290

• Highlights your final answer

• Try to avoid calculation mistake

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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 ☐	
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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	40
Q.2	44
Q.3	
Q.4	~~38~~ 43
Section-B	
Q.5	40
Q.6	
Q.7	
Q.8	51
Total Marks Obtained	~~210~~ 216

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.

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Section A : Electrical and Electronic Measurements

(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.

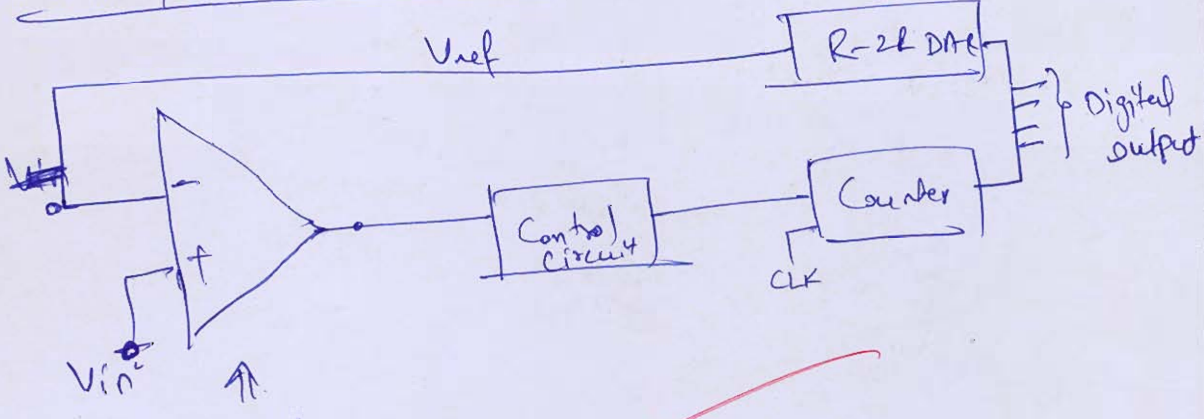
[12 marks]

Digital voltmeter that gives the output in digital or discrete form, which can be easily read by any one.

Merits of DVM

→ It has very high sensitivity
→ It has very high accuracy hence error is less.
→ Power consumption is negligible since it takes very less amount of current
→ It gives wide range of frequency response
as it gets least affected by noise.
→ It can measure small values of emfs.

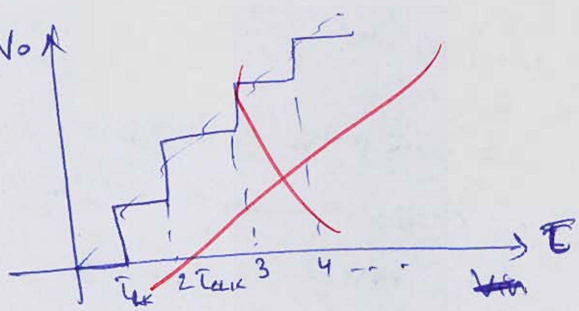
Ramp type Digital voltmeter



When Vin (input) is given to the comparator the output is generated based on difference of Vref.
Initially Vref = 0, hence output will be present which is given to control circuit

This makes the counter to start counting. with each clock cycle counter will count and will reach the value corresponding input and based on that by ~~using~~ using R-2R DAC ⇒ Vref feedback is given which makes the ~~difference~~ difference zero. and count stops.

So, This DVM given the output in the form of ramp



~~It~~ It takes $2^n \times T_{ck}$ to get to the maximum count.

So the Ramp type DVM given the output corresponding to 'Vin' and ~~takes a~~ time for output increases as the input voltage increases

7

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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]

$K = 520$ rev/kWh

$$K = \frac{\#\text{revolution}}{\text{Energy (kWh)}}$$

$$\text{Energy} = \frac{V I \cos\phi}{1000} \times t$$

$$= \frac{230 \times 6 \times 1.0}{1000} \times 10 = 13.8 \text{ kWh}$$

So,

$$520 = \frac{\#\text{revolution}}{13.8}$$

$$\boxed{\#\text{revolution} = 7176 \text{ revolutions}}$$

Now, # revolution = 1722

So, $520 = \dfrac{1722}{\text{Energy}} \Rightarrow \text{Energy} = 3.311 \text{ kWh}$

$$\text{Energy} = \frac{V I \cos\phi \times t}{1000}$$

$$3.311 = \frac{230 \times 9 \times 0.707}{1000} \times t$$

$$\boxed{t = 2.263 \text{ hr}}$$

11

Good Approach

Do not write this m

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]

(i) $R = R_m + R_{se}$

$= R_m(1+\alpha_1 \Delta T) + R_{se}(1+\alpha_2 \Delta T)$

In case of series connection temperature coefficient of resistance is average value

i.e, $\alpha = \frac{\alpha_1 + \alpha_2}{2}$

$= \frac{0.004 + 0.00015}{2}$

$\alpha = 2.075 \times 10^{-3}$

~~(ii) with DC, of $V_s = 150V$~~

~~$I = 0.05A$ (given)~~

~~Now with AC $V_{rms} = 150V$ at 100 Hz~~

~~$Z = R_m + R_{se} + jX_{se}$~~

~~$= 400\Omega + jX\,2\pi \times 100 \times 0.75$~~

~~$= 400 + j150\pi$~~

~~$I = 150$~~

~~$X_{se}(2\pi f L)$~~

~~$(X_{se} = 2\pi f L)$~~

(ii) with DC Supply $V_s = 150V$, $I = 0.05 A$

So, $R_m + R_{se} = \frac{150}{0.05} = 3000\Omega$

$R_m = 400\Omega$ (given), $\therefore R_{se} = 2600\Omega$

Now with AC supply of 150V,

$Z = R_m + R_{se} + jX_{se}$

$= 3000 + j2\pi \times 100 \times 0.75)$ ($f = 100 Hz$)

