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Detailed Solutions

ESE-2025 Mains Test Series

Electrical Engineering Test No : 3

Section A : Electrical and Electronic Measurements

Q.1 (a) Solution:

Digital Voltmeter (DVM):

- A digital voltmeter (DVM) displays the value of AC or DC voltage being measured directly as discrete numerals in the decimal number system.
- Numerical readout is advantageous in many applications because it reduces human reading and interpolations because errors and eliminates parallax errors.
- The use of digital voltmeters increase the speed with which reading can be taken, also the output of digital voltmeter can be fed to memory devices for storage and future computations.
- A digital voltmeter is a versatile and accurate voltmeter which has many laboratory applications.

Types of DVMs:

(i) Ramp type DVM. (ii) Integrating type DVM. (iii) Potentiometric type DVM.
(iv) Successive approximation type DVM. (v) Continuous type DVM.

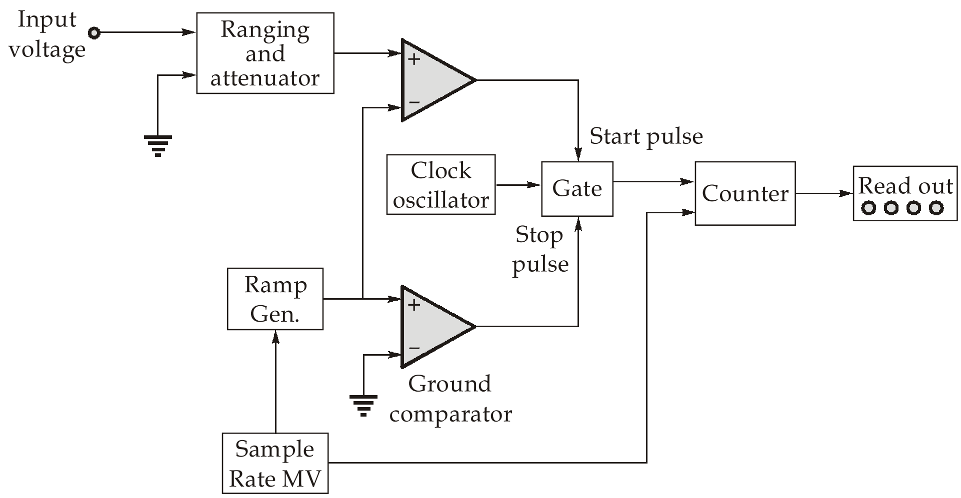
Basic Function:

In every case the basic function that is performed is an analog to digital (A/D) conversion.

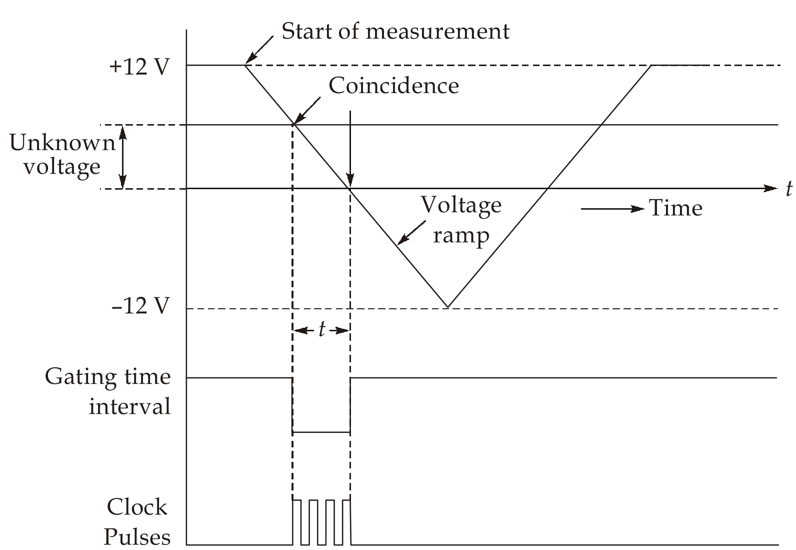
For example a voltage value may be changed to a proportional time interval, which starts and stops a clock oscillator. In turn the oscillator output is applied to an electronic counter which is provide with a read out in terms of voltage values.

Ramp Type Digital Voltmeter:

- When an analog voltage of ramp type is applied to the ramp type digital voltmeter it measure the time interval with an electronic time interval counter and count is displayed as a number of digits on electronic indicating tubes of the output read out of the voltmeter.
- Block diagram of ramp type DVM is shown on figure below:



- The conversion of a voltage value of a time interval is as shown in figure below:



(Timing diagram showing voltage to time conversion)

- The decimal number as indicated by the read out is a measure of the value of input voltage.
- The sample rate multivibrator determines the rate at which the measurement cycles are indicated.

- The sample rate circuit provides an indicating pulse for the ramp generator to start its next ramp voltage.
- At the same time it sends a pulse to the counter which sets all of them to 0. This momentarily removes the digital display of the readout.

Q.1 (b) Solution:

Given : $V_L = 230$ V, $I_L = 6$ A, $t = 10$ hours

$\cos\phi = 1$

Meter constant, $K = 520$ rev/kWh

N = Number of Revolution

$\Rightarrow$ Energy consumption = kWh × t

$$= \frac{V_L I_L \cos\phi}{1000} \times 10$$

= 13.8 kWh

$$\text{Meter constant} = \frac{N}{\text{kWh}}$$

$\Rightarrow$ $N = K \times \text{kWh} = 520 \times 13.8$

= 7176 revolution

Now, if meter makes 1722 revolution, $I_L = 9$ A and $\cos\phi = 0.77$, $t = 1$ sec.

Then, Meter constant,
$$K = \frac{1722}{\frac{230 \times 9 \times 0.707}{1000} \times h}$$

$$520 = \frac{1722}{1.4634 \times h}$$

$$h = \frac{1722}{520 \times 1.4634}$$

= 2.263 hours

Therefore, Time $\simeq$ 2.263 hours

Q.1 (c) Solution:

Total resistance of instrument circuit

$$= \frac{150}{0.05} = 3000\ \Omega$$

Resistance of coil, $R = 400\ \Omega$

$\therefore$ Series resistance, $R_s = 3000 - 400 = 2600\ \Omega$

(i) Change in resistance of coil/°C

$$= 0.004 \times 400 \times 1 = 1.60\ \Omega$$

Changes in swamping resistance/°C

$$= 0.00015 \times 2600 \times 1 = 0.39\ \Omega$$

Total change in resistance of instrument circuit/°C

$$= 1.60 + 0.39 = 1.99\ \Omega$$

∴ Resistance temperature coefficient of instrument

$$= \frac{\text{Change in resistance/°C}}{\text{Total resistance}} = \frac{1.99}{3000} = 0.00066/°C$$

