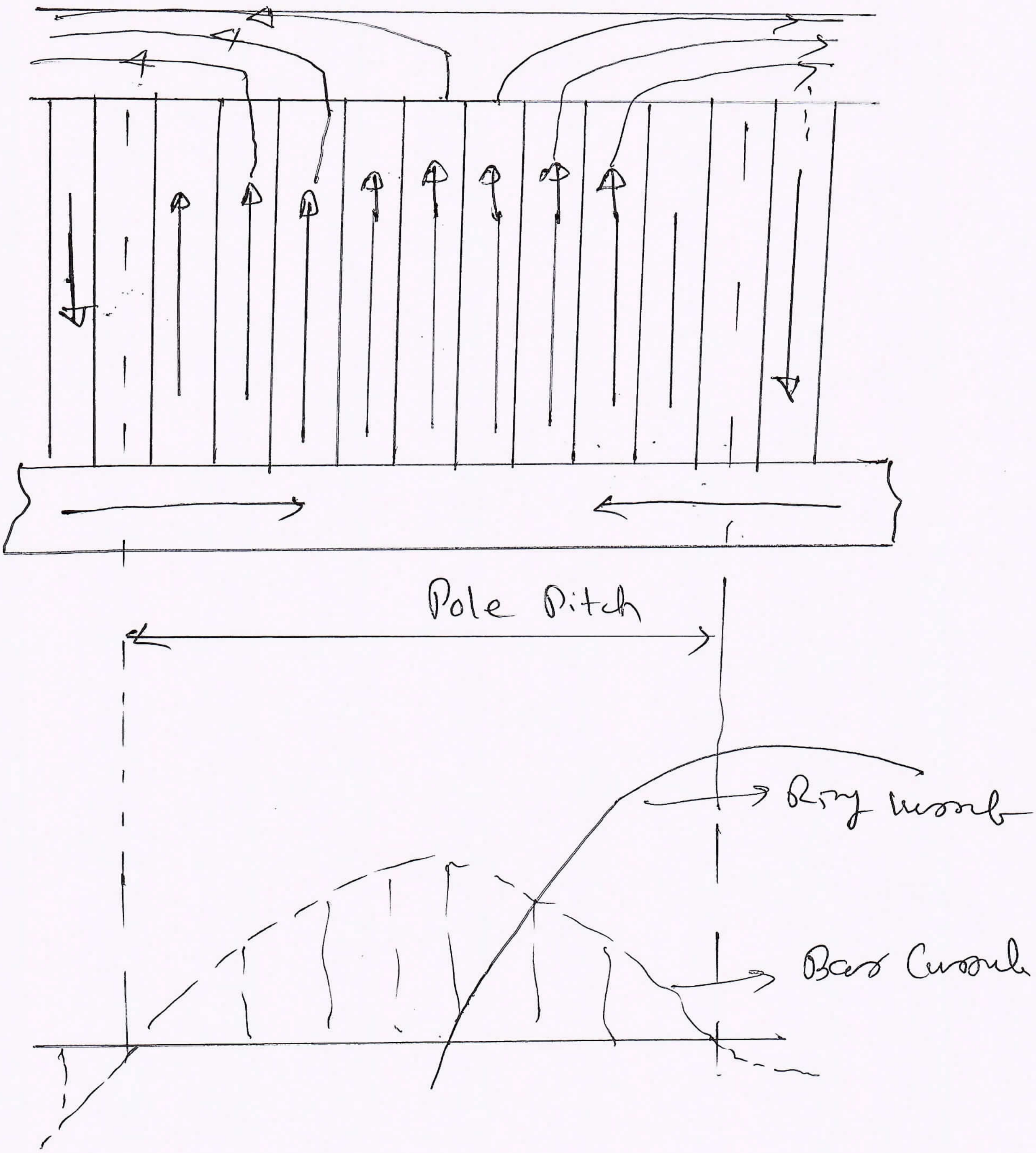
$$= \pi D_{me}$$

$$r_e = 0.021 \times \frac{l_{me}}{A_e}$$

$\rho = 0.021 \Rightarrow$ Resistivity of Copper

Copper Loss in End Rings

$$= 2 \times I_e^2 \times r_e$$


Pole Pitch
Ring Current
Bar Current

Module - 4

7 b - Find the main dimension of 15 kw, 3φ, 400V, 50 Hz, 2810 r.p.m, Squirrel Cage I.m having Efficiency of 0.88 and Full load power factor 0.9
specific magnetic loading = 0.5 wb/m²
Specific Electric loading = 25000 ac/m
Take the Rotor Peripheral Speed 20 m/s at synchronous speed