$= 3000 + j150\pi \ \Omega$

$I = \frac{V}{Z} = \frac{150}{3000 + j150\pi} \Rightarrow |I| = 0.0494 A$

As current is decreased reading of voltmeter will be

$|V| = \frac{0.0494}{0.05} \times 150 = 148.2V$

Alterating in reading $= 148.2 - 150$

$= -1.8V$

(iii) To Compensate the frequency error

$C = \frac{L_m}{R_{se}^2} \times 0.41$

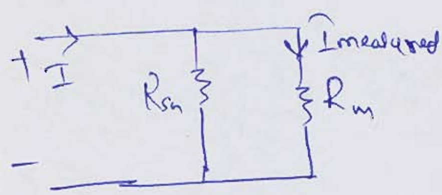
$C = \frac{0.75}{(2600)^2} \times 0.41 \Rightarrow C = 45.49 nF$

(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]

With DC



$$I_{measured} = I \times \frac{R_{sh}}{R_{sh}+R_m}$$

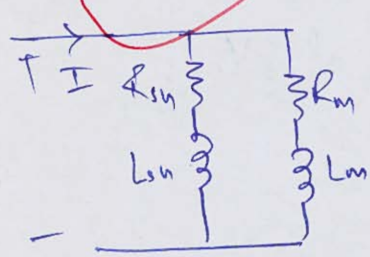
$$= I \times \frac{30}{30+3}$$

$R_{sh} = 30\,\Omega$

$R_m = 3\,\Omega$

$$I_1 = I_{measured\,DC} = \frac{10\,I}{11} \quad \text{—(1)}$$

With AC



$$I_{measured\,(AC)} = I \times \frac{Z_m}{Z_m + Z_{sh}}$$

$$I_2 = I \times \frac{Z_{sh}}{Z_{sh} + Z_m}$$

$$Z_{sh} = R_{sh} + j\omega L_{sh}$$

$$= 30 + j\,2\pi \times 50 \times 0.003 = 30 + j0.3\pi\,\Omega$$

$$Z_m = R_m + j\omega L_m$$

$$= 3 + j\,2\pi \times 50 \times 0.12 = 3 + j12\pi\,\Omega$$

$$I_2 = I \times \frac{30 + j0.3\pi}{(30 + j0.3\pi) + (3 + j12\pi)}$$

$$|I_2| = 0.59\,I$$

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$$error = |I_2| - |I|$$

$$= 0.59 I - \frac{10}{11} I = -0.319 I$$

$$\%error = \frac{I_2 - I_1}{I_1} \times 100$$

$$= -\frac{0.319}{10/11} \times 100$$

$$\%error = -35.09\ \%$$

with inductance coming into picture when supply is AC, the meter results in very high error.

For this ~~fo~~ frequency compensation is to be done to make the meter read accurately.

This is done by using the shunt coil (i.e, moving coil) with suitable impedance, such that

$$\frac{L_m}{R_m} = \frac{L_{sh}}{R_{sh}}.$$

At this condition ~~4~~ error due to frequency will be eliminated.

7

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 the given electrostatic voltmeter.

$$T_d = \frac{1}{2} V^2 \cdot \frac{dc}{dx}$$

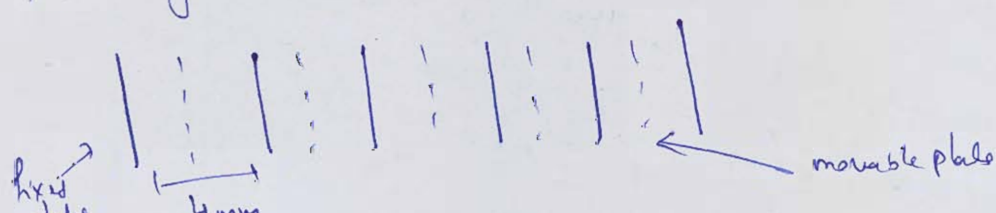
and controlling torque is $T_c = K\theta$

At Equilibrium

$$T_d = T_c$$

$$\Rightarrow \frac{1}{2} V^2 \frac{dc}{dx} = K\theta \quad — (1)$$

Now given the construction, as



~~with the~~ for the full deflection, $x = 4$ mm

Hence, movable plates will be coinciding with fixed plates

and total change in Capacitance will be

$$C = 5 \times \frac{\varepsilon_0 A}{x}$$

$$\frac{dc}{dx} = -\frac{5 \varepsilon_0 \times A}{x^2} \quad — (2)$$

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Now using (1) and (2)

$$\frac{1}{2} \times (10 \times 10^3)^2 \times \left(- \frac{5 \times 8.854 \times 10^{-12} \times A}{(4 \times 10^{-3})^2} \right) = K \times \frac{100 \times \pi}{180}$$

$$A = \frac{1}{2} \pi r^2 = \frac{1}{2} \times \pi \times (40 \times 10^{-3})^2$$