(ii) Reactance of coil at 100 Hz $= 2\pi \times 100 \times 0.75 = 471.2\ \Omega$

Impedance of instrument at 100 Hz,

$$= \sqrt{(3000)^2 + (471.2)^2} = 3037\ \Omega$$

Current drawn by instrument at 100 Hz

$$= \frac{150}{3037} = 0.0494\ \text{A}$$

∴ Reading of instrument at 100 Hz,

$$= \left(\frac{0.0494}{0.05}\right) \times 150 = 148.2\ \text{V}$$

$$\text{Error} = \frac{148.2 - 150}{150} \times 100 = 1.2\%\ \text{low}$$

(iii) In order that there is no frequency error, value of capacitance to be connected across R_s,

$$C = 0.41 \frac{L}{R_s^2} = 0.41 \times \frac{0.75}{(2600)}\text{F} = 0.0455\ \mu\text{F}$$

Q.1 (d) Solution:

Resistance of fixed (field) coils,

$$R_1 = 3.0\ \Omega$$

Reactance of fixed coils at 50 Hz,

$$X_1 = 2\pi \times 50 \times 0.12 = 37.7\ \Omega$$

Resistance of moving coil, $R_2 = 30\ \Omega$

Reactance of moving coil at 50 Hz,

$$X_2 = 2\pi \times 50 \times 0.003 = 0.9425\ \Omega$$

Let the current being measured be I

With D.C. Current through fixed coils,

$$I_1 = \frac{I R_2}{(R_1 + R_2)} = \frac{I \times 30}{(3+30)} = 0.909I$$

Current through moving coils, $$I_2 = \frac{I R_1}{(R_1 + R_2)} = \frac{I \times 3}{(3+30)} = 0.0909I$$

Deflection, $$\theta \propto I_1 I_2 = K_1 I_1 I_2 = 0.0826\ K_1 I^2$$

With A.C. Impedance of fixed coil,

$$Z_1 = \sqrt{(3)^2 + (37.3)^2} = 37.8\ \Omega$$

Phase angle, $$\alpha_1 = \tan^{-1}\frac{37.7}{3} = 85.4°$$

Impedance of moving coil, $$Z_2 = \sqrt{(30)^2 + (0.9425)^2} = 30\ \Omega$$

Phase angle, $$\alpha_2 = \tan^{-1}\frac{0.09425}{30} = 1.8°$$

Current through fixed coil, $$I = \frac{Z_2\angle\alpha_2}{Z_1\angle\alpha_1 + Z_2\angle\alpha_2}\cdot I = 0.588I\angle - 47.7°$$

Current through moving coil, $$I = \frac{Z_2\angle\alpha_2}{Z_1\angle\alpha_1 + Z_1\angle\alpha_2}\cdot I = 0.743I\angle 36°$$

Phase difference between I_1 and I_2 is

$$\phi = -47.7° - 36° = -83.7$$

$$\therefore \qquad \cos\phi = 0.1097$$

Deflection with a.c.

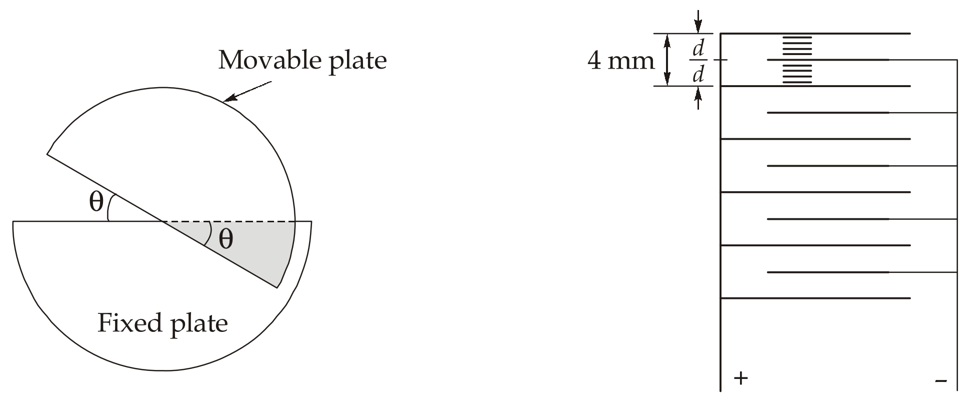
$$\theta = K_1 I_1 I_2 \cos\phi$$
$$= K_1 \times 0.588 \times I \times 0.743 \times I \times 0.1097$$
$$= 0.048\ K_1 I^2$$

$$\text{Percentage error} = \frac{\text{Reading on a.c.} - \text{reading on d.c.}}{\text{Reading on d.c.}} \times 100$$

$$= \frac{0.048K_1I^2 - 0.0826K_1I^2}{0.0826K_1I^2} \times 100 = -41.96\%$$

Q.1 (e) Solution:

Suppose the deflection is θ rad. The fixed and movable plates overlap each other over angle θ and form a capacitor as shown in figure below, suppose r is the radius of movable plate



Electrostatic voltmeter

∴ Area of plates forming the capacitor $A = \frac{\theta r^2}{2}$. Capacitance between fixed and moving plates

$$C = 2\times\left(\frac{\varepsilon A}{d}\right) = 2\left(\frac{\varepsilon\theta r^2}{2d}\right) = \frac{\varepsilon\theta r^2}{d}$$

This is because there are two capacitors, each having a capacitance of $\varepsilon A/d$ between fixed and movable plates. The capacitance are in parallel as shown in figure,

$$\therefore \quad \frac{dC}{d\theta} = \frac{\varepsilon r^2}{d}$$

There are 6 fixed plates and 5 movable plates and hence there are 5 units exerting torque

$$\text{Torque exert by each unit} = \frac{1}{2}V^2\frac{dC}{d\theta}$$

$$\text{Torque exerted by } n \text{ units,} \quad T_d = n\times\frac{1}{2}V^2\frac{dC}{d\theta} = \frac{n}{2}\frac{\varepsilon r^2}{d}V^2 = \frac{n}{2}\frac{\varepsilon r^2}{d}V^2$$

Let the final steady deflection be θ

$$\therefore \quad \text{Controlling torque, } T_c = K\theta$$

$$\text{or} \quad K\theta = \frac{n}{2}\frac{\varepsilon r^2}{d}V^2$$

$$\therefore \quad \text{Spring constant, } K = \frac{n}{2\theta}\frac{\varepsilon r^2}{d}V^2$$

It is given that :

Number of units, $n = 5$

Deflection, $\theta = 100°$

Permittivity, $\varepsilon = 8.85 \times 10^{-12}$ (for air)

Separation between fixed plates $2d = 4$ mm

$\therefore \quad d = 2 \text{ mm} = 2 \times 10^{-3}$ m

Radius of movable plates $= 40 \text{ mm} = 40 \times 10^{-3}$ m,

Voltage, $V = 10 \text{ kV} = 10 \times 10^3$

Substituting these values in (i), we have

$$\text{Spring constant, } K = \frac{5}{2\times100}\times\frac{(8.85\times10^{-12})\times(40\times10^{-3})^2\times(10\times10^3)^2}{2\times10^{-3}}$$

$$= 17.7 \times 10^{-6} \text{ N-m/degree}$$

Q.2 (a) (i) Solution:

Total power consumed, $P = P_1 + P_2 = 9000 - 1800 = 7200$ W

$$\text{Power consumed by each phase} = \frac{7200}{3} = 2400 \text{ W}$$

$$\text{Voltage of each phase} = \frac{440}{\sqrt{3}} = 254 \text{ V}$$

$$\tan\phi = \sqrt{3}\times\frac{10800}{7200} = 2.598$$

$$\phi = 68.947$$

$$\cos\phi = 0.359$$

1. Power factor,

$$\text{Current in each phase} = \frac{2400}{254\times0.359} = 26.32 \text{ A}$$

$$\text{Impedance of each phase} = \frac{254}{26.32} = 9.65\ \Omega$$

$$\text{Resistance of each phase} = \frac{2400}{(26.32)^2} = 3.46\ \Omega$$

$$\text{Reactance of each phase} = \sqrt{(9.65)^2-(3.46)^2} = 9\ \Omega$$

In order that one of the wattmeters should read zero, the power factor should be 0.5

$\therefore \quad \cos\phi = 0.5$

and $\quad \tan\phi = 1.73$

Now, $\tan\phi = \dfrac{X}{R}$

Reactance of circuit, $X = R\tan\phi = 3.46 \times 1.73 = 6\ \Omega$

$\therefore$ Capacitive reactance required

$$X_C = 9 - 6 = 3\ \Omega$$

2. Value of capacitance, $C = \dfrac{1}{2\pi \times 60 \times 3} = 884\ \mu\text{F}$

Q.2 (a) (ii) Solution:

Given, $R_3 = 5\ \Omega,\quad C = 1\text{ mF}$

$R_1 = 159\ \Omega$ and $R_2 = 10\ \Omega$

By using balance equation,

$$(R_4 + j\omega L_4)\left(\frac{R_3}{R_3 j\omega C + 1}\right) = R_2R_1$$

$$R_4R_3 + j\omega L_4R_3 = R_2R_1 + R_2R_1R_3\, j\omega C$$

Comparing real and imaginary part on two sides we get

$$R_4 = \frac{R_2R_1}{R_3}$$

and $L_4 = R_2R_1C$

$$R_4 = \frac{159 \times 10}{5} = 318\ \Omega$$

and $L_4 = 159 \times 10 \times 1 \times 10^{-3} = 1.59\text{ H}$

$$\text{Quality factor, } Q = \frac{\omega L_4}{R_4} = \frac{2\pi \times 50 \times 1.59}{318} = 1.57$$

Q.2 (b) (i) Solution:

Primary winding turns, $N_p = 1$

Secondary winding turns, $N_s = 98$

$\therefore$ Turns ratio, $n = 98$

Nominal ratio, $K_n = \dfrac{500}{5} = 100$

Magnetizing current components is in phase while the loss component is in quadrature with the flux,

$\therefore$ Magnetizing mmf $= 8$ A

Mmf equivalent to loss $= 10$ A

Magnetizing current, $I_m = \dfrac{\text{Magnetizing mmf}}{\text{Primary winding turns}} = \dfrac{8}{1} = 8\text{ A}$

Loss component, $I_e = \dfrac{\text{loss mmf}}{\text{primary winding turns}} = \dfrac{10}{1} = 10\text{ A}$

Output volt-ampere, VA = 15

Impedance of secondary load burden

$$= \frac{VA}{I_s^2} = \frac{15}{(5)^2} = 0.6\ \Omega$$

It is given that the external burden is purely resistive

∴ Resistance of external burden = 0.6 Ω

Reactance of external burden = 0 Ω

Resistance of total secondary circuit burden

$$= 0.6 + 0.35 = 0.95\ \Omega$$

Reactance of total secondary circuit burden

$$= 0 + 0.3 = 0.3\ \Omega$$

Secondary phase angle, $\delta = \tan^{-1}\dfrac{0.3}{0.95} = 17°30'$

So, $\cos\delta = 0.95$ and $\sin\delta = 0.3$

Actual ratio, $R = \dfrac{I_e\cos\delta + I_m\sin\delta}{I_s} = 98 + \dfrac{10\times0.95\times8\times0.3}{5} = 100.38$

$$\text{Ratio (current) error} = \frac{100-100.38}{100.38}\times100 = -0.38\%$$

$$\text{Phase angle, } \theta = \frac{180}{\pi}\left[\frac{I_m\cos\delta - I_e\sin\delta}{nI_s}\right]$$

$$= \frac{180}{\pi}\left[\frac{8\times0.95-10\times0.3}{98\times5}\right] = 0.537°$$

Q.2 (b) (ii) Solution:

Advantages of PMMC instruments are:

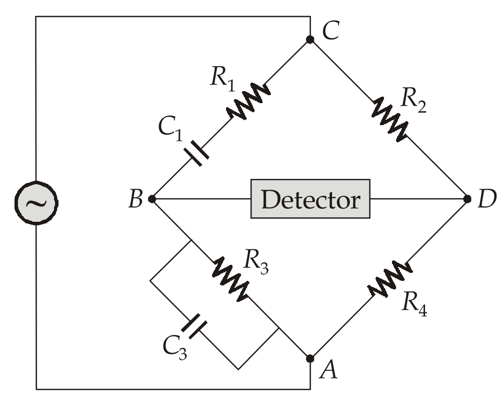
- The scale is uniformly divided.
- The power consumption is very low (25 μW - 200 μW).
- The torque-weight ratio is high which gives a high accuracy. The accuracy is of the order of generally 98 percent of full scale deflection.

- A single instrument may be used for many different current and voltage ranges by using different values for shunts and multipliers.
- Since the operating force are large on account of large flux densities which may be as high as 0.5 Wb/m^2, the errors due to stray magnetic fields are small.
- Self-shielding magnets make the core magnet mechanism particularly useful in aircraft and aerospace application, where a multiplicity of instruments must be mounted in close proximity to each other.

Disadvantages are:

- These instruments are useful only for d.c. The torque reverses if the current reverses. If the instrument is connected to a.c. the pointer cannot follow the rapid reversals and the deflection corresponds to mean torque, which is zero. Hence the instruments can not be used for a.c.
- The cost of these instruments is higher.

