• Improve presentation

• Highlights your final answer.

288

MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-3 : Electrical and Electronic Measurements + Electrical Materials

Name ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	Kolkata ☐	Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the *answer sheet (viz. Name & Roll No).*
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the *question is specified in this Question Cum* Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	32
Q.2	48
Q.3	
Q.4	~~45~~ 49
Section-B	
Q.5	33
Q.6	
Q.7	
Q.8	48
Total Marks Obtained	~~206~~ 210

Signature of Evaluator: Saurabh kumar

Cross Checked by ....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Do not write in this margin

Section A : Electrical and Electronic Measurements

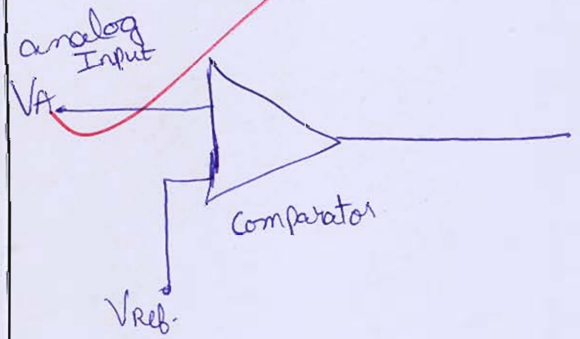
1 (a) What is a Digital Voltmeter? What are its merits? Explain Ramp type digital voltmeter technique along with suitable block diagram. Also show the functioning of ramp type DVM with the help of timing diagram.

[12 marks]

Digital Voltmeter is a device that is used to present the output voltage across its terminals in digital display.

Block diagram of Ramp Type digital voltmeter:

Ramp Type :
$T = (2^N - 1)T_{clk}$



2

Incomplete Solution

Do not write in this margin

Do not write in this margin

Q.1 (b) A single phase, watt-hour meter has a constant load of 6 A at 230 V passing through it for 10 hours at unity power factor. If the meter constant is 520 revolutions per kWh, how many revolutions does the meter disc makes during this period? If the same meter makes 1722 revolutions when operated at 230 V and a constant load of 9 A passing through it for certain duration with a power factor of 0.707, determine the duration of operation of the meter in hour.

[12 marks]

We know

Energy meter constant $= K = \frac{\text{No. of revolutions}}{\text{KWhr}}$

$= \frac{N}{P \times t}$

given

$K = 520$ rev/KWhr

$P = VI\cos\phi = 6 \times 230 \times 1 = 1.38\,KW$

as UPF $\cos\phi = 1$

$t = 10$ hr

so $520 = \frac{N}{1.38 \times 10} \Rightarrow N = 7176$

so energy meter makes 7176 revolutions.

If same meter:

makes $N = 1722$ revolutions

when $V = 230V$, $I = 9A$

$t = ?$, $Pf = 0.707$

so $P = VI\cos\phi = 230 \times 9 \times 0.707$

$= 1.463\,KW$

K = meter const $= 520$ rev/KWhr

so $K = \frac{N}{P \times t} \Rightarrow t = \frac{N}{P \times K}$

Do not write in this margin

so $t = \frac{1722}{1.46349 \times 520} = 2.62 hrs$

Hence energy meter takes 2.62hrs to make 1722 revolutions.

11

Good Approach

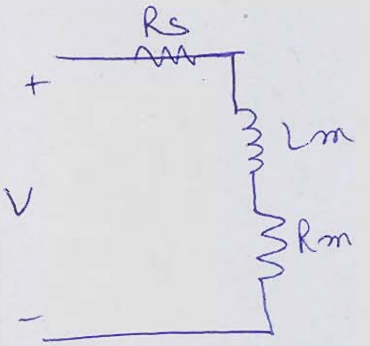
Q.1 (c) The coil of a 150 V moving iron voltmeter has a resistance of 400 Ω and an inductance of 0.75 H. The coil is made of copper which has a resistance temperature coefficient of 0.004/°C. The current consumed by the instrument when placed on a 150 V dc supply is 0.05 A. The series resistance of the voltmeter is of Manganin with a resistance temperature coefficient 0.00015/°C. Estimate:

(i) The temperature coefficient of the instrument.

(ii) The alternation of the reading between direct current and alternating current at 100 Hz.

(iii) The capacitance of the capacitor necessary to eliminate the frequency error.

[12 marks]



$R_m = 400\,\Omega$

$L_m = 0.75\,H$

on 150V DC   L → Short ckt.

$I_m = 0.05\,A$

so $V_m = I_m \times R_m = 400 \times 0.05 = 20\,V$

so series Resistance : $R_s = R_m(m-1)$

where $m = \frac{V}{V_m} = \frac{150}{20} = 7.5$

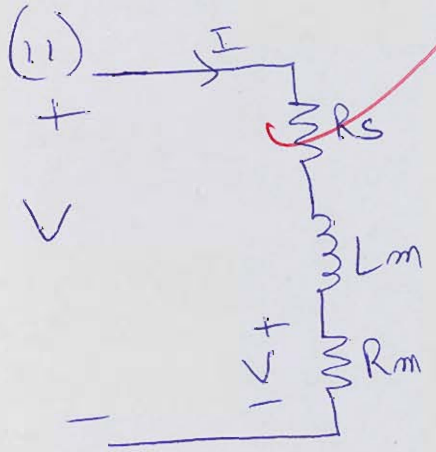
$R_s = 400(7.5-1) = 2600\,\Omega$

↑ made of Manganin

(i) temp. coefficient of instrument = α

$\alpha = \frac{\alpha_{cu} + \alpha_{mn}}{2} = 2.075 \times 10^{-3}/°C$

(ii)



at $f = 100\,Hz$

$I_{AC} = \frac{V}{\sqrt{(R_s+R_m)^2 + (2\pi f L_m)^2}}$

$= \frac{150}{\sqrt{(2600+400)^2 + (2\pi \times 100 \times 0.75)^2}}$

$\therefore I_{AC} = 0.0494\ A$

at $I_{DC} = 0.05\ A \longrightarrow 150V$

so $I_{AC} = 0.0494A \longrightarrow V_{True} = 150 \times \frac{0.0494}{0.05}$

$= 148.2V$

so

error or alteration $= V_{True} - V_{measure} = 150 - 148.2$

$= 1.8V$

so % error $= \frac{V_m - V_T}{V_T} \times 100 = \frac{148.2 - 150}{150} \times 100$

% error $= -1.2\%$

iii) $C = 0.41 \frac{L_m}{R_s^2}$

$= 0.41 \times \frac{0.75}{(2600)^2}$

$C = 45.488\ nF$

Hence to eliminate the frequency error we should connect a capacitor of capacitance 45.488nF in parallel.

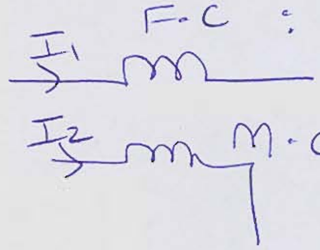
11

Good Approach

Q.1 (d) A dynamometer ammeter is fitted with two fixed coils having a total resistance of 3.0 Ω and a total inductance of 0.12 H, and a moving coil of resistance 30 Ω and an inductance of 0.003 H. Calculate the error in reading when the instrument is calibrated with d.c. and used on a.c. 50 Hz with moving coil shunted directly across the field coils. Comment upon the results.