(— 10 marks)

Ans: Given Data

15 kw, 3φ, 400V, 50 Hz, 2810 r.p.m

Squirrel Cage $\eta = 0.88$ $\cos\phi = 0.9$

$B_{av} = 0.5\ wb/m^2$ $q = 25000\ ac/m$

$V_a = 20\ m/s$ at $N_s = 3000\ rpm$

$C_0 = 11\ K_{ws} B_{av}\ q \times 10^{-3}$

$= 11 \times 0.955 \times 0.5 \times 25000 \times 10^{-3}$

$C_0 = 131.3$

$$KVA\ input = \frac{Output}{\eta \times p.f}$$

$$= \frac{15}{0.88 \times 0.9}$$

$Q = 18.84$

$N_s = \frac{120f}{P} = \frac{120 \times 50}{}$ $P = \frac{3000}{120\times50}$ 6000/3000

$P = 2$

$n_s = 50$ r.p.s

$\left(N_s = \frac{120 \times f}{P}\right)$

$P = 2$

$$D^2 L = \frac{Q}{C_0 n_s}$$

$$= \frac{18.84}{131.3 \times 50}$$

$$D^2 L = 2.87 \times 10^{-3}$$

$V_a = \pi D n_s = 20$ m/s

$$D = \frac{20}{\pi \times 50} =$$

$D = 0.1273$ m

$$\frac{1}{L} = \frac{D^2}{2.87 \times 10^{-3}}$$

$$\left(\frac{1}{L}\right) = \left(\frac{0.1273 \times 0.1273}{2.87 \times 10^{-3}}\right)$$

$L = 0.177$ m

$D = 0.1273$ m | $L = 0.177$ m

Module - 4

8a - With usual notation, derive the output equations of 3 phase induction machine.

(— 10 marks)

Ans:

Output Equation for 3φ I.M

Induced emf/phase $= E_{ph} = 4.44 f \phi_m T_{ph} k_{ws}$

$f = Pns/2$

Current through each conductor $I_z = \frac{I_{ph}}{a}$

a = no of parallel path

$I_z = I_{ph}$

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

$= 3 \times 4.44 f \phi_m T_{ph} k_{ws} I_{ph} \times 10^{-3}$

$= 3 \times 4.44 \left(\frac{Pns}{2}\right) \phi_m T_{ph} k_{ws} I_{ph} \times 10^{-3}$

$= 3 \times 2.22 (Pns) B_m A_i k_{ws} (T_{ph} I_{ph}) \times 10^{-3}$

$= 6.66 \, P ns B_m A_i k_{ws} (T_{ph} I_{ph}) \times 10^{-3}$

Z = No of Phases × $2T_{ph}$

= 3 × $2T_{ph}$

= $6T_{ph}$

$Q = 1.11 (P\phi) \times I_2 (6T_{ph}) \times n_s \times K_{w} \times 10^{-3}$

$Q = 1.11 (P\phi) (I_2 Z) n_s K_w \times 10^{-3}$

S.M.L = Bav = $P\phi / \pi D L$

S.E.L = ac = $\frac{I_2 Z}{\pi D}$

$I_2 Z = ac \cdot \pi D$

$Q = 1.11 (B_{av} \pi D L)(ac \pi D) n_s K_w \times 10^{-3}$

$Q = 1.11 \pi^2 B_{av}\, ac\, D^2 L n_s \times 10^{-3} K_w$

$= (11 B_{av}\, ac\, K_w \times 10^{-3}) D^2 L n_s$

$$\boxed{Q = C_0 D^2 L n_s}$$ Output Equation

$C_0 = 11 B_{av}\, ac\, K_w \times 10^{-3}$

C_0 = Output Coefficient

For best p.f $\tau = \frac{\pi D}{P} = \sqrt{0.18 L}$

Minimum cost $= \frac{L}{\tau} = 1.5$ to 2

(Rotating) $Q = \left(\frac{H.P \times 0.746}{\eta \times p.f} \right)$

8b – Discuss the factors to be considered while deciding the length of Air Gap, no of stator and rotor slots in an induction motor. (– 10 marks)