Q.2 (c) (i) Solution:



The impedance of arm BC is,

$$Z_1 = R_1 - \frac{j}{\omega C_1}$$

The admittance of the parallel arm is

$$Y_3 = \frac{1}{R_3} + j\omega C_3$$

Using the bridge balance equation, we have

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_2 = Z_1 Z_4 Y_3$$

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

$$R_2 = \left(\frac{R_1R_4}{R_3} + \frac{C_3R_4}{C_1}\right) - j\left(\frac{R_4}{\omega C_1 R_3} - \omega C_3 R_1 R_4\right)$$

Equating the real and imaginary terms, we have

$$\frac{R_4}{\omega C_1 R_3} = \omega C_3 R_1 R_4$$

$$\therefore \quad \omega^2 = \frac{1}{C_1 R_1 R_3 C_3}$$

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

$$f = \frac{1}{2\pi\sqrt{800 \times 0.5 \times 10^{-6} \times 400 \times 1 \times 10^{-6}}}$$

$$= \frac{10^6}{2\pi \times 400} = 0.398 \text{ kHz}$$

Q.2 (c) (ii) Solution:

Meter current for full scale deflection,

$$I_m = \frac{V}{R_m} = \frac{25 \times 10^{-3}}{25} = 1 \text{ mA}$$

Voltage multiplying factor, $m = \frac{V}{v} = \frac{10}{25 \times 10^{-3}} = 400$

Multiplier resistance, $R_s = (m - 1)R_m = (400 - 1)25 = 9975\ \Omega$

Total resistance of voltmeter circuit,

$$R_v = 25 + 9975 = 10000\ \Omega$$

Resistance of meter with 10° C rise in temperature

$$R_{mt} = 25(1 + 0.004 \times 10) = 26\ \Omega$$

Resistance of multiplier with 10°C rise in temperature

$$R_{st} = 9975(1 + 0.00015 \times 10) = 9990\ \Omega$$

Total resistance of voltmeter circuit with 10° C rise in temperature

$$R_v = 9990 + 26 = 10016\ \Omega$$

$$\text{Voltmeter reading} = \left(\frac{10000}{10016}\right) \times 10 = 9.984 \text{ V}$$

$$\text{Percentage error} = \left(\frac{9.984 - 10}{10}\right) \times 100 = 0.16\% \text{ low}$$

Q.3 (a) Solution:

Given,

Total instrument resistance, $R = 25\ \Omega$

Full scale deflection, $\theta = 150°$

Input voltage, $V = 90$ mV

Moving coil dimensions = 25 mm × 25 mm

Coil area = 625×10^{-6} m^2

Number of turns = 120

Spring constant, $K = 0.45 \times 10^{-6}$ N-m/deg

Specific resistance of conductor,

$$\rho = 1.7 \times 10^{-8}\ \Omega\text{-m}$$

Coil resistance, R_C = 40% of instrument resistance

$$= \frac{40}{100} \times 25 = 10\,\Omega$$

Length of mean turn = $2\,(l + b) = 2(25 + 25) = 100$ mm

Let the cross section area of conductor be A

For n series turns resistance,

$$R_c = N\rho l/A$$

$$R_c = \frac{120 \times 1.7 \times 10^{-8} \times 100 \times 10^{-3}}{A}$$

$$\therefore \quad A = \frac{120 \times 1.7 \times 10^{-8} \times 100 \times 10^{-3}}{10} = 2.04 \times 10^{-8}\ \text{m}^2$$

Let d be the diameter of conductor wire

$$A = \pi\frac{d^2}{4} = 2.04 \times 10^{-8}$$

$$\therefore \quad d = \left[\frac{4}{\pi} \times 2.04 \times 10^{-8}\right]^{1/2} = 0.161\ \text{mm}$$

$$\text{Current in the instrument} = \frac{\text{Voltage}}{\text{Instrument resistance}} = \frac{90\ \text{mV}}{25} = 3.6\ \text{mA}$$

Using the torque relation for moving coil instrument

$$T_d = T_c$$

Where, Deflecting torque, $T_d = NBAI$

Controlling torque, $T_c = K\theta$

$$NBAI = K\theta$$

$$120 \times B \times 625 \times 10^{-6} \times 3.6 \times 10^{-3} = 0.45 \times 10^{-6} \times 150$$

$$B = \frac{67.5\times10^{-6}}{2.7\times10^{-4}} = 0.25 \text{ Wb/m}^2$$

Q.3 (b) (i) Solution:

Primary winding turns, $N_P = 1$

Secondary winding turns, $N_S = 400$

Turn ratio, $n = \frac{N_S}{N_P} = 400$

Secondary circuit burden impedance

$$= \sqrt{(2)^2 + (3)^2} = 3.606\ \Omega$$

For secondary winding circuit,

$$\cos\delta = \frac{2}{3.606} = 0.554$$

and $$\sin\delta = \frac{3}{3.606} = 0.832$$

Secondary induced voltage, $E_S = 6 \times 3.606 = 21.64$ V

Primary induced voltage, $E_P = \frac{E_S}{n} = \frac{21.64}{400} = 0.054$ V

Loss component of current referred to primary winding

$$I_e = \frac{\text{Iron loss}}{E} = \frac{2}{0.054} = 37.04 \text{ A}$$

Magnetizing current, $$I_m = \frac{\text{Magnetizing mmf}}{\text{Primary winding turns}} = \frac{100}{1} = 100 \text{ A}$$

Actual ratio, $$R = n + \frac{I_e\cos\delta + I_m\sin\delta}{I_s}$$

$$= 400 + \frac{37.04\cos\delta + 100\sin\delta}{I_s}$$

$$= 400 + \frac{(37.04\times0.554) + (100\times0.832)}{6}$$

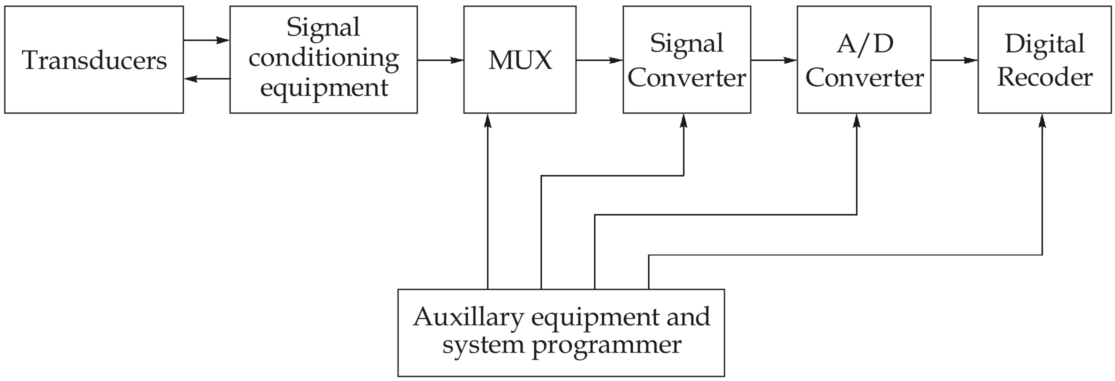
$$= 400 + \frac{103.72}{6} = 400 + 17.28 = 417.28$$

Percentage ratio error $= \frac{K_n - R}{R}\times100$; (Where K_n = nominal ratio)

$$= \frac{400 - 417.28}{417.28}\times100 = -4.14\%$$

Q.3 (b) (ii) Solution:

A generalized diagram of a digital data acquisition system is shown in below:



A digital data acquisition system may include some or all of the components shown in figure above. The essential functional operations of a digital data acquisition system are:

(a) handling of analog signals

(b) making the measurement

(c) converting the data to digital form and handling it

(d) internal programming and control

The various components and their functions are described below:

1. **Transducers:** They convert a physical quantity into an electrical signal which is acceptable by the data acquisition system.
2. **Multiplexer:** Multiplexing is the process of sharing a single channel with more than one input.
3. **Signal converter:** A signal converter translates the analog signal to form acceptable by the A/D converter.
4. **A/D converter:** An A/D converter converts the analog voltage to its equivalent digital form.
5. **Digital recorders:** Records of information in digital form may be load on punched cords, floppy discs, magnetic takes etc.