Putting the value of A, we get

$$\boxed{K = 0.19925 \quad Nm/rad.}$$

(4)

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]

$W_1 = 9000\,W, \quad W_2 = -1800\,W$

1. P.F angle is given by

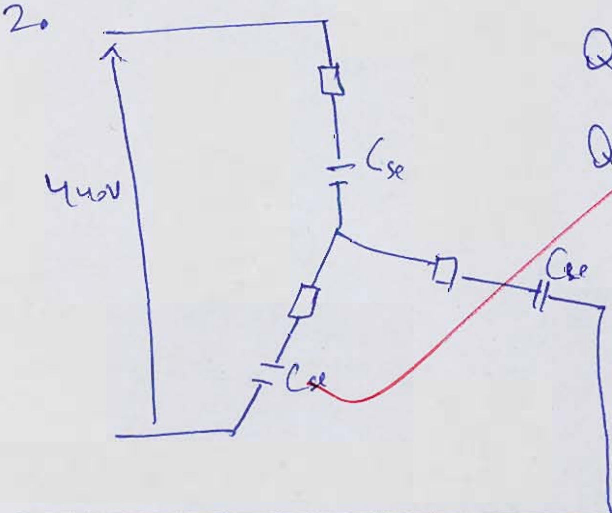
$$\phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right]$$

$$= \tan^{-1}\left[\frac{\sqrt{3}(9000 + 1800)}{9000 - 1800}\right] = 68.95^\circ$$

$P.F = \cos\phi = \cos 68.95^\circ$

$\boxed{P.F = 0.3592}$

2.



C_{se} → Series Capacitor added to get desired result.

$Q = P\tan\phi$

$Q = (W_1 + W_2)\cdot\tan\phi$

Now, for whole power to be measured by wattmeter A

As, $W_A = VI\cos(\phi - 30^\circ)$

$W_B = VI\cos(\phi + 30^\circ)$

Do not write in this margin

Hence, $\phi = 60^\circ$, $W_B = 0$

$W_A = W_1 + W_2 = 9000 - 1800 = VI\cos(60-30)$

$\Rightarrow \quad I = \dfrac{7200}{440 \times \cos 30^\circ} = 18.895\ A$

Now ϕ to be increase,

$Q_S = Q_{Load} - Q_C$

$Q_{Load} = P\tan\phi_{Load} = (9000-1800) \times \tan(68.95)$

$= 18707.83\ VAR$

$Q_S = P\tan\phi_{new} = 7200 \times \tan 60^\circ$

$= 12470.76\ VAR$

$Q_C = Q_{Load} - Q_S = 18707.83 - 12470.76$

$= 6237.06\ VA$

$Q_C = 3 \times I^2\ X_C \qquad \left(\because X_C = \dfrac{1}{\omega C}\right)$

$6237.06 = 3 \times 18.895^2 \times \dfrac{1}{2\pi \times 60 \times C_{ph}}$

$\boxed{C_{ph} = 455.5\ \mu F} \Rightarrow C_{se}$

(6)

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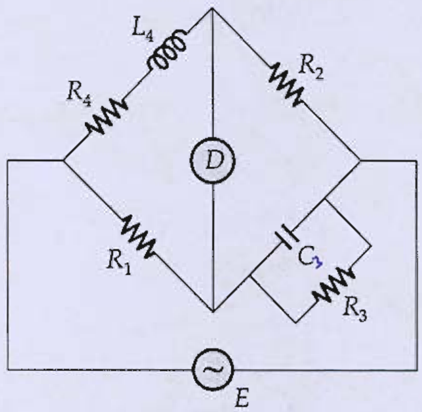
(a) (ii) In a Maxwell's bridge, the fixed - value bridge components have the following values:

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

At balance,

$$(R_4 + j\omega L_4) \times \frac{\left(R_3 \times \frac{1}{j\omega C_3}\right)}{\left(R_3 + 1/j\omega C_3\right)} = R_1 R_2$$

$$\frac{R_4 R_3}{j\omega C_3} + \frac{L_4 R_3}{C_3} = R_1 R_2 R_3 + \frac{R_1 R_2}{j\omega C_3}$$

Equating real and imaginary parts.

$$\frac{L_4 R_3}{C_3} = R_1 R_2 R_3 \Rightarrow \boxed{L_4 = R_1 R_2 C_3}$$

and

$$\frac{R_4 R_3}{C_3} = \frac{R_1 R_2}{C_3} \Rightarrow \boxed{R_4 = R_1 R_2 / R_3}$$

$$Q = \frac{\omega L_4}{R_4} = \omega \times \frac{R_1 R_2 C_3}{R_1 R_2 / R_3} = \omega R_3 C_3$$

$$Q = 2\pi \times 50 \times 5 \times 10^{-3}$$

$$\boxed{Q = 1.57}$$

5

Good Approach

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) $I_\mu = 8\,A$, $I_w = 10\,A$, $K = 500/5 = 100$