[12 marks]

Dynamometer has 2 coils one is Fixed coil (FC) and another is Moving coil (MC).



F.C : $R = 3\,\Omega$ and $L = 0.12H$
Let I_1 be the passing current

M.C : $R = 30\,\Omega$ and $L = 0.003H$
Let I_2 be the passing current.

in dynamometer ammeter | MC and FC are connected in Parallel.

$$T_d = I_1 I_2 \cos\alpha \frac{dM}{d\theta}$$

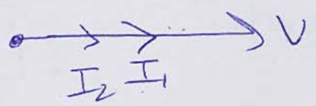
where α is angle btw the two coils.

Let reference voltage be V on both AC and AC scale.

<u>when calibrated with DC:</u>

L_{FC} & L_{MC} acts as short circuit.

so Phasor:



so $\alpha = 0$
ie No error.

<u>In case of AC Measurements:</u>

L is not short ckt.

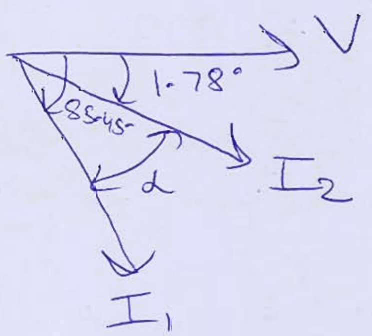
$$\phi_{FC} = \tan^{-1}\left(\frac{\omega L_{FC}}{R_{FC}}\right) = \tan^{-1}\left(\frac{2\pi \times 50 \times 0.12}{3}\right)$$

$$\phi_{FC} = 85.45^\circ \quad \text{wrt } V_{reference}$$

$$\phi_{MC} = \tan^{-1}\left(\frac{\omega L_{mc}}{R_{mc}}\right) = \tan^{-1}\left(\frac{2\pi\, 50 \times 0.003}{30}\right)$$

$$= 1.78^\circ \quad \text{wrt } V_{reference}$$

so phasor



so $\alpha = 85.45^\circ - 1.78^\circ$
$= 83.67^\circ$

6

so In case of AC measurement there will be error

$$\text{error} = \frac{\text{Measured} - \text{True}}{\text{True}} \times 100$$

$$= \frac{\cos 83.67 - 1}{1} \times 100$$

Incomplete solution

Q.1 (e) An electrostatic voltmeter is constructed with six parallel, semicircular fixed plates equivalent is 4 mm intervals and 5 interleaved semicircular movable plates that move in planes midway between the fixed plates in air. The movement of the movable plates is about an axis through the center of the circles of the plates system perpendicular to the planes of the plates. The instrument is spring-controlled. If the radius of the movable plates is 40 mm calculate the spring constant if 10 kV corresponds to a full-scale deflection of 100°. Neglect fringing edge effects and plate thickness. The permittivity of air is 8.85×10^{-12} F/m.

[12 marks]

For electrostatic Voltmeter

$$T_d = \frac{1}{2} V^2 \frac{dC}{d\theta}$$

and $T_c = K\theta$

given $\theta = 100^\circ$; $V = 10 KV$

Area of Movable plate $= \pi r^2 = \pi \times (40 \times 10^{-3})^2$

$= 1.6\pi \times 10^{-3} m^2$

$\epsilon_0 = 8.85 \times 10^{-12}$ F/m

$$C = \frac{A \epsilon_0}{d}$$

(2)

In complete Solution

Do not write in this margin

Q.2 (a) (i) The power flowing in a 3-phase, 3-wire balanced load system is measured by two wattmeter method. The reading of wattmeter-A is 9000 W and of wattmeter-B is –1800 W.

1. What is the power factor of the system?
2. If the voltage of the circuit is 440 V, what is the value of capacitance which must be introduced in each phase in series, which causes the whole of the power measured to appear on wattmeter A? (The frequency is 60 Hz).

[14 marks]

i)

Reading of Wattmeter-A : $W_A = 9000W$

Reading of Wattmeter-B : $W_B = -1800W$

so Total Active Power : $P = W_A + W_B$

$P = 7200W$

Reactive Power $= \sqrt{3}(W_A - W_B)$

$= \sqrt{3}(9000 - (-1800))$

$= \sqrt{3} \times 10800$ VAR

so Power factor of the system is given by : $\cos\phi$

where $\phi = \tan^{-1}\left|\frac{\sqrt{3}(W_A - W_B)}{W_A + W_B}\right|$

$= \tan^{-1}\left(\frac{\sqrt{3} \times 108\cancel{00}}{72\cancel{00}}\right) = 68.94°$

So Power Factor $= \cos\phi = \cos 68.94$

$= 0.36$ lag.

as one of the wattmeter's measures negative power so intuitively the pf of the system should have been less than 0.5.

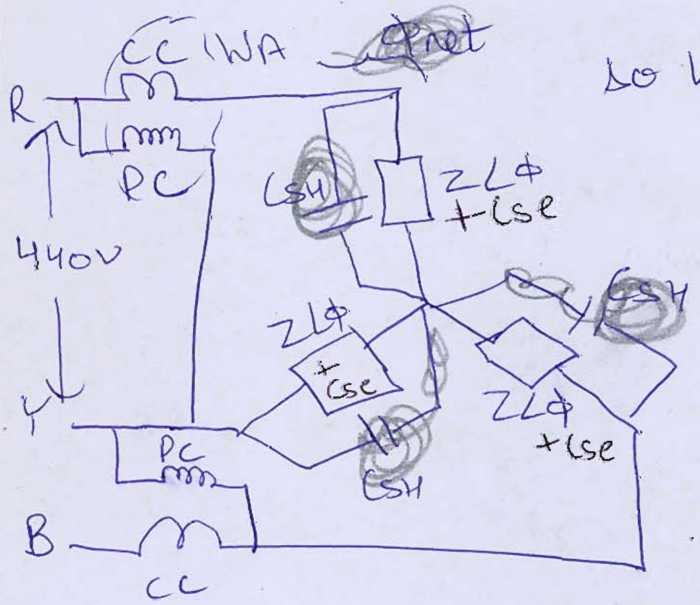
2) Given: Voltage of circuit = 440V (l-l)

Whole Power to be measured by Wattmeter A?