Ans: Factors for deciding Length of Air Gap in Induction motor

1) Length of Air Gap – by power factor
Air Gap consumes maximum amount of mmf out of various parts of magnetic circuit of I.M

mmf ∝ Flux density × lg

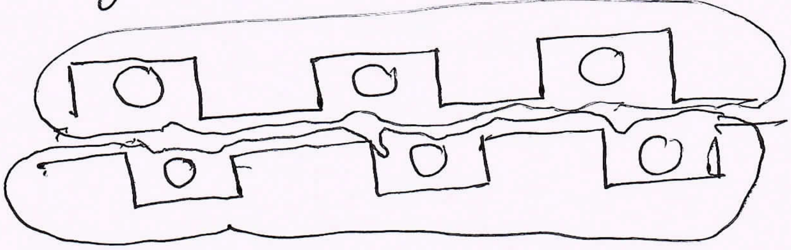
Im increases and p.f reduces

So lg ↑ p.f ↓

2) Overload Capacity
x depends upon XL

XL ↓ Overload capacity increases

lg ↑ Overload capacity increases



3) Pulsation Loss: Lg should be increased to reduce tooth pulsation loss which is due to variation in reluctance of Air Gap.

4) Unbalanced Magnetic Pull

When due to eccentricity of shaft, radial forces are not balanced and unbalanced magnetic pull occurs.

If l_g is small, UMP increases.

5) Cooling - more l_g > more cooling

6) Noise - Noise is due to variation of Reluctance of air gap leakage flux path. l_g is more then noise can be reduced. ($l_g = 0.2 + 2\sqrt{DL}$ mm)

Factor For Stator Slots	Factor Rotor Slots
1) Tooth Pulsation Loss	$S_r \neq S_s$
2) Leakage Reactance	$(S_s - S_r) \neq \pm P, \pm 2P, \pm 5P$
3) Magnetising Current	- to avoid Synchronous cusps
4) Iron Loss	
5) Cost	$(S_s - S_r) \neq \pm 3P$
Semi Closed are preferred.	- To avoid magnetic Locking
No of slots/pole/phase = 3 or more for Integral slot winding	$(S_s - S_r) \neq \pm 1, \pm 2, \pm(\frac{P}{2}), \pm(P \pm 2)$
=> 3.5 for Fractional slot winding	- to avoid noise and vibration
Slot pitch = 15 mm to 25 mm	

Module - 5

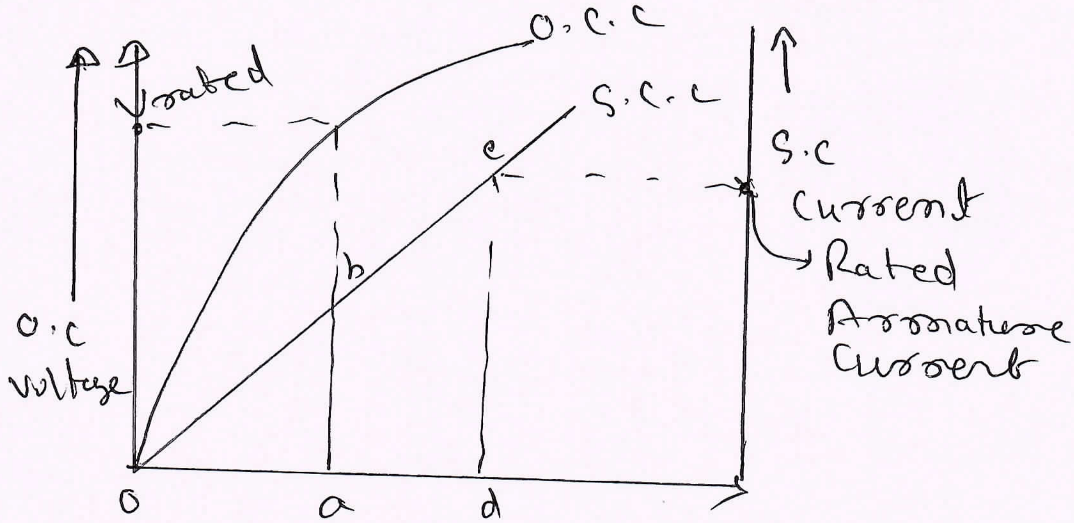
9a - What is SCR of synchronous machine? What are the effects of SCR on m/c performance?