$n = 98$, $R_s = 0.35\,\Omega$, $X_s = 0.3\,\Omega$

~~$\delta = \tan^{-1}\left(\frac{X_s}{R_s}\right) = \tan^{-1}\left(\frac{0.3}{0.35}\right)$~~

given Rated load Hence, $I_s = 5A$

and Burden $= V_s I_s$

$15 = V_s \cdot 5$

$V_s = 3\,V$

As load is ~~inductive~~ non inductive hence,

$$R_L = \frac{V_s}{I_s} = \frac{15/5}{5} = \frac{3}{5} = 0.6\,\Omega$$

Now $\delta = \tan^{-1}\left(\frac{X_s}{R_s+R_L}\right) = \tan^{-1}\left(\frac{0.3}{0.35+0.6}\right)$

$= 17.525°$

$$\theta = \frac{I_0 \cos(\alpha+\delta)}{n I_s}$$

$$= \frac{I_0 \cos\alpha \cdot \cos\delta + I_0 \sin\alpha \cdot \sin\delta}{n I_s}$$

$$= \frac{I_\mu \cos\delta - I_w \sin\delta}{n I_s}$$

$$= \frac{8 \times \cos 17.525 - 10 \times \sin 17.525}{98 \times 5} = 9.42 \times 10^{-3}\,\text{rad}$$

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Phase angle error $\theta = 9.423\times10^{-3} \times \frac{180}{\pi}$

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

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

$$= n + \frac{I_w \cos\delta + I_M \sin\delta}{I_s}$$

$$= 98 + \frac{10\times\cos 17.525 + 8\times\sin(17.525)}{5} = 100.388$$

Ratio error (σ_c)

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

$$= -3.87\times10^{-3}$$

$$\boxed{\%\,\sigma_c = -0.387}$$

(ii) Advantages ~~and~~ of PMMC instrument

→ PMMC instruction has the following advantages.

(i) They have a linear scale. ~~few~~ ~~less~~

(ii) They have high sensitivity

(iii) They have high deflecting torque so that its torque to weight ratio is high

(iv) They have robust construction ~~and~~

(v) They have very low power loss.

Disadvantages of PMMC Instrument

→ they can only be used to measure the DC quantity. It cannot measure AC quantity.

→ they gets affected by external magnetic field.

→ If the control spring gets broken/damaged, the pointer return to zero since, current is flowing through spring.

15

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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

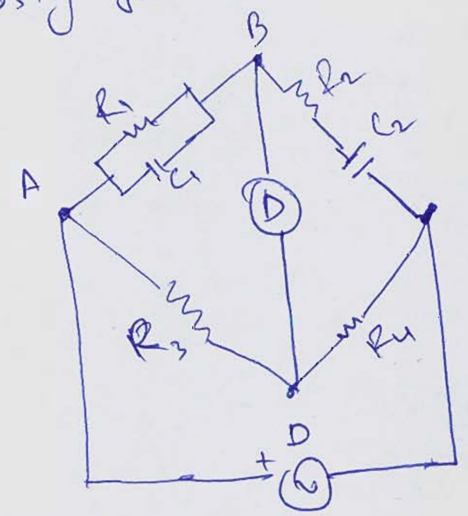
Arm DA : A pure resistance R.

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) using given data



given bridge is wein bridge used for determining the frequency.

At balance

$$\frac{R_1 \times \frac{1}{j\omega C_1}}{\left(R_1 + \frac{1}{j\omega C_1}\right)} \times R_4 = \left(R_2 + \frac{1}{j\omega C_2}\right) \cdot R_3$$

$$\frac{R_1 R_4}{j\omega C_1} = \left(R_2 R_3 + \frac{R_3}{j\omega C_2}\right)\left(R_1 + \frac{1}{j\omega C_1}\right)$$

$$\frac{R_1 R_4}{j\omega C_1} = R_1 R_2 R_3 + \frac{R_1 R_3}{j\omega C_2} + \frac{R_2 R_3}{j\omega C_1} - \frac{R_3}{\omega^2 C_1 C_2}$$

Equating the real and imaginary Parts.

$$R_1 R_2 R_3 - \frac{R_3}{\omega^2 C_1 C_2} = 0$$

$$R_1 R_2 = \frac{1}{\omega^2 C_1 C_2}$$

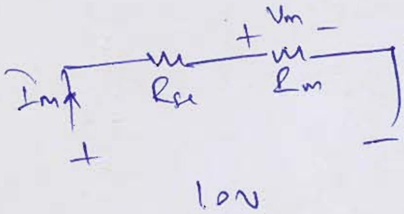
$$\Rightarrow \quad \omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

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

$$\boxed{f = 397.88\ Hz}$$

(ii) Initially to extend the range, required series series will be,



$V_m = 25\,mV$

$I_m = \frac{V_m}{R_m} = \frac{25}{25} = 1\,mA$

So, $10 = I_m R_{se} + V_m$

$10 = 1\times10^{-3} \times R_{se} + 25\times10^{-3}$

$$\boxed{R_{se} = 9975\ \Omega}$$

Now when temperature increased by $10^\circ C$

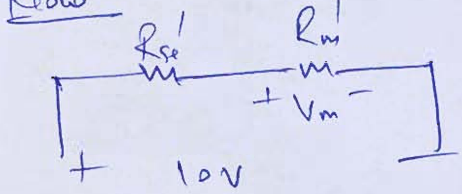
$R_m' = (1 + \alpha_1 \Delta T) \cdot R_m$