$P_{net} = W_A + W_B = 7200\,W$

For whole power to be measured by Wattmeter A the pf of the system should be 0.5 lag ie

$\phi_{net} = 60°$



so $W_A = V_{RY} \times I_R \cos 60°$

$\Rightarrow I_R = \dfrac{7200}{440 \times 0.5}$

$\Rightarrow I_R = 32.727A$

so $Z = R + j(X_L - X_C)$

for previous case ie (i) $W_A = 9000 = V_{RY} I_R \cos\phi$

$\Rightarrow I_R = \dfrac{9000}{440 \times 0.36} = 56.818A$

$I_R = I_{old}$

so $Z_{old} = \dfrac{V_{ph}}{I_{old}} = \dfrac{440/\sqrt{3}}{56.818} = 4.471\,\Omega$

so $R = |Z|\cos\phi = 4.471 \times 0.36 = 1.609\,\Omega$

$X_L = |Z|\sin\phi = 4.471 \times \sqrt{1-(0.36)^2} = 4.171\,\Omega$

so new Power factor $= 0.5 = \cos 60°$

$\Rightarrow \phi_{net} = 60°$

$\tan\phi_{net} = \dfrac{X_L - X_C}{R_L}$

$\tan 60 = \sqrt{3} = \dfrac{4.171 - X_C}{1.609}$

$\Rightarrow X_C = 1.384\,\Omega = \dfrac{1}{\omega C_S}$

given $f = 60$ Hz

$\Rightarrow C_S = \dfrac{1}{2\pi \times 60 \times 1.384} = 1.916$ mF

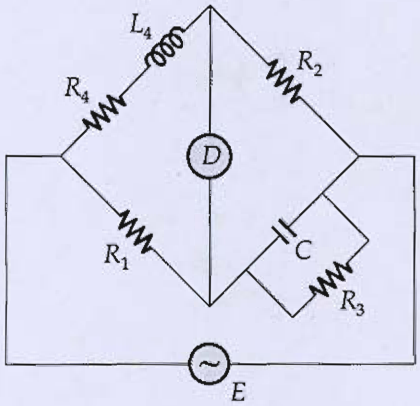
$\Rightarrow$ $\boxed{C_S = 1.916 \text{ mF}}$ series capacitance to be inserted to measure all power from a single wattmeter.

7

2 (a) (ii) In a Maxwell's bridge, the fixed - value bridge components have the following values:

$R_3 = 5\ \Omega$, $C = 1$ mF

If $R_1 = 159\ \Omega$ and $R_2 = 10\ \Omega$ at balance then find the Q-factor for the unknown impedance (L_4 and R_4 unknown impedance) at a supply frequency of 50 Hz.



[6 marks]

$Z_4 = R_4 + j\omega L_4$

$Z_2 = R_2$

$Z_1 = R_1$

$Z_3 = \dfrac{R_3 \times \frac{1}{j\omega C_3}}{R_3 + \frac{1}{j\omega C_3}} = \dfrac{R_3}{1 + j\omega C_3 R_3}$

6

at bridge balance $Z_4 Z_3 = Z_2 Z_1$

$\Rightarrow (R_4 + j\omega L_4) \times \dfrac{R_3}{1+j\omega C_3 R_3} = R_2 R_1$

$\Rightarrow R_3 R_4 + j\omega L_4 R_3 = R_2 R_1 + j\omega C_3 R_3 R_2 R_1$

by seperating real and imaginary parts:

& substituting values

Real: $R_3 R_4 = R_2 R_1$

$\Rightarrow R_4 = \dfrac{R_2 R_1}{R_3} = \dfrac{\overset{2}{\cancel{10}} \times 159}{\cancel{5}}$

$\Rightarrow \boxed{R_4 = 318\ \Omega}$

img- Parts:

$\boxed{L_4 = C_3 R_2 R_1 = 1.59\text{H}}$

so $Q = \dfrac{\omega L_4}{R_4} = \dfrac{2\pi \times 50 \times 318}{1.59}$

$\Rightarrow \boxed{Q = 62831.85}$

Q.2 (b) **(i)** A current transformer having a 1 turn primary is rated at 500/5 A, 50 Hz with an output of 15 VA. At rated load with non-inductive burden, the inphase and quadrature components (referred to the flux) of the exciting mmf are 8 and 10 A respectively. The number of turns in the secondary is 98, and the resistance and leakage reactance of the secondary winding are 0.35 Ω and 0.3 Ω respectively. Calculate the ratio and phase angle error.

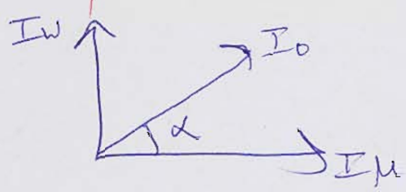
(ii) What are the advantages and disadvantages of PMMC instruments?

[12 + 8 marks]

(i) $N_p = 1$

so Nominal ratio $K = \frac{I_p}{I_s} = \frac{500}{5} = 100$

$I_\mu = 8A$ and $I_w = 10A$



$N_s = 98$

so $n = \frac{98}{1} = 98$

given secondary is non-inductive burden.

$I_0 = \sqrt{I_\mu^2 + I_w^2} = \sqrt{64+100} = 12.806 A$

$\alpha = \tan^{-1}\left(\frac{I_w}{I_\mu}\right) = \tan^{-1}\left(\frac{10}{8}\right) = 51.34°$

given output $= 15 VA = V_s I_s$

$\Rightarrow V_s = \frac{15}{5} = 3$

so $R_{burden} = \frac{V_s}{I_s} = \frac{3}{5} = 0.6 \Omega$

so secondary burden angle $\delta = \tan^{-1}\left(\frac{x_e}{r_e + R_{burden}}\right)$

$= \tan^{-1}\left(\frac{0.3}{0.35+0.6}\right) = 17.525°$

we know

actual ratio $R = n + \frac{I_0 \sin(\alpha+\delta)}{I_s}$

$$R = 98 + \frac{12.806 \sin(51.34 + 17.525)}{5}$$

$$R = 100.388$$

so
Ratio error $\sigma_{CT} = \frac{\text{Measured} - \text{True}}{\text{True}} \times 100$

$$= \frac{K - R}{R} \times 100 = \frac{100 - 100.388}{100.388} \times 100$$

$$\sigma_{CT} = -0.386\%$$

also
Phase angle error: $\theta_p = \frac{I_o \cos(\alpha + \delta)}{n I_s} \times \frac{180}{\pi}$ °

$$= \frac{12.806 \cos(51.34 + 17.525)}{98 \times 5} \times \frac{180}{\pi}$$

$$\boxed{\theta_p = 0.54^\circ}$$

(ii) Advantages and Disadvantages of a PMMC Instrument.

Advantages:

1) It has a linear scale.
2) It has high torque to weight ratio.
3) ~~B~~It has self shielding property because of presence

of permanent magnet.

4) It does not require any compensating coil to reduce or neglect the effect of external magnetic field.

5) It is used to measure DC/ average voltage or current.

Disadvantages:

1) It is expensive compared to a moving iron instrument.

2) It can not be used for AC measurement applications.

18

Do not write in this margin

Q.2 (c) (i) An ac bridge with terminals ABCD has following components:

Arm AB : A resistance of 800 Ω in parallel with a capacitor of 0.5 μF.

Arm BC : A resistance of 400 Ω in series with a capacitor of 1 μF.