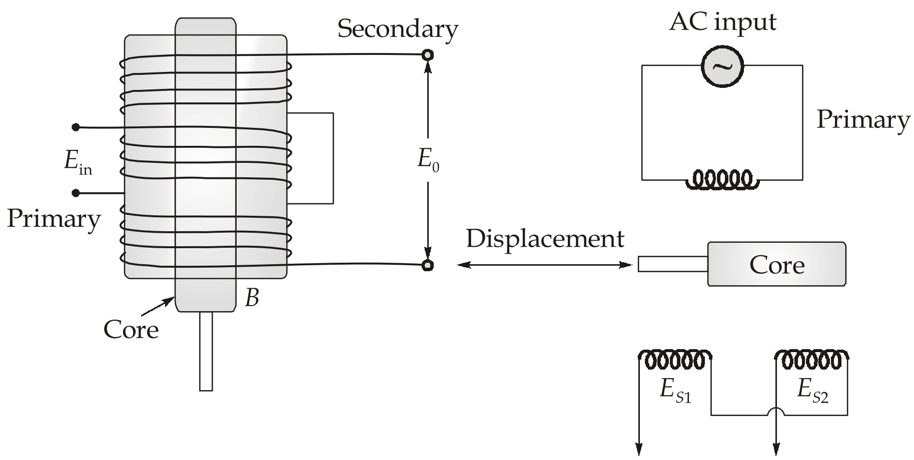
Q.3 (c) Solution:

LVDT consists of a transformer consisting of a single primary winding P_1 and two secondary windings S_1 and S_2 wound on a hollow cylindrical former. The secondary windings have an equal number of turns and are identically placed on either side of the primary windings. The primary winding is connected to an ac source.

A movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and two secondaries.

The displacement to be measured is applied to an arm attached to the soft iron core.

When the core is in its normal (null) position, equal voltages are induced in the two secondary windings. The frequency of the ac applied to the primary winding varies from 50 Hz to 20 kHz.



The output voltage of the secondary windings S_1 is E_{S1} and that of secondary winding S_2 is E_{S2}.

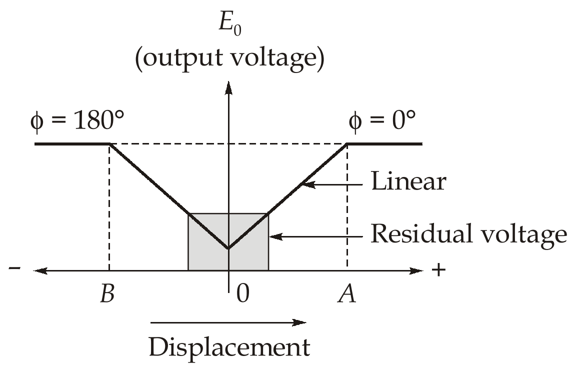
In order to convert the output from S_1 to S_2 into a single voltage signal, the two secondaries S_1 and S_2 are connected in series opposition. Hence the output voltage of the transducer is the difference of the two voltages. Therefore the differential output voltage is $E_0 = E_{S1} - E_{S2}$.

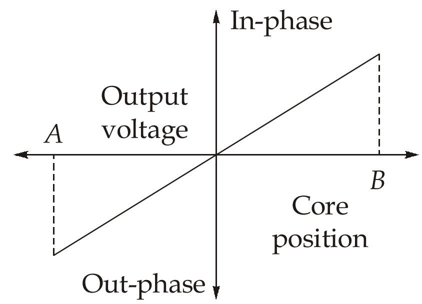
When the core is at its normal position, the flux linking with both secondary windings is equal, and hence equal emf's are induced in them. Hence at null position, $E_{S1} = E_{S2}$. Since the output voltage of the transducer is the difference of the two voltages, the output voltage E_0 is zero at null position.

Now, if the core is moved to the left of the null position, more flux links with winding S_1 and less with winding S_2. Hence output voltage E_{S1} of the secondary winding S_1 is greater than E_{S2}. The magnitude of the output voltage of secondary is then $E_{S1} - E_{S2}$, in phase with E_{S1} (the output voltage of secondary winding S_1).

Similarly if the core is moved to the right of the null position, the flux linking with winding S_2 becomes greater than that linked with winding S_1. The output voltage in this case is $E_0 = E_{S2} - E_{S1}$ and is in phase with E_{S2}.

The output voltage of an LVDT is a linear function of the core displacement within a limited range of motion (say 5 mm from the null position).





Advantages of LVDT:

- ***Linearity*:** The output voltage of this transducer is practically linear for displacement upto 5 mm.
- ***Infinite resolution*:** The change in output voltage is stepless. The effective resolution depends more on the test equipment than on the transducer.
- ***High output*:** It gives a high output (therefore there is no need for intermediate amplification devices).
- ***High sensitivity*:** The transducer possesses a sensitivity as high as 40 V/mm.
- ***Ruggedness*:** These transducers can usually tolerate a high degree of vibration and shock.
- ***Less friction*:** There are no sliding contacts.
- ***Low hysteresis* :** This transducer has low hysteresis, hence repeatability is excellent under all conditions.
- ***Low power consumption*:** Most LVDTs consume less than 1 W of power.

Q.4 (a) (i) Solution:

Given full scale reading of all three meters = 100

$$\text{Reading of } B = 90$$
$$\text{Reading of } C = 20$$
$$\text{Reading of } D = 60$$

$$\delta B = \pm 0.4\% \text{ of reading} = \frac{\pm 0.5 \times 90}{100} = \pm 0.45$$

$$\delta C = \pm 1.2\% \text{ of full scale value} = \frac{\pm 1.2 \times 100}{100} = \pm 1.2$$

$$\delta D = \pm 1.5\% \text{ of reading} = \frac{\pm 2 \times 60}{100} = \pm 1.2$$

Given, $A = \dfrac{B}{CD}$

Taking log on both side,

$$\log A = \log B - \log C - \log D$$

Differentiating with respect to A,

$$\frac{\delta A}{A} = \frac{\delta B}{B} - \frac{\delta C}{C} - \frac{\delta D}{D}$$

$$\text{For maximum limiting error} = \pm\left(\frac{0.45}{90} + \frac{1.2}{20} + \frac{1.2}{60}\right)\times 100$$

$$= \pm(0.5 + 6 + 2) = \pm 8.5\%$$

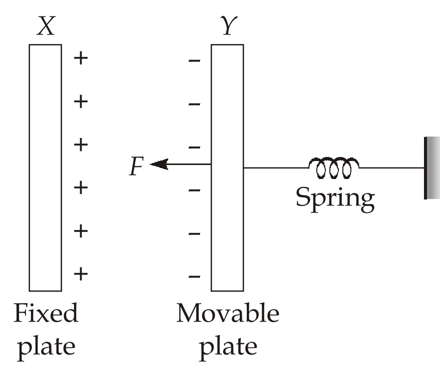
Q.4 (a) (ii) Solution:

Let,

V = Potential difference applied to plate X and Y

C = Capacitance between two plates

F = Force between plates



$$\text{Energy stored} = \frac{1}{2}CV^2$$

Let there be small change by dV in the applied voltage, the plate Y move towards X by small distance 'dx'.