$= (1 + 0.004 \times 10) \times 25 = 26\ \Omega$

and $R_{se}' = (1 + \alpha_2 \Delta T) \times R_{se}$

$= (1 + 1.5\times10^{-4} \times 10) \times 9975 = 9989.96\ \Omega$

Now



$$I_m' = \frac{10}{R_{se}' + R_m'} = \frac{10}{26 + 9989.96}$$

$$I_m' = 0.9984 \text{ mA}$$

$$\% \text{error} = \frac{I_m' - I_m}{I_m} \times 100$$

$$= \frac{0.9984 - 1}{1} \times 100$$

$$\boxed{\% \text{error} = -0.1594 \%}$$

Good Approach

18

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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]

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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]

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

[20 marks]

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(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]

$\% \varepsilon_B \Rightarrow \pm 0.5\%$ reading, $\% \varepsilon_C = \pm 1.2\%$ of full scale

$\% \varepsilon_D = \pm 1.5\%$ of reading.

Now ~~% ε~~ = For a instrument that have error of ~~reading~~ fullscale,

$\% \varepsilon = \frac{\text{fullscale value}}{\text{Reading value}} \times \%\text{error at fullscale.}$

~~So, $\% \varepsilon_C = \frac{100}{60} \times 1.2 = 2\%$~~

~~Now Error in reading of A~~

~~$= \% \varepsilon_B + \% \varepsilon_C + \% \varepsilon_D$~~

~~$= 0.5 + 2 + 1.5 = 4\%$~~

~~$\boxed{\% \varepsilon_A = 4\%}$~~

~~$A = \frac{B}{CD} = \frac{20}{60 \times 100}$~~

~~maximum limiting error in reading of $A = \frac{20}{60 \times 100} \times \frac{4}{100}$~~

~~$= 1.33 \times 10^{-4}$~~

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$\% \varepsilon_B = 0.5 \times \frac{900}{90} = 0.5556\%$

$\% \varepsilon_C = 1.2\%$

$\% \varepsilon_D =$ ~~1.5 × 60~~ $1.5 \times \frac{100}{60} = 2.5\%$

$\% \varepsilon_A = \% \varepsilon_B + \% \varepsilon_C + \% \varepsilon_D$

$= 0.5556 + 1.2 + 2.5$

$\boxed{\% \varepsilon_A = 4.2556\%}$

maxi limiting error $= A \times \% \varepsilon_A$

$A = \frac{R}{C_D} = \frac{90}{20 \times 60} = 0.075$

3

$\varepsilon_A = 0.075 \times \frac{4.2556}{100}$

$\boxed{\varepsilon_A = 3.1917 \times 10^{-3}}$

(ii) In electrostatic instrument,

~~Fx W = F.dx~~ $W = T_d \, d\theta$

and energy stored will be given by

$= \frac{1}{2} C V^2$

Change in stored energy will be

$\Rightarrow \frac{1}{2}(C+\Delta C)(V+\Delta V)^2$

energy supplied = $V i\, dt$

and $i = \frac{d}{dt}(CV)$

$= C\frac{dV}{dt} + V\frac{dC}{dt}$

energy = $VC\frac{dV}{dt} \times dt + V^2\frac{dC}{dt} \cdot dt$

$= VC\, dV + V^2 dC$

energy supplied = work done + change in stored energy

$VC\,dV + V^2 dC = T_d\, d\theta + \frac{1}{2}(C+\Delta C)(V+\Delta V)^2$

After solving the equation by ignoring the higher order terms, we get

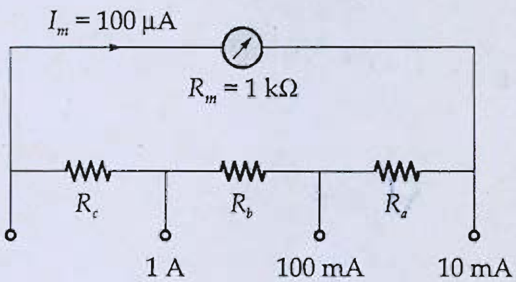
$$T_d = \frac{1}{2} V^2 \cdot \frac{dC}{d\theta}$$

and

$$F_d = \frac{1}{2} V^2 \cdot \frac{dC}{dx}$$

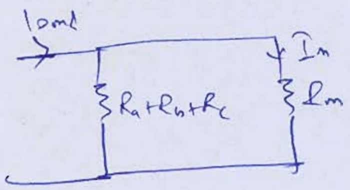
6

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



[20 marks]

For I = 10 mA



By current division rule

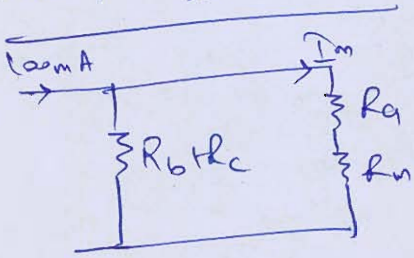
$$I_m = I \times \frac{R_a+R_b+R_c}{R_a+R_b+R_c+R_m}$$

$$\Rightarrow 100\times10^{-6} = 10\times10^{-3}\ \frac{R_a+R_b+R_c}{R_a+R_b+R_c+1}$$

$$\Rightarrow R_a+R_b+R_c+1 = 100(R_a+R_b+R_c)$$

$$\Rightarrow R_a+R_b+R_c = 1/99 \quad (1)$$ (R_a, R_b, R_c are in kΩ)