Arm CD : A resistance of 1000 Ω

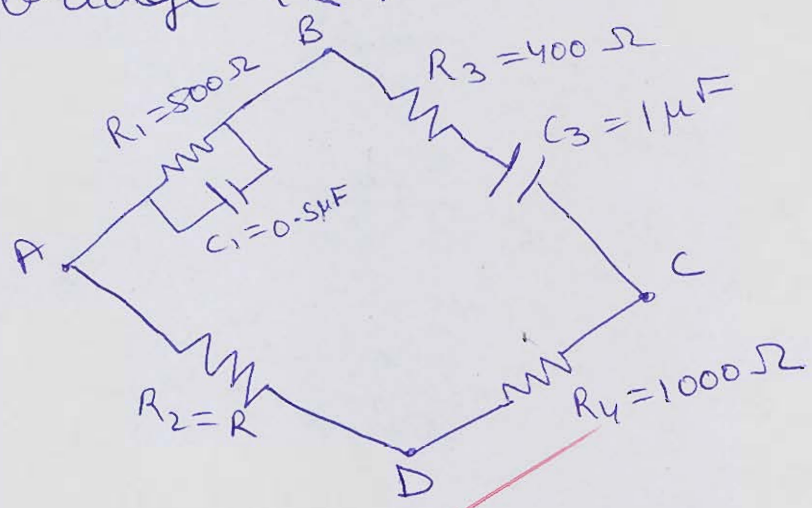
Arm DA : A pure resistance R.

Find the value of the frequency at which the bridge will balance.

(ii) A moving coil instrument whose resistance is 25 Ω gives a full scale deflection with a voltage of 25 mV. This instrument is to be used with a series multiplier to extend its range to 10 V. Calculate the error caused by 10°C rise in temperature. (The temperature coefficient of copper is 0.004/°C and that of manganin is 0.00015/°C).

[12 + 8 marks]

(i) so bridge is :



at bridge balance $Z_{AB} Z_{CD} = Z_{AD} Z_{BC}$

now

$$Z_{AB} = \frac{R_1 \times \frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = \frac{R_1}{1 + j\omega C_1 R_1}$$

$$Z_{CD} = R_4$$

$$Z_{AD} = R_2$$

$$Z_{BC} = R_3 + \frac{1}{j\omega C_3} = \frac{1 + j\omega C_3 R_3}{j\omega C_3}$$

so substituting in bridge balance equation

$$\left(\frac{R_1}{1 + j\omega C_1 R_1}\right) \times \left(R_4\right) = R_2 \frac{(1 + j\omega C_3 R_3)}{j\omega C_3}$$

$\Rightarrow j R_1 R_4 \omega C_3 = (R_2 + j\omega C_3 R_3 R_2)(1 + j\omega C_1 R_1)$

$= R_2 - \omega^2 C_3 R_3 R_2 C_1 R_1$

$+ j(\omega C_1 R_1 R_2 + \omega C_3 R_3 R_2)$

by seperating Real and imaginary parts

$R_1 R_4 \omega C_3 = \omega [C_1 R_1 R_2 + C_3 R_3 R_2]$

substituting values

$R_2 = R = \frac{R_1 R_4 C_3}{C_1 R_1 + C_3 R_3} = \frac{800 \times 1000 \times 10^{-6}}{0.5 \times 10^{-6} \times 800 + 1 \times 10^{-6} \times 400}$

$\Rightarrow \boxed{R = 1000\ \Omega}$

(1)

so Real Part :

$R_2 - \omega^2 C_3 R_3 R_2 C_1 R_1 = 0$

Good Approach

$\Rightarrow \omega = \sqrt{\frac{1}{C_3 R_3 C_1 R_1}}$

so $f = \frac{1}{2\pi}\sqrt{\frac{1}{1\times10^{-6} \times 400 \times 0.5\times10^{-6} \times 800}}$

$\boxed{f = 397.88\ Hz}$

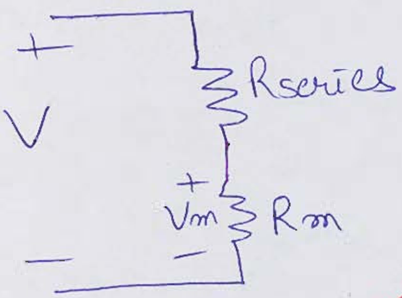
PTO for (ii)

ii) Moving coil instrument

$R_{meter} = R_m = 25\,\Omega$

$V_m = 25\,mV$ — R_m made of Cu and R_s of Manganin

$V = 10\,V$



so $R_{series} = R_m(m-1)$

where $m = \frac{V}{V_m} = \frac{10}{25\times10^{-3}}$

$m = 400$

$\Rightarrow R_s = 25(400-1) = 9975\,\Omega$

we know

$R = R_0(1+\alpha\Delta T)$; $\alpha_{cu} = 0.004/°C$, $\alpha_{mn} = 0.00015$

given $\Delta T = 10°C$

so with 10°C Rise in temp.

$R_m' = R_{m_0}(1+\alpha_{cu}\Delta T)$

$= 25(1+0.004\times10) = 26\,\Omega$

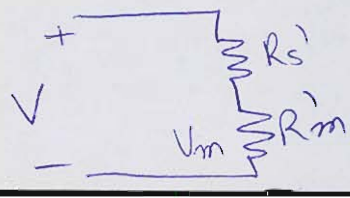
6

$R_s' = R_{s0}(1+\alpha_{Mn}\Delta T)$

$= 9975(1+0.00015\times10)$

$R_s' = 9989.962\,\Omega$

so now ckt. is



so $V_{m\,new} = \frac{V\times R_m'}{R_m'+R_s'}$

$\Rightarrow V_{m\,new} = 10 \times \frac{26}{26 + 9989.962}$

$V_{m\,new} = 25.958\ mV$

So

$\text{Error} = \frac{\text{Measured} - \text{True}}{\text{True}} \times 100$

$\text{True} = V_m = 25\ mV$

$\therefore Er = \frac{25.958 - 25}{25} \times 100$

$\therefore \boxed{\text{error} = 3.832\ \%}$

Do not write in this margin

Q.3 (a) A PMMC voltmeter with resistance of 25 Ω has a full scale deflection of 150° for a voltage of 90 mV across it. The coil dimensions are 25 mm × 25 mm having number of turns equal to 120. Current carrying turns are made of conductor with specific resistivity $= 1.7 \times 10^{-8}$ Ω-m. The control spring constant is 0.45×10^{-6} N-m/degree. The coil resistance is 40% of total instrument resistance. The value of diameter of conductor wire used in coil winding and flux density in air gap will be respectively

[20 marks]

Q.3 (b) (i) A current transformer has a single turn primary and 400 turns on secondary winding. The resistance and reactance of the secondary circuit are 2 Ω and 3 Ω respectively including transformer winding. When 6 A current is flowing in the secondary winding, the magnetizing mmf is 100 AT and iron loss is 2 W, find the value of ratio error.

(ii) Give a generalized diagram of digital data acquisition system. Also explain the various components and their functions.