For increase in applied voltage, current flow will be

$$i = \frac{dq}{dt} = \frac{d}{dt}(CV) = C\frac{dV}{dt} + V\frac{dC}{dt}$$

$$\text{Input energy} = Vi\,dt = V^2\,dC + CV\cdot dV$$

$$\text{Change in stored energy} = \frac{1}{2}(C + dC)(V + dV)^2 - \frac{1}{2}CV^2$$

$$= \frac{1}{2}V^2 dC + CV\cdot dC$$

(After neglecting higher order terms)

Using principle of energy conservation,

Input electrical energy = Increased in stored energy + Mechanical work done

$$V^2\,dC + CV\cdot dV = \frac{1}{2}V^2 dC + CV\cdot dV + F\cdot dx$$

On solving further, $$F = \frac{1}{2}V^2\frac{dC}{dx}$$

Q.4 (b) Solution:

The total shunt resistance R_{sh} is determined by

$$R_{\text{sh}} = \frac{R_m}{n-1} \qquad \text{Where, } n = \frac{I}{I_m}$$

Given, $I_m = 100\ \mu\text{A}$

and $R_m = 1000\ \Omega$

Step-1 :

For 10 mA range:

$$n = \frac{I}{I_m} = \frac{10\,\text{mA}}{100\ \mu\text{A}} = 100$$

$$R_{\text{sh}\,1} = \frac{R_m}{n-1} = \frac{1000\,\Omega}{100-1} = 10.1\ \Omega$$

Step-2 :

When the meter is set on the 100 mA range, the resistance R_b and R_c provides the shunt. The shunt can be found from the equation

$$R_{sh\,2} = (R_b + R_c) = \frac{I_m(R_m + R_{sh\,1})}{I}$$

$$= \frac{100\,\mu\text{A}(10.1 + 1000)}{100\text{ mA}} = 1.01\ \Omega$$

Step-3 :

The resistor which provides the shunt resistance on the 1 A range can be found from the equation.

$$R_c = \frac{I_m(R_m + R_{sh\,1})}{I}$$

$$= \frac{100\,\mu\text{A}(10.1 + 1000)}{1000\text{ mA}} = 0.101\ \Omega$$

Step-4:

$$R_b + R_c = 1.01\ \Omega$$
$$R_b = 1.01 - R_c = 1.01\ \Omega - 0.101\ \Omega$$
$$= 0.909\ \Omega$$

Step-5:

Resistor R_a is found by

$$R_a = R_{sh\,1} - (R_b + R_c) = 9.09\ \Omega$$

Q.4 (c) (i) Solution:

Given, Supply voltage, $V = 230$ V

Reading of dynamometer type wattmeter

$$P = VI\cos(\phi - \beta)\cos\beta$$

If $\beta = 2°$ $\quad 800 = 230 \times I \times \cos(\phi - 2°)\cos 2°$ ...(i)

If $\beta = 1°$ $\quad 640 = 230 \times I \times \cos(\phi - 1°)\cos 1°$ ...(ii)

Using (i) and (ii), we get

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

$$[\cos\phi\cos 2° + \sin\phi\sin 2°] = 1.25 \times [\cos 1°\cos\phi + \sin\phi\sin 1°]$$

$$\sin\phi\,[\sin 2° - 1.25 \times \sin 1°] = \cos\phi\,[1.25\cos 1° - \cos 2°]$$

$$\tan\phi = \left\{\frac{1.25\cos 1° - \cos 2°}{\sin 2° - 1.25\sin 1°}\right\}$$

$$\phi = 87.01°$$

$$\text{Using power relation} = VI\cos(\phi - 1°)\cdot\cos 1° = 320$$

$$230 \times I\cos(87.01° - 1°)\cos 1° = 320$$

$$I = \frac{320}{230 \times \cos(86.01)\cos 1°} = 19.99\text{ A}$$

Q.4 (c) (ii) Solution:

Multiplying power of shunt,

$$m = \frac{I}{I_m} = \frac{50}{5} = 10$$

In order that the meter may read correctly at all frequencies the time constants of meter and shunt circuits should be equal. Under this condition multiplying power m is,

$$m = 1 + \frac{R}{R_{sh}}$$

∴ Resistance of shunt, $$R_{sh} = \frac{R}{m-1} = \frac{0.09}{10-1} = 0.01\ \Omega$$

Also, $$\frac{L}{R} = \frac{L_{sh}}{R_{sh}}$$

∴ Inductance of shunt, $$L_{sh} = \frac{L}{R}R_{sh} = \frac{90}{0.09}\times 0.01 = 10\ \mu\text{H}$$

With d.c. the current through the meter for a total current of 50 A is,

$$I_m = \frac{R_{sh}}{R+R_{sh}}\times I = \frac{0.01}{0.09+0.01}\times 50 = 5.0\ \text{A}$$

With 50 Hz, the current through the meter for a total current of 50 A is

$$I_m = \frac{R_{sh}}{\sqrt{(R+R_{sh})^2+\omega^2L^2}}\times I$$

$$= \frac{0.01\times 50}{\sqrt{(0.09+0.01)^2+(2\pi\times 50\times 90\times 10^{-6})^2}}$$

$$= 4.81\ \text{A}$$

Since the meter reading is proportional to the current,

$$\text{Error} = \frac{4.81-5}{5}\times 100\% = -3.8\%$$

The meter reads 3.8% low.

Section B : Electrical Materials

Q.5 (a) Solution:

(i) $$\varepsilon = \varepsilon_r\varepsilon_0 = 6.0\times 8.85\times 10^{-12}\ \text{F/m}$$

$$= 5.31\times 10^{-11}\ \text{F/m}$$

Thus, the capacitance is

$$C = \varepsilon\frac{A}{l} = (5.31\times 10^{-11}\text{F/m})\left(\frac{6.45\times 10^{-4}}{2\times 10^{-3}}\right)$$

$$= 1.71\times 10^{-11}\ \text{F}$$

(ii) Charged stored, $$Q = CV = (1.71\times 10^{-11}\text{F})\times 10\ \text{V}$$

$$= 1.71\times 10^{-10}\ \text{C}$$

(iii) The dielectric displacement,

$$D = \varepsilon E = \varepsilon \frac{V}{l} = \frac{(5.31 \times 10^{-11} \text{F/m}) \times 10}{2 \times 10^{-3}}$$

$$= 2.66 \times 10^{-7} \text{ C/m}^2$$

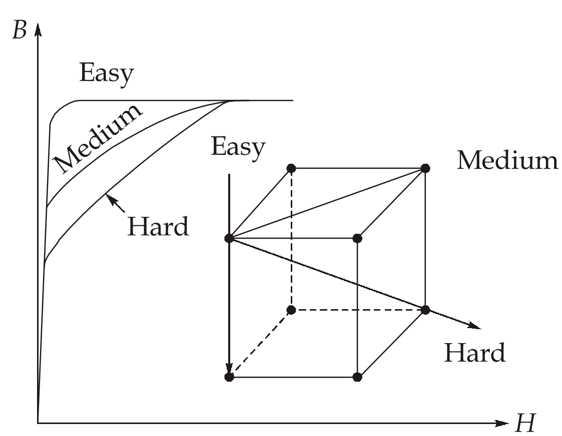
(iv) The polarization, $P = D - \varepsilon_0 E$

$$= D - \varepsilon_0 \frac{V}{l} = 2.66 \times 10^{-7} - \frac{8.85 \times 10^{-12} \times 10}{2 \times 10^{-3}}$$

$$= 2.22 \times 10^{-7} \text{ C/m}^2$$

Q.5 (b) Solution:

Magnetic Anisotropy: The term "magnetic anisotropy" means that magnetic properties are dependent on the crystallographic direction. This property is critical for the development of permanent or hard magnetic materials. The coercivity of magnetic materials is related to the magnetic anisotropy in two ways. First, there is the magnetocrystalline anisotropy. Simply stated, this means that for a given single crystal material, magnetic properties, such as the coercive field, change depending on the crystallographic direction. The second type of magnetic anisotropy is known as magnetoshape anisotropy or shape anisotropy. This anisotropy means that if we have particles of two identical materials, with one particle being needle-like (acicular) and the other one nearly spherical, then the acicular particle will have a higher coercivity because of its shape. The cause of shape anisotropy can be traced to the difference in the demagnetization factors.



Importance of magnetic anisotropy in transformer Cores:

The magnetocrystalline anisotropy is important in many applications of hard and soft materials. We use grain-oriented steels for transformer cores so that the steel magnetizes easily along the easy directions. Owing to the magnetocrystalline anisotropy present in an iron single crystal, the magnetization develops most easily along the [100] direction.

The crystallographic direction in which the magnetization develops with a smaller coercivity is known as the easy magnetization direction or the easy axis. This represents the direction(s) in which the average magnetic moment will be directed for a material with no application of an external magnetic field. Alignment of magnetic moments along the easy-axis directions would minimize the free energy of the material. On the contrary, for a BCC iron single crystal, the [111] direction that represents a body diagonal will be the hard magnetization direction or hard axis. All the body diagonals, that is, the <111> family of directions, and not just the [111] direction, will represent the hard axes for BCC iron.

Q.5 (c) Solution:

(i) Burger vector $'b' = \frac{1}{2}[1\ 1\ 0]$

Direction $'t' = [1\ 1\ 2]$

Given is the mixed dislocation, it can move only in a plane containing both b and t.

Let the indices of slip plane be $(h\ k\ l)$

Then, $t_1h + t_2k + t_3l = 0$

$\Rightarrow \quad h + k + 2l = 0 \quad$ ...(i)

and $b_1h + b_2k + b_3l = 0$

$\Rightarrow \quad \frac{1}{2}h + \frac{1}{2}k + 0l = 0 \quad$ ...(ii)

Solving equations (i) and (ii)

$$\frac{1}{2}h = -\frac{1}{2}k$$

$$h = -k$$

and, $2l = -h - k = -h + h = 0$

$\Rightarrow \quad l = 0$

Slip plane is $(h\ k\ l) = (1\ \bar{1}\ 0)$

(ii) This is because if we join all four end centred lattice point to a common lattice points of unit cells (points joining two unit cells), a new unit cell is formed which is primitive tetragonal only which has single four fold axis symmetry.

Hence due to symmetry there is no end centred tetragonal unit cell.

Q.5 (d) Solution:

Given,

$$B_1 = 4\text{ Wb/m}^2, \quad H_1 = 2400\text{ A/m}$$

$$B_2 = 2.8\text{ Wb/m}^2, \quad H_2 = 800\text{ A/m}$$

$$B = \mu H$$

$$4 = \mu(2400)$$

$$\mu = \frac{4}{2400}$$

$$\mu_0\mu_r = \frac{1}{600}$$

$$4\pi \times 10^{-7}\,\mu_{r1} = \frac{1}{600}$$

$$\mu_{r1} = \frac{1}{4\pi\times10^{-7}\times600}$$

$$B = \mu H$$

$$2.8 = \mu \times 800$$

$$\mu = \frac{2.8}{800}$$

$$4\pi \times 10^{-7} \times \mu_{r2} = \frac{2.8\times10^7}{800\times4\pi}$$

$$\mu_{r2} = 2785.21$$

$$\chi_{m1} = \mu_{r1} - 1$$

$$= 1326.29 - 1 = 1325.29$$

$$M_1 = \chi_{m1}H_1 = 1325.29 \times 2400 = 3180696$$

$$\chi_{m2} = \mu_{r2} - 1$$

$$= 2785.21 - 1 = 2784.21$$

$$M_2 = \chi_{m2} \times H_2$$

$$= 2784.21 \times 800 = 2227368$$

Change in magnetization (M) = $M_1 - M_2$

$$= 3180696 - 2227368 = 953328$$

$$\text{Percentage change} = \left(\frac{M_1 - M_2}{M_1}\right)\times100\%$$

$$= \frac{953328}{3180696}\times100 = 29.97\%$$

Q.5 (e) Solution:

- Since molybdenum has BCC crystal structure, there are 2 atoms in the unit cell.
- The density can be given by,

$$\rho = \frac{\text{Mass of atoms in unit cell}}{\text{Volume of unit cell}}$$

$$= \frac{(\text{Number of atoms in unit call}) \times (\text{Mass of one atom})}{\text{Volume of unit cell}}$$

$$= \frac{2\left(\frac{M_{at}}{N_A}\right)}{a^3}$$

So, $$a = \left(\frac{2M_{at}}{\rho N_A}\right)^{1/3} = \left(\frac{2 \times 95.94}{10.22 \times 6.022 \times 10^{23}}\right)^{1/3} \text{cm}$$

$$= 3.147 \times 10^{-10} \text{ m}$$

- The atomic concentration (n_{at}) is 2 atoms in a cube of volume a^3.

So, $$n_{at} = \frac{2}{a^3} = \frac{2}{(3.147 \times 10^{-10})^3} \text{m}^{-3} = 6.415 \times 10^{28} \text{ m}^{-3}$$

- For a BCC cell, the lattice parameter a and the radius of the atom R are related by,

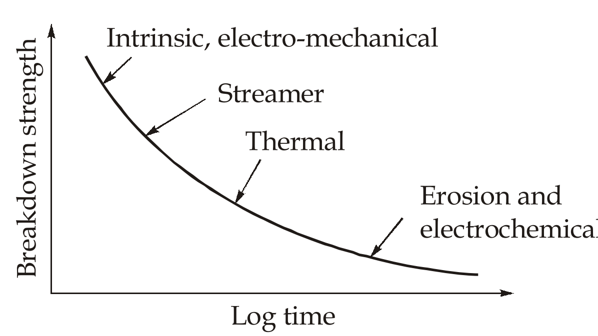
$$R = \frac{a\sqrt{3}}{4} = \frac{(3.147 \times 10^{-10})\sqrt{3}}{4} \text{m} = 1.363 \times 10^{-10} \text{ m}$$

Q.6 (a) Solution:

Dielectric strength is defined as the maximum voltage required to produce a dielectric breakdown through the material and is expressed as volts per unit thickness. The higher the dielectric strength of a material the better its quality as an insulator.