(→ 10 marks)

Ans:-

Definition: It is the ratio of field current required to produce rated voltage on open circuit to field current required to circulate rated current on short circuit.

$$\text{Short Circuit Ratio} = \frac{I_f \text{ for O(Voltage)}}{I_f \text{ for SC current}}$$



Effect of SCR on Performance

1) Voltage Regulation
2) Stability
3) Parallel Operation
4) Short Circuit Currents
5) Self Excitation

Value of SCR should be HIGH
for High Stability, Low Regulation

High SCR requires large AirGap

Field System will be large.

m/c becomes costlier.

1) $SCR \propto \frac{1}{X_a} \propto \frac{1}{\text{Armature Reaction}}$

small SCR, poor Regulation

2) Air Gap length $\propto$ SCR

3) machine size $\propto$ SCR

4) Cost $\propto$ SCR

5) $\text{Power} = \frac{EV}{X_s} \sin\delta$

$= P \propto \frac{1}{X_s} \propto \sin\delta$

Power $\propto$ SCR

6) SCR is large, max power o/p.

7) stability $\propto SCR = \frac{EV}{X_s} \cos\delta$

8) stability $\propto$ SCR $\propto$ Air Gap Length

9b - Determine the main dimensions for 1000 KVA, 50 Hz, 3φ 375 r.p.m alternator. The average Gap Density is 0.55 wb/m² and ampere conductors per meter are 28000. Use Rectangular Poles and assume ratio of length of pole pitch in order that bolted on pole construction is used for which the maximum permissible peripheral speed is 50 m/s. Runaway Speed is 1.8 Times Synchronous Speed.

Ans: Given Data

1000 KVA, 50Hz, 3φ, 375 R.P.M alternator

$B_{av} = 0.55\ wb/m^2$ $\quad q = 28000\ ac/m$

Rectangular Pole

$L/T =$ Bolted Pole Construction

$V_a = 50\ m/s$ $\quad$ Run Away Speed $= 1.8 \times N_s$

$$n_s = \frac{375}{60} = 6.25\ r.p.s$$

$$P = \frac{2 \times 50}{6.25} = 16 \quad \therefore \text{Poles} = 16$$

K_{ws} = winding Factor = 0.955

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

$$= 11 \times 0.955 \times 0.55 \times 28000 = 162$$

$$Q = C_o D^2 L n_s$$

$$D^2 L = \frac{Q}{C_o n_s} = \frac{1000}{162 \times 6.25} = 0.989\ m^3$$

For Rectangular Pole

$L/\tau = 1$ to 5

let $L/\tau = 1$ $\quad \tau = \frac{\pi D}{P} = \frac{\pi D}{16}$

$$\boxed{L = 0.1963 D}$$

$$D^2 (0.1963 D) = 0.989$$

$$D = \left(\frac{0.989}{0.1963}\right)^{1/3}$$

$$D = 1.714 \text{ m}$$

$$L = 0.1963 \times 1.714 = 0.336 \text{ m}$$

Peripheral Speed $V_a = \frac{\pi D N}{60}$

$$V_a = \frac{\pi \times 1.714 \times 375}{60}$$

$$V_a = 33.65 \text{ m/sec}$$

Peripheral Runaway Speed $= 1.8 \times V_a$

Runaway Speed $= 1.8 \times 33.65$
$= 60.5$ m/s

So let $L/\tau = 2 \quad \therefore L = 2\tau$

$L = 0.392 D$

$D^2 (0.392 D) = 0.989 \quad \therefore \boxed{D = \left(\frac{0.989}{0.392}\right)^{1/3} = 1.36 \text{ m}}$