[14 + 6 marks]

Do not write in this mar

Q.3 (c) Explain in detail the working principle of linear variable differential transducer (LVDT). Write down its advantages.

[20 marks]

Do not write in this mar

Q.4 (a) (i) The variable 'A' is related to three other variables B, C and D as $A = \frac{B}{CD}$. The variables B, C and D are measured with meters of accuracy ± 0.5% of reading, ±1.2% of full scale value and ±1.5% of reading respectively. If actual readings are respectively 90, 20 and 60 with 100 being full scale value for B, C and D, then find the maximum limiting error in reading of A.

(ii) Derive the expression for force developed by an electrostatic instrument.

[12 + 8 marks]

(i) $A = \frac{B}{CD}$

so max^m possible error in A $= \epsilon_{rB} + \epsilon_{rC} + \epsilon_{rD}$

now given:

$B = 90 \pm 0.5\%$

error in C is $\pm 1.2\%$ for full scale value

we know error at reading $= \frac{\text{error @ Full scale} \times \text{Full scale value}}{\text{Reading value}}$

give $C = 20$
and Full scale $= 100$

so error in C : $\epsilon_C = \frac{1.2 \times 100}{20}$

$\epsilon_C = \pm 6\%$

$D = 60 \pm 1.5\%$

so $A = \frac{B}{CD} = \frac{90}{20 \times 60} = 0.075$

error in A : $\epsilon_A = \epsilon_B + \epsilon_C + \epsilon_D$

so $\epsilon_A = 0.5 + 6 + 1.5$

$\Rightarrow \epsilon_A = \pm 8\%$

so

$$A = 0.075 \pm 8\%$$

so Max^m limiting error in A = 8%

Max^m limiting error is the max^m possible error in a reading.

5 10

---

ii) Electrostatic Instrument is used for DC/AC voltage measurements. It has a non-linear scale.

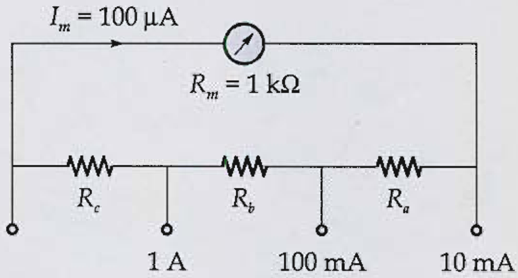
Electrostatic Instrument uses fluid friction damping.

Torque equation is given by:

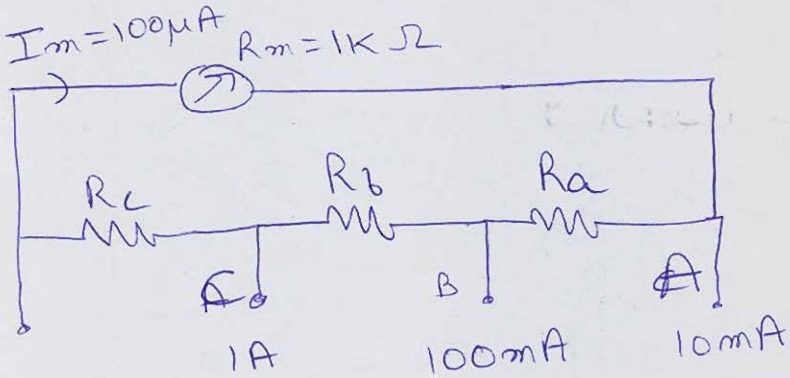
$$T_d = \frac{1}{2} V^2 \frac{dc}{d\theta}$$

4

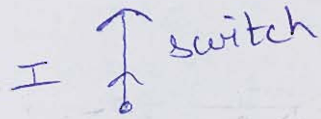
Q.4 (b) Calculate the value of the shunt resistors for the circuit shown below:



[20 marks]



$$R_{SH} = \frac{R_m}{m-1}$$



~~Let us~~ When switch is connected at A

$I = 10\,mA$; $I_m = 100\,\mu A$

So $m = \frac{I}{I_m} = \frac{10 \times 10^{-3}}{100 \times 10^{-6}} = 100$

$R_s = R_a + R_b + R_c$

$R_s = \frac{R_m}{m-1} = \frac{1000}{99}$

$\Rightarrow R_a + R_b + R_c = \frac{1000}{99}$ —(1)

When switch connected at B:

$I = 100\,mA$

$\therefore m = \frac{I}{I_m} = \frac{100 \times 10^{-3}}{100 \times 10^{-6}} = 1000$

so $R_c + R_b$ = $\frac{R_m + R_a}{m-1} = \frac{1000 + R_b + R_a}{1000 - 1}$

$\therefore$ ~~$999R_a - R_b - R_c = 1000$ — (2)~~

$-R_a + 999R_b + 999R_c = 1000$ — (2)

switch connected at C

$I = 1A$; $R_{SH} = R_c$

~~$R_{SH} = R_b + R_a$~~ & $R_m' = R_m + R_a + R_b$

$m = \frac{I}{I_m} = \frac{1}{100 \times 10^{-6}} = 10{,}000$

$\therefore R_{SH} = \frac{R_m'}{m-1} = \frac{1000 + R_a + R_b}{10{,}000 - 1}$

$\therefore$ ~~$9999R_a + 9999R_b - R_c = 1000$ — (3)~~

$-R_a - R_b + 9999R_c = 1000$ — (3)

so equations in matrix form

Go through the made easy solution

6

18

~~$$\begin{bmatrix} 1 & 1 & 1 \\ 999 & -1 & -1 \\ 9999 & 9999 & -1 \end{bmatrix} \begin{bmatrix} R_a \\ R_b \\ R_c \end{bmatrix} = \begin{bmatrix} \frac{1000}{99} \\ 1000 \\ 1000 \end{bmatrix}$$~~

~~solving~~ in matrix form

~~$R_a =$~~

$$\begin{bmatrix} 1 & 1 & 1 \\ -1 & 999 & 999 \\ -1 & -1 & 9999 \end{bmatrix} \begin{bmatrix} R_a \\ R_b \\ R_c \end{bmatrix} = \begin{bmatrix} 1000/99 \\ 1000 \\ 1000 \end{bmatrix}$$

solving

$\Rightarrow R_a = 9.09\,\Omega$; $R_b = 0.909\,\Omega$; $R_c = 0.101\,\Omega$

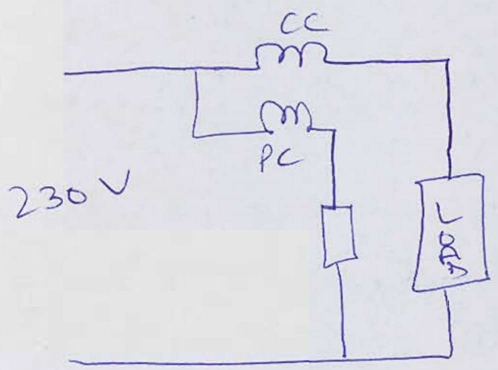
Q.4 (c) (i) A dynamometer type wattmeter with pressure coil angle of 2° measure 800 W for 1 - ϕ inductive load supplied by 230 V. If this wattmeter is replaced by another wattmeter with pressure coil angle 1° reading obtained is 640 W, find the value of current drawn by load.