Now for I = 100 mA



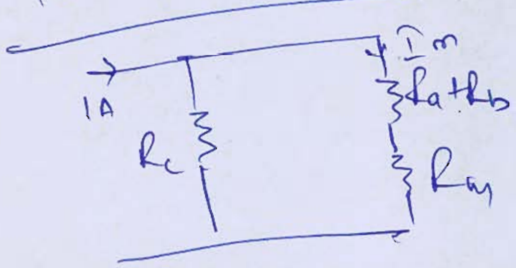
Similarly,

$$100\times10^{-6} = 100\times10^{-3} \times \frac{R_b+R_c}{R_a+R_b+R_c+1}$$

$$R_a+R_b+R_c+1 = 1000\ R_b + 1000\ R_c$$

$$-R_a + 999 R_b + 999 R_c = 1 \quad (2)$$

Now for I = 1 A



Again,

$$100\times10^{-6} = 1\times\frac{R_c}{R_a+R_b+R_c+R_m}$$

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$R_a + R_b + R_c + 1 = 10000 R_c$

$\Rightarrow -R_a - R_b + 9999 R_c = 1$ — (3)

On solving (1), (2) and (3)

we get,

$R_a = 9.091 \Omega$

$R_b = 0.9091 \Omega$

$R_c = 0.101 \Omega$

~~10.1 Ω~~

~~1.01 Ω~~

0

Go through the made easy solution

0

18

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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) $\beta = 2^\circ$, power measured by wattmeter is given by,

$P_{measured} = VI \cos\beta \cdot \cos(\phi - \beta)$

So, $800 = VI \cos 2^\circ \times \cos(\phi - 2^\circ)$ — (1)

with $\beta = 1^\circ$

$640 = VI \cos 1^\circ \times \cos(\phi - 1^\circ)$ — (2)

So, $\frac{\cos(\phi - 2)}{\cos(\phi - 1)} = 1.2506$

On solving this, we get,

$\phi = 87.02^\circ$

Now

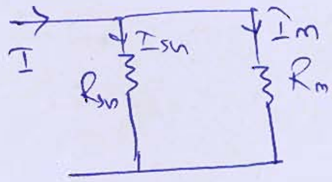
as, $VI \cos\beta \cdot \cos(\phi - \beta) = 800$ (for $\beta = 2^\circ$)

So, ⇒ $230 \times I \times \cos 2 \times \cos(87.02 - 2) = 800$

$I = 40.043$ A

6

8



$I_m = 5A$, $R_m = 0.09\Omega$

$I = 50A$

$\therefore I_{sh} = 50 - 5 = 45A$

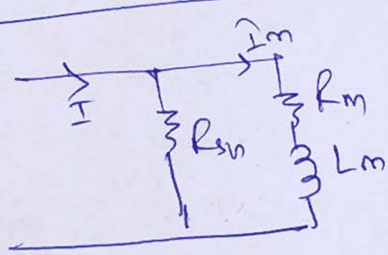
Now, $I_{sh} R_{sh} = I_m . R_m$

$45 \times R_{sh} = 5 \times 0.09$

$\boxed{R_{sh} = 0.01\Omega}$

(3)

Now with $f = 50Hz$



$I = 50A$

$I_m = I \times \frac{R_{sh}}{R_{sh} + R_m + j\omega L_m}$ (By Current Division Rule)

$= \frac{50 \times 0.01}{0.01 + 0.09 + j \times 2\pi \times 50 \times 90 \times 10^{-3}} = |0.0177 A|$

(8)

$error = \frac{0.0177 - 5}{5} \times 100$

$= -99.646\%$

↑ very high error

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Section B : Electrical Materials

(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) $C = \dfrac{\varepsilon_0 \varepsilon_r A}{d} = \dfrac{8.854 \times 10^{-12} \times 6.0 \times 6.45 \times 10^{-4}}{2 \times 10^{-3}}$

$C = 17.13\ pF$

(ii) $Q = CV$

$= 17.13 \times 10^{-12} \times 10$

$Q = 0.1713\ nC$

(iii) $D = \varepsilon_0 \varepsilon_r E = \varepsilon_0 \varepsilon_r \times \dfrac{V}{d}$

$= 8.854 \times 10^{-12} \times 6 \times \dfrac{10}{2 \times 10^{-3}}$

$D = 0.2656\ \mu C/m^2$

(iv) $D = \varepsilon_0 E + \vec{P}$

$\Rightarrow D = \varepsilon_0 \dfrac{V}{d} + \vec{P}$

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$$2.656 \times 10^{-7} = 8.854 \times 10^{-12} \frac{\times 10}{2 \times 10^{-3}} + P$$

$$\boxed{P = 2.2135 \times 10^{-7} \ C/m^2}$$

11

Good Approach

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

[12 marks]

Magnetic anisotropy is the property of magnetic material, which shows that its magnetic permeability when measured from different directions gives different value.

i.e., when the magnetic properties are not same and differ with the change in direction from it is measured. The material is said to be magnetically anisotropic.

In Transformer cores, it is important the flux remain inside the core and does not leak from it such that losses will be minimized. So, magnetic anisotropy is important so that the flux in the transformer core flow in the path having low reluctance and in the direction which will make its linkage maximum with the secondary windings. ~~So the~~

For this to happen, permeability of core should have different value such that flux will flow in desired direction only.