$$\boxed{L = 0.392 \times 1.36 = 0.533 \text{ m}}$$

$V_a = \pi \times 1.36 \times 375/60 = 26.5$ m/s

$\boxed{V_a = 1.8 \times 26.7 = 48 \text{ m/sec}}$

is within < 50 m/sec

10 a - The field coils of a salient pole alternator are wound with a single layer winding of bare Copper strip 30 mm deep, with separation insulation 0.15 mm thick. Find winding length, No of Turns and thickness of conductor to develop an mmf of 1200 A. Potential Difference of 5 V per coil and with loss of 1200 W/m² of Total coil Surface. Mean length of Turn is 1.2 m, Resistivity of Cu 0.021 Ω/m (10 mark)

Given Data:

Salient Pole Alternator - Single layer winding (bare Copper - 30 mm deep)

insulation ⇒ 0.15 mm thick

winding length = ? T_{stator}, T_{Rotor}

Thickness of Conductor = ?

mmf = 1200 A

Voltage per coil = 5 V

Loss = 1200 W/m²

L_{mt} = 1.2 m ρ = 0.021 Ω/m

Area of field Conductor

$$a_f = \rho \times (I_f T_f)/V_e$$

$$= 0.021 \times 1.2 \times \frac{1200}{5}$$

$$= 60.4 \text{ mm}^2$$

Height of Conductor $= \frac{60.4}{30} = 2$ mm

Revised Conductor area = 60 mm²

Total heat dissipating Surface

$S = 2 \times l_{mt} (h_f + d_f)$

$= 2 \times 1.2 (h_f + 0.03)$

$= 2.4 h_f + 0.072 \; m^2$

Total Loss Dissipated

$Q_f = 1200 [2.4 h_f + 0.072]$

$= 2880 h_f + 86.4$

$I_f = \frac{Q_f}{V_c} = \frac{(2880 h_f + 86.4)}{S}$

$= 5.76 h_f + 17.3$

$I_f T_f = (5.76 h_f + 17.3) T_f$

$= 1200$

$I_f T_f = 5.76 h_f T_f + 17.3 T_f$

$= 1200$

Height Occupied by conductor $= 2 + 0.15$

$= 2.15 \; mm$

$h_f = T_f \times 2.15 \times 10^{-3}$

$I_f T_f = 5.76 \times T_f \times 2.15 \times 10^{-3} T_f + 17.3 T_f = 1200$

$x^2 + 5x - 1200 = 0$, $I_f T_f \Rightarrow 0.012384 T_f^2 + 17.3 T_f = 1200$

$(0.012384) T_f^2 + 17.3 T_f - 1200 = 0$

~~$x + 5$~~

$T_f = 91$ Height of field winding $= 2.15 \times 91 = 196 \; mm$

10 b – Explain the Factors to be Considered in the selection of no of armature slots of a Synchronous m/c (→10 marks)

Ans: Factors Considered for No of Armature Slots in Synchronous m/c.

1) Balanced winding – To avoid overheating
2) Cost → more slots → more cost
3) Hot Spot Temperature – slots/pole/phase 3 to 4 for salient
4) Leakage Reactance – more with lesser slots
5) Tooth Ripples – Less with more slots
6) Flux Density in Iron Parts
7) Turbo Alternator is having 7 to 9 slots/pole/phase

Slot pitch

Low Voltage m/c ≤ 2.5 cm

Medium voltage m/c Upto 6 kV ≤ 4 cm

High voltage m/c upto 15 kV ≤ 6.0 cm

8) – Flux Density in Teeth ≤ 1.7 to 1.8 wb/m²

depth of slot = 3 x width of slot

Slot loading < 1500 ac/slot

For Fractional slot winding

No of slots/pole/phase = 3.5

width of slot = slot pitch - Tooth width

S.M. Jorasnadur
Chief