(ii) Calculate the constants of a shunt to extend the range of 0 - 5 A moving iron armature to 0 - 50 A. The instrument constants are $R = 0.09\ \Omega$ and $L = 90$ mH. If the shunt is made non-inductive and the combination is correct on d.c., find the full scale errors at 50 Hz.

[10 + 10 marks]

(i) Let Pressure coil (PC) angle be β

$\beta = 2°$ & Power factor of load angle be ϕ



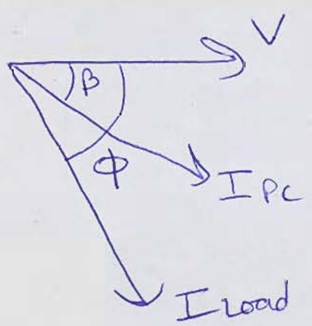
Case 1: $\beta = 2°$

$P_{measured} = 800\,W$

$V = 230\,V$

we know for wattmeter

$$P_{measure} = V I \cos\beta \cos(\phi - \beta)$$



$\therefore 800 = 230\, I \cos 2° \cos(\phi - 2)$ — ①

Case 2 : $\beta = 1°$, $P_m = 640\,W$

ie $640 = V I \cos 1° \cos(\phi - 1)$ — ②

dividing ① & ②

$$\frac{800}{640} = \frac{\cos 2° \cos(\phi - 2°)}{\cos 1° \cos(\phi - 1)}$$

$\therefore \dfrac{\cos(\phi - 2)}{\cos(\phi - 1)} = 1.2505$

~~cos φ cos 2 − sin φ~~ solving above equation we get: $\phi = 86.97°$

so using eq^n ①

$800 = 230 \times I \times \cos 2 \cos(86.97 - 2)$

$\Rightarrow \boxed{I = 39.695\,A}$ (8) (9)

Hence current drawn by inductive load is 39.695 A.

(ii) Given: $I_m = 5A$

$R_m = 0.09\,\Omega$ and $L = 90\,mH$

non-inductive shunt : R_{SH}

$I = 50A$

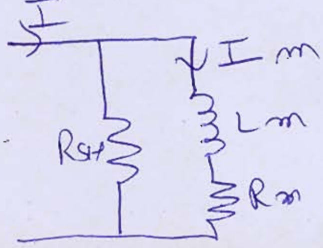
Moving iron Instrument.

combination is correct on DC side

so $R_{SH} = \dfrac{R_m}{m-1}$ where, $m = \dfrac{I}{I_m} = \dfrac{50}{5}$

$m = 10$

$\Rightarrow R_{SH} = \dfrac{0.09}{10 - 1} = \dfrac{0.09}{9} = 0.01\,\Omega$

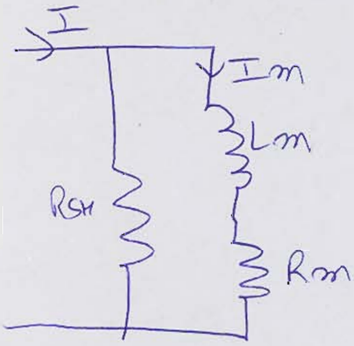


with DC: L → short circuit.

$I_m = 50A$ measures correctly [given]

Do not write in this margin

for AC combination:



so $I_m = \dfrac{I \times R_{SH}}{\sqrt{(R_{SH}+R_m)^2 + (2\pi f L_m)^2}}$

$f = 50\,Hz$

$L_m = 90\,mH$

by current division rule.

$\therefore I_m = \dfrac{50 \times 0.01}{\sqrt{(0.01+0.09)^2 + (2\pi \times 50 \times 90 \times 10^{-3})^2}}$

$I_m = 0.0176\ A$

so $\text{Error} = \dfrac{\text{Measured} - \text{True}}{\text{True}} \times 100$

$\dfrac{0.0176 - 5}{5} \times 100$

$\therefore$ $\boxed{\text{Error} = -99.64\,\%}$

4

8

Do not write in this margin

Section B : Electrical Materials

Q.5 (a) Consider a parallel-plate capacitor having an area of 6.45×10^{-4} m^2 and a plate separation of 2×10^{-3} m across which a potential of 10 V is applied. If a material having a dielectric constant of 6.0 is positioned within the region between the plates, compute:

(i) The capacitance.

(ii) The magnitude of the charge stored on each plate.

(iii) The dielectric displacement D.

(iv) The polarization.

[12 marks]

i) $C = \frac{A\epsilon_0\epsilon_r}{d} = \frac{6.45 \times 10^{-4} \times 6 \times 8.85 \times 10^{-12}}{2 \times 10^{-3}}$

$= \underline{17.124 \text{ pF}}$

ii) $Q = CV = 17.124 \times 10$

$Q = \underline{0.17124 \text{ nC}}$

iii) we know $D = \sout{\epsilon_0\epsilon_r E}$

we know $V = E \cdot D$

Energy stored in capacitor per unit volume [w] $= \frac{1}{2}CV^2 = \frac{1}{2}C$

iv) ~~Polarization : P = ε0(εr − 1) E~~

so

$w = \frac{1}{2} \times 17.124 \times 10^2$

$= 0.8562 \times 10^{-9}$ Joules

also

$w = \frac{1}{2}\epsilon_0 E^2$

$\therefore E^2 = \frac{2 \times 0.8562 \times 10^{-9}}{8.85 \times 10^{-12}}$

Do not write in this margin

so $E = 13.91 \ V/m$

and $V = E \cdot D$

$\Rightarrow$ dielectric displacement

$$D = \frac{V}{E} = \frac{10}{13.91}$$

$$D = 0.7189 \ m$$

iv) we know Polarization

$$P = \epsilon_0 (\epsilon_r - 1) E$$

$$\Rightarrow P = 8.85 \times 10^{-12} (6-1) \times 13.91$$

$$P = 6.155 \times 10^{-10} \ C/m^2$$

5

Do not write in this margin

Q.5 (b) What is magnetic anisotropy? Explain the importance of magnetic anisotropy in transformer cores.

[12 marks]

~~Whe~~ In some magnetic material the property depend upon the direction in which they are measured. Such type of materials are known as anisotropic materials.

Magnetic Anisotropy can be induced in a material in 3 ways:

1) Cold Working: Heating and Forcefully cooling.

→ Cold Working such as cold rolling induces magnetic anisotropy in the direction of rolling.

2) Magnetic Annealing: Slow heating and slow cooling.

→ In this process heat treatment is done on a material in presence of magnetic ~~on~~ field to induce anisotropy.

3) Magnetic Quenching: heating and fast cooling.

→ In this method the material is cooled upto curie temperature in presence of magnetic field.

→ It induced anisotropy either in the direction of field or in the direction perpendicular to the field.

→ In transformer cores we use CRGOS material ie Cold Rolled Grained Oriented Steel.
In this material we use cold working to induce anisotropy in the direction of rolling.