So, material for transformer core is made such that the flux gets alligned in the direction and not come out of the core.

8

Go through the made easy Solution

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(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]

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(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]

$B = \mu_0 (H + M)$

$4 = 4\pi \times 10^{-7} (2400 + M)$

$\Rightarrow M_1 = 3180648.862$ A/m

Now, with $B = 2.8$, $H = 800$

$2.8 = 4\pi \times 10^{-7} (800 + M)$

$M_2 = 2227369.203$ A/m

Change in magnetization

$\Delta M = M_1 - M_2$

$= 3180648.862 - 2227369.203$

$\Delta M = 953329.66$ A/m

10

Elaborate it more

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(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]

$\rho = 10.22\ g/cm^3$, $M = 95.94\ g/mol$

As, $\rho = \dfrac{n M}{N_A \times V_c}$ $N_A \to$ avagadro's number

atomic concentration $= \dfrac{n}{V_c} = \dfrac{\rho N_A}{M}$

$= \dfrac{10.22 \times 6.023 \times 10^{23}}{95.94}$

$\dfrac{n}{V_c} = 6.416 \times 10^{22}$ atoms/m^3

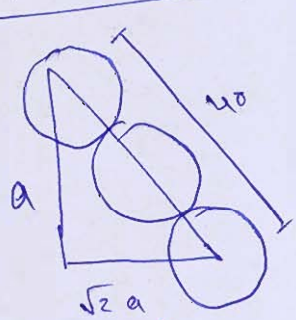
For bcc crystal $n = 2$ and $V_c = a^3$

$\dfrac{2}{a^3} = 6.416 \times 10^{22}$

$a = 3.1472 \times 10^{-8}\ m$ lattice parameter

11

For BCC crystal



So, By pythagoras theorem

$(4r)^2 = a^2 + (\sqrt{2}a)^2$

$16r^2 = 3a^2$

$r = \dfrac{\sqrt{3}}{4} a = \dfrac{\sqrt{3}}{4} \times 3.1472 \times 10^{-8}$

$r = 1.3627 \times 10^{-8}\ m$

Good Approach

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

[20 marks]

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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 wr th

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(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]

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(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]

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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]

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) For Clausius-Mossotti equation, some assumption are made as follows:

(a) Polarizability of molecules in material is isotropic
(b) arrangement of molecules in the material is isotropic
(c) Polarization in the material is by elastic displacement only.

Now the polarization in dielectric is given by

$$P = N\alpha E_i$$

and $E_i = E + \frac{\gamma P}{\varepsilon_0}$

C-M equation is valid only for cubic crystal and $\gamma = 1/3$ for cubic crystal, Hence,

$$P = N\alpha\left(E + \frac{P}{3\varepsilon_0}\right)$$

$$P\left(1 - \frac{N\alpha}{3\varepsilon_0}\right) = N\alpha E$$

also, $P = \varepsilon_0(\varepsilon_r - 1)\cdot E$

Using this, we get

$$\varepsilon_0(\varepsilon_r - 1)\left(1 - \frac{N\alpha}{3\varepsilon_0}\right) = N\alpha$$

$$\varepsilon_r - 1 = \frac{N\alpha/\varepsilon_0}{1 - N\alpha/3\varepsilon_0} \quad —(1)$$

Adding '3' on both sides,

$$\varepsilon_r + 2 = \frac{\frac{N\alpha}{\varepsilon_0} + 3 - \frac{N\alpha}{\varepsilon_0}}{1 - N\alpha/3\varepsilon_0} \quad —(2)$$

Using (1) & (2)

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha/\varepsilon_0}{1 - N\alpha/3\varepsilon_0} \Big/ \frac{3}{1 - N\alpha/3\varepsilon_0}$$

$$\boxed{\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha}{3\varepsilon_0}}$$ → Claussius-Mossotti equation for non polar dielectric material

9 Good Approach

(ii) $R_H = -8.25 \times 10^{-5}\ m^3/C$

$T = 300^\circ K$, $\sigma = 2.5\ \mho/cm$

1. As the Hall coefficient is negative, this shows that the semiconductor is n-type

2. $R_H = \frac{1}{ne} \Rightarrow 8.25 \times 10^{-5} = \frac{1}{n \times 1.6 \times 10^{-19}}$

4

$n = 7.576 \times 10^{22}$

$$\boxed{n = 7.576 \times 10^{22}\ m^{-3}}$$ → density of charge carriers

3. as, $\sigma = ne\mu$

and $R_H = \frac{1}{ne}$

$\sigma = \frac{\mu}{R_H}$

$\Rightarrow 2.5 \times 100 = \frac{\mu}{8.25 \times 10^{-5}}$

$\mu = 0.020625 \ m^2/Vsec$

$\mu = 206.25 \ cm^2/Vsec$

mobility of the charge carrier

Good Approach

9

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(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.

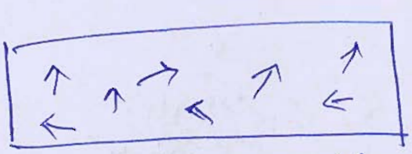
[12 + 8 marks]

(i) There are following ~~the~~ type of magnetic material

→ Diamagnetic
→ Paramagnetic
→ Ferro magnetic
→ Anti ferromagnetic
→ Ferri magnetic

→ Diamagnetic material does not have permanent dipole moments and it does not show any hysteresis effect.
It repels the magnetic field lines.