7

Do not write in this margin

Q.5 (c) (i) The Burgers vector of a mixed dislocation line is $\frac{1}{2}[1\ \ 1\ \ 0]$. The dislocation line lies along the $[1\ \ 1\ \ 2]$ direction. Find the slip plane on which this dislocation lies.

(ii) Explain, why end centered tetragonal geometry does not exist.

[8 + 4 marks]

Do not write in this margin

Q.5 (d) The magnetic field intensity $H = 2400$ A/m in a material when $B = 4$ Wb/m^2. When $\vec{H}$ is reduced to 800 A/m, $B = 2.8$ Wb/m^2, calculate the change in Magnetization M.

[12 marks]

we know

Magnetization $\vec{M} = \mu_0(\mu_r - 1)\vec{H}$

as changes in a single material

so $\mu_r \rightarrow$ same. and $B = \mu_0 \mu_r H$

also $\vec{B} = \mu_0(\vec{H} + \vec{M})$

when $H = 2400$ A/m, $B = 4$ Wb/m^2

so $M = \dfrac{B}{\mu_0} - H$

$M = \dfrac{4}{4\pi \times 10^{-7}} - 2400 = 3.18 \times 10^6$ A/m

when $H' = 800$ A/m, $B' = 2.8$ Wb/m^2

so $M'' = \dfrac{2.8}{4\pi \times 10^{-7}} - 800 = 2.2257 \times 10^6$ A/m

so change in Magnetization:

$\Delta H = M - M'' = 0.954 \times 10^6$ A/m

10

.5 (e) Molybdenum has the BCC crystal structure, a density of 10.22 $g\,cm^{-3}$ and an atomic mass of 95.94 $g\ mol^{-1}$. Find the atomic concentration, lattice parameter a and atomic radius of molybdenum.

[12 marks]

in BCC crystal structure:

$4r = a\sqrt{3}$ and $N = 2$

also

we know $\rho = \frac{N \cdot A}{N_A V_c}$ —①

atomic concentration $= \frac{N}{N_A} = \frac{2}{6.022\times10^{23}}$

$= 3.321\times10^{-24}$ atoms/molecules.

so using ①

$V_c = \frac{N A}{N_A \rho}$ substituting values

$= \frac{2\times 95.94}{6.022\times10^{23}\times 10.22\times10^{-6}}$

11

$V_c = 3.1177\times10^{-17}\ m^3$

Good Approach

we know Volume of unit cell $= a^3$

$a^3 = 3.117\times10^{-17}\ m^3$

$\Rightarrow$ $\boxed{a = 3.147\ \mu m}$

we know in BCC: $4r = a\sqrt{3}$

$\therefore$ atomic radius $= \frac{a\sqrt{3}}{4} = 1.3628\ \mu m$

Do not write in this marg

Do not write in this margin

.6 (a) Define dielectric strength. Discuss different types of dielectric breakdowns in solids.

[20 marks]

Do not write in this mar

Q.6 (b) (i) The resistivity of a doped silicon sample is 9×10^{-3} Ωm. The hall coefficient was measured to be 7.2×10^{-4} m^3 $columb^{-1}$. Assuming single carrier conduction, find the mobility and density of charge carrier.

(ii) What are type-I and type-II superconductors? Draw the magnetization versus magnetic field characteristic for type-I and type-II superconductors. Why superconductivity is observed for signals upto radio frequencies?

[12 + 8 marks]

Do not write in this margin

6 (c) (i) Explain the features of soft-magnetic materials with suitable examples and uses.

(ii) A material with magnetic property such that when it was placed in a magnetic field, $B = 4\ \text{Wb/m}^2$, magnetic field intensity was found to be 4800 A/m. If $\vec{H}$ is reduced to 640 A/m and $B = 1.8\ \text{Wb/m}^2$, then calculate the percentage change in magnetization M of the material.

[8 + 12 marks]

Q.7 (a) Explain the phenomenon of superconductivity. Briefly explain its salient features, mechanism and applications.

The periphery of a copper disk 50 cm in radius and 10^{-3} mm in thickness is maintained at a potential of 50 V. A thin rod 1 cm in radius is soldered to the disk at its centre (at right angles to the plane of the disk) and maintained at a potential of 49 V. If the resistivity of copper is 1.7×10^{-8} Ωm, calculate the current through the disk.

[20 marks]

Do not write in this margin

7 (b) (i) What is magnetoresistance effect? Calculate the current produced in a small germanium plate of area 1 cm^2 and thickness 0.3 mm when a potential difference of 2 V is applied across the faces.
(Given: Concentration of free electrons in germanium is $2 \times 10^{19}/m^3$ and mobilities of electrons and holes are 0.40 m^2/V-sec and 0.20 m^2/V-sec respectively).

(ii) Explain why end-centred tetragonal geometry does not exist in Bravais crystal structures.

[12 + 8 marks]

Do not write in this margin

Q.7 (c) Explain briefly the polarization occurring in dielectric materials. What are different types of polarization occurring in dielectric material?

If a dielectric material contains 3.2×10^{19} polar molecules/m^3 and the relative permittivity of material is $\epsilon_r = 2.4$ with applied external electric field $\vec{E} = 10^4 \overrightarrow{a_x}$ V/m, then calculate the value of polarization and dipole moment in each molecule. (Consider all molecules have same dipole moment).

[20 marks]

Do not write in this margin

Q.8 (a) (i) Derive the Clausius-Mossotti equation in case of non polar dielectric material in presence of dc field relating polarization (α) and dielectric constant of the material. Take number of molecules per unit volume of dielectric 'N'.

(ii) The Hall coefficient of a certain silicon specimen was found to be -8.25×10^{-5} m^3/C at 300° K. If the conductivity is 2.50 ℧/cm, then find :

1. type of semiconductor.
2. density of charge carrier.
3. mobility of charge carrier.

[10 + 10 marks]

(i) Assumptions for Clausius - Mossoti equation:

1) Polarizability of the molecules is isotropic in nature.

2) Orientation of the molecules is isotropic in nature.

3) Polarization is only due to elastic displacement.

4) Absence of short ranged non dipolar interaction.

This equation is used to cubic crystal system.