→ Paramagnetic material, They have permanent dipoles, but these dipoles are randomly oriented. So in the absence of magnetic field, They show net zero magnetization.

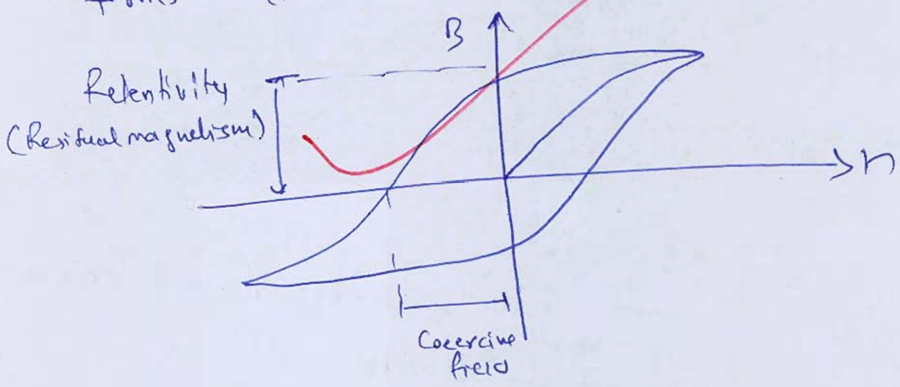


They do not show hysteresis effect

→ Ferromagnetic material
These material have Permanent magnetic dipoles alligned Parallely.

They show magnetization even in the absense of magnetic field, this is known as Spontaneous magnetization.

These materials show hysterisis effect, ie, when the material is magnetized, its dipole allign in the direction of magnetic field and when the magnetic field is removed it show retentivity i.e, residual magnetism, To destroy that Coercive field in opposite direction is required. If the material is magnetized alternately in opposite directions This forms Hysterais loop, as shown.



Fe. Anti ferro magnetic material ⇒ They have dipoles alligned antiparallel to each other. Hence net magnetization in the absence of field is zero.

| ↑ ↓ ↑ ↓ ↑ ↓ |

Hysteresis loop

Ferri magnetic material

They also have permanent dipoles alligned antiparallel to each other but with unequal magnitude, Hence show sponteneous magnetization.

| ↑↓ ↑↓ ↑↓ ↑↓ |

In these material are classified as Hard and Soft magnetic material.

→ Material having large area of hysteresis curve are Classified in Hard magnetic material which are used in Permanent magnet.

→ Soft magnetic material have narrow hysteresis loop, and used in High frequency transformer and inductors.

Hard magnetic material are difficult to magnetize and demagnetize i.e, low permeability.
But soft magnetic material are easy to magnetize and demagnetize, as they have high permeability,

By C-M equation,

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha}{3\varepsilon_0} \quad \text{—(1)}$$

At low frequencies $\alpha = \alpha_e + \alpha_i$ —(2)

at high frequencies $\alpha \simeq \alpha_e$ —(3)

and $\varepsilon_r \simeq n^2$ —(4)

using above information in (1), (2), (3) and (4)

$$\Rightarrow \frac{\dfrac{\varepsilon_r - 1}{\varepsilon_r + 2}}{\dfrac{n^2 - 1}{n^2 + 2}} = \frac{\alpha_e + \alpha_i}{\alpha_e}$$

$$\Rightarrow \frac{\dfrac{4.94 - 1}{4.94 + 2}}{\dfrac{2.69 - 1}{2.69 + 2}} = \left(1 + \frac{\alpha_i}{\alpha_e}\right)$$

$$\Rightarrow \frac{\alpha_i}{\alpha_e} = 0.5755$$

$$\Rightarrow \frac{\alpha_e}{\alpha_i} = 1.7375$$

16

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) Energy loss due to hysteresis phenomena is given by

= Area of curve × scale factors × frequency × volume

= 180 × ~~10^{-4}~~ × 0.004 × 10 × 60 × Volume × time

Density = $\frac{mass}{Volume}$ ⇒ 7200 = $\frac{20}{Volume}$

Volume = $1/360$ m^3

$E = 180 \times 0.004 \times 10 \times 60 \times \frac{1}{360} \times 3600$

Energy loss/hr = 4320 J/hr

Good Approach

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(ii) Soft magnetic material

These are the material which can be easily magnetized and demagnetized by the application of magnetic field.

Properties

→ They have a very high Permeability
→ low retentivity and low Coercivity
→ they form a ~~very~~ narrow hysteresis Curve

Eg ⇒ Permaalloy, Ni-Zn ferrite, Superalloy etc.

Application

→ These are used in High frequency application, to make transformer cores and inductors
→ Used in Audio / TV transformer
→ Us

8

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Space for Rough Work

Space for Rough Work

$VI \sin(\Delta - \phi) = 88 = 88$

VI

$$\frac{\sin(88-\phi)}{\sin(89-\phi)} =$$

$$\frac{4}{2.8} = \frac{\mu_{r_1}}{\mu_{r_2}} \frac{H_1}{H_1}$$

$$X = \frac{\partial M}{\partial H}$$