Hence $\gamma = \frac{1}{3}$ → internal field constant.

so N → No. of molecules per unit volume

Polarization : $P = N \alpha E_i$ —①

where $E_i = E + \frac{\gamma P}{\epsilon_0} = E + \frac{P}{3\epsilon_0}$ —②

(E_i → Internal Electric field)

also we know

$P = \epsilon_0 (\epsilon_r - 1) E$ —③

so substituting these ② in ①

$$P \; \cancel{\epsilon_0(\epsilon_r-1)E} = N\alpha\left(E + \frac{P}{3\epsilon_0}\right)$$

$$P = N\alpha E + \frac{N\alpha P}{3\epsilon_0}$$

$$\therefore \quad P\left(1 - \frac{N\alpha}{3\epsilon_0}\right) = N\alpha E$$

$$P = \frac{N\alpha E}{1 - \frac{N\alpha}{3\epsilon_0}}$$

using ③

$$\epsilon_0(\epsilon_r - 1)\cancel{E} = \frac{N\alpha \cancel{E}}{1 - \frac{N\alpha}{3\epsilon_0}}$$

$$\therefore \epsilon_r - 1 = \frac{N\alpha/\epsilon_0}{1 - \frac{N\alpha}{3\epsilon_0}} \quad — ④$$

add +3 on both sides

$$\epsilon_r + 2 = \frac{N\alpha/\epsilon_0}{1 - \frac{N\alpha}{3\epsilon_0}} + 3 = \frac{\cancel{\frac{N\alpha}{\epsilon_0}} + 3 - \cancel{\frac{N\alpha}{\epsilon_0}}}{1 - \frac{N\alpha}{3\epsilon_0}}$$

$$\therefore \epsilon_r + 2 = \frac{3}{1 - \frac{N\alpha}{3\epsilon_0}} \quad — ⑤$$

9

Good Approach

dividing equation ④ and ⑤

$$\therefore \boxed{\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha}{3\epsilon_0}} \Rightarrow \text{required CM eq}^n.$$

Do not write in this margin

ii) $R_H = -8.25 \times 10^{-5} \ m^3/C$; $T = 300^\circ K$

$\sigma = 2.50 \ \mho/cm = 2.50 \times 10^2 \ \mho/m$

1) as Hall coefficient R_H is negative
$\Rightarrow$ semiconductor is n-type.

2) density of charge carriers : ρ

$$\rho = \frac{NA}{N_A V} = \frac{nA}{V}$$

3) mobility of charge carrier

$$\mu = |\sigma R_H| = 2.50 \times 10^2 \times 8.25 \times 10^{-5}$$

$$\therefore \mu = 20.625 \times 10^{-3} \ m/V\text{-}s$$

9

Good Approach

8 (b) (i) Differentiate between different types of magnetic materials on the basis of magnetic dipoles and hysteresis loops.

(ii) The following data refers to a dielectric material having $\varepsilon_r = 4.94$, $n^2 = 2.69$, where n is the index of refraction. Calculate the ratio between electronic and ionic polarization for this material.

[12 + 8 marks]

(i) Different types of Magnetic materials on basis of magnetic dipoles:

1) Diamagnetic Material: has no magnetic dipoles and susceptability is small and negative.

2) Paramagnetic Materials: has magnetic dipoles but are arranged in random order. Magnetic susceptability is small and +ve.

3) Ferromagnetic Materials: Magnetic dipoles are aligned in parallel direction. χ_m is +ve and large.

[↑↑↑↑]

4) Antiferromagnetic : Magnetic dipoles are arranged in antiparallel and are equal in magnitude.

[↑↓↑↓↑↓] χ_m is small and positive

5) <u>Ferrimagnetic:</u> Have Anti parallel alignment of dipoles but are not equal in magnitude. χ_m is large and +ve.

[↑↓ ↑↓ ↑↓ ↑↓]

<u>Differentiation of Ferrite Magnetic Material on basis of hyperesis loop:</u>

1) <u>Soft Magnetic Material:</u> The ~~at~~ hysteresis loop is smaller or narrower.
eg: Permalloy.

2) <u>Hard Magnetic Material:</u> It has wider hysteresis loop and used to form permanent magnets.
eg: Ba - Sr ferrites.

10

3) <u>Rectangular Loop Ferrite:</u> It has hysteresis loop as rectangular and used as magnetic memories.
eg: Mn - Mg ferrites etc.

Do not write in this margin

ii) $\epsilon_r = 4.94$, $n^2 = 2.69$

$$\frac{\alpha_e}{\alpha_i} = ?$$

by Claussius Mossati eq^n

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N[\alpha_e + \alpha_i]}{3\epsilon_0}$$

and by maxwell's relation we can replace $\epsilon_r = n^2$ in CM equation where $\alpha = \alpha_e$

$$\therefore \frac{4.94 - 1}{4.94 + 2} = \frac{N[\alpha_e + \alpha_i]}{3\epsilon_0} \quad -(1)$$

and

$$\frac{2.69 - 1}{2.69 + 2} = \frac{N\alpha_e}{3\epsilon_0} \quad -(2)$$

dividing (1) by (2)

$$\frac{0.5677}{0.360} = \frac{\alpha_e + \alpha_i}{\alpha_e}$$

7

Good Approach

$$\therefore 1 + \frac{\alpha_i}{\alpha_e} = 1.5769$$

$$\frac{\alpha_i}{\alpha_e} = 0.5769$$

$$\Rightarrow \boxed{\frac{\alpha_e}{\alpha_i} = 1.733}$$

Do not write in this margin

Q.8 (c) (i) A ferromagnetic material of 20 kg mass and 7200 kg/m^3 density is subjected to an AC supply of 60 Hz frequency. The hysteresis loop area of the material is 180 cm^2. The scale factors on ordinate and abscissa are 1 cm = 0.004 Wb/m^2 and 1 cm = 10 AT/m respectively. Calculate the energy loss per hour in the specimen due to the hysteresis phenomena in the specimen.

(ii) What is a soft magnetic material? Give examples of soft magnetic materials and list their applications.

[10 +10 marks]

i) Hysteresis loop area $= 180\ cm^2$
$= 180 \times 10^{-4}\ m^2$

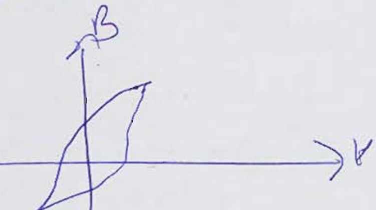
$= 180 \times 0.004 \times 10$ Joule
$= 7.2\ \frac{Wb\,AT}{m^3}$

Energy loss per hour in specimen due to hysteresis phenomenon is

$= \frac{7.2 \times 20 \times ~~7200~~ 60}{7200}$
$= 1.2$

(5)

(ii) A soft magnetic material is the material which has a narrow hysteresis loop.



→ It can be rapidly magnetised and demagnetized and hence is used to design cores of transformers and used in high frequency applications.

Properties : 1) Low Coercivity
2) Low Retentivity
3) Low Hysteresis Loss
4) High permeability and susceptability

eg's : Fe - Zn alloy, Fe - Ni Alloys, Permalloy, Superalloy, Mu Metal

Applications : → used to design core of transformers.
→ used in high frequency applications.

8

OOOO

Space for Rough Work

$\rho = \frac{NA}{N_A V}$

$\psi L_4 R_3 = \psi C_3 R_3 R_2 R_1$

$L_4 = C_3 R_2 R_1$

$V_H = \frac{BI}{\rho_v W}$

$1.518 \times \frac{180}{\pi}$

$\frac{N\alpha}{3\epsilon_0} = \frac{\epsilon_r - 1}{\epsilon_r + 2}$

$\frac{N p^2}{kT}$

$P = N\alpha E_i$ where $E_i = E + \frac{\gamma P}{\epsilon_0}$

2225769.203

Space for Rough Work