In the case of solids, mechanism of breakdown is a complex phenomenon , and varies depending on the time of application of voltage as shown in the figure. The various breakdown mechanisms can be classified as follows:

(a) Intrinsic or ionic breakdown
(b) Electromechanical breakdown
(c) Thermal breakdown
(d) Electrochemical breakdown
(e) Treeing and tracking
(f) Internal discharges



(a) Intrinsic Breakdown:

- When voltage is applied only for short duration of the order of 10^{-8} sec, the dielectric strength of a solid dielectric increases very rapidly to an upper limit called the intrinsic electric strength.
- Maximum strength usually obtainable ranges from 5-10 MV/cm.
- Intrinsic breakdown depends upon the presence of free electrons which are capable of migration through the lattice of the dielectric. Usually, small numbers of conduction electrons are present, along with some structural imperfections and small amounts of impurities. The impurity atoms or molecules act as traps for the conduction electrons up to certain ranges of electric fields and temperatures. When these ranges are exceeded, additional electrons in addition to trapped electrons are released and participate in the conduction process.
- Based on this principle, there are two types of intrinsic breakdown mechanisms:

(i) Electronic breakdown:

- Intrinsic breakdown occurs in time of the order of 10^{-8} s and therefore, is assumed to be electronic in nature.
- Initial density of conduction (free) electrons is assumed to be large and electron-electron collisions occurs.
- When electric field is applied, electrons gain energy and cross the forbidden gap from the valence band to the conduction band. When this process is repeated, more and more electrons become available in conduction band, eventually leading to breakdown.

(ii) Avalanche or streamer breakdown:

- This is similar to breakdown in gases due to cumulative ionization.
- Conduction electrons gain sufficient energy above a certain critical electric field and cause liberation of electrons from the lattice atoms by collision.
- The electron within dielectric moving from cathode to anode will gain energy from the field and loses it during collisions. When the energy gained by an electron exceeds the lattice ionization potential, an additional electron will be liberated due to collision of the first electron. This process repeats itself resulting in the formation of an electron avalanche, and breakdown will occur when the avalanche exceeds a certain critical size.
- In practice, breakdown does not occur by the formation of a single avalanche, but occurs as a result of many avalanches formed and extending step by step through the entire thickness of the material.

(b) Breakdown due to Treeing and Tracking

- When a solid dielectric subjected to electrical stresses for a long time fails, two kinds of visible marking are observed.
  a. Presence of conducting path across the surface of the insulation.
  b. Mechanism whereby leakage current passes through the conducting path, finally leading to the formation of spark. Insulation deterioration occurs as a result of these sparks.
- Spreading of spark channels during tracking, in the form of the branches of a tree is called treeing.
- Consider a system of a solid dielectric having a conducting film and two electrodes on its surface. In practice, the conducting film very often is formed due to moisture. On application of voltage, the film starts conducting, resulting in generation of heat, and the surface starts becoming dry. The conducting film becomes separate due to drying, and so sparks are drawn damaging the dielectric surface. With organic insulating material, the dielectric carbonizes at the region of sparking, and carbonized regions act as permanent conducting channels resulting in increased stress over the rest of the region. This is a cumulative process, and insulation failure occurs when carbonized tracks bridge the distance between the electrodes. This phenomenon is called tracking.
- Treeing occurs due to the erosion of material at the tips of the spark and results in the roughening of the surface and hence, becomes a source of dirt and contamination. This causes increased conductivity resulting either in the formation of conducting path bridging the electrodes or in a mechanical failure of the dielectric.
- Usually tracking occurs even at very low voltages, whereas treeing requires high voltage.

(c) Breakdown due to Internal Discharges:

- Solid insulating materials contain voids or cavities within the medium or at the boundaries between the dielectric and the electrodes. These voids are generally filled with a medium of lower dielectric strength, and the dielectric constant of the medium in the voids is lower than that of the insulation.
- The electric field strength in the voids is higher than that across the dielectric. Therefore, even under normal working voltages the field in the voids may exceed their breakdown value, and breakdown may occur.

(d) Electromechanical Breakdown:

- When solid dielectrics are subjected to high electric fields, failure occurs due to electrostatic compressive forces, which can exceed the mechanical compressive strength.
- If the thickness of specimen is d_0 and is compressed to a thickness d under an applied voltage V, the highest apparent electric stress before breakdown is:

$$E_{max} = \frac{V}{d_0} = 0.5\sqrt{\left(\frac{Y}{\varepsilon_0 \varepsilon_r}\right)}$$

  where, Y - Young's modulus
- Mechanical instability occurs when $d/d_0 = 0.6$
- The above equation is only approximate as Y depends on the mechanical stress. Also when the material is subjected to high stresses, the theory of elasticity does not hold good and plastic deformation has to be considered.

(e) Thermal Breakdown:

- When an electric field is applied to a dielectric, conduction current flows through the material. Current heats up the specimen and the temperature rises. Equilibrium is reached when the heat used to raise the temperature of the dielectric, plus the heat radiated out, equals the heat generated, causing breakdown.
- Thermal breakdown sets-up an upper limit for increasing the breakdown voltage when the thickness of insulation is increased.
- Heat generated is proportional to the frequency and hence thermal breakdown is more serious at high frequency.
- Thermal breakdown stresses (MV/cm) are lower under a.c. condition than under d.c.

(f) Chemical and Electrochemical Deterioration and Breakdown:

- In presence of air and other gases, dielectric materials undergo chemical changes when subjected to continuous electrical stresses. Some of the reactions that occur are:

  Oxidation: In the presence of air or oxygen, materials such as rubber and polyethylene undergo oxidation giving rise to surface cracks.

  Hydrolysis: When moisture or water vapour is present on the surface of the solid dielectric, hydrolysis occurs and the materials lose their electrical and mechanical properties. Electrical properties of materials such as paper, cotton tape and other cellulose materials deteriorate very rapidly due to hydrolysis.

Chemical Action: Progressive chemical degradation can occur due to a variety of processes such as chemical instability at high temperature, oxidation, cracking in the presence of air and hydrolysis due to moisture and heat.

- Chemical and electrochemical deterioration increases very rapidly with temperature.

Q.6 (b) (i) Solution:

Given,

Resistivity of the sample = $\rho_i = 9 \times 10^{-3}\ \Omega m$

Hall coefficient, R_H = $7.2 \times 10^{-4}\ m^3\ columb^{-1}$

Hall coefficient is positive for holes.

$$R_H = \frac{A}{en_h} \text{ (where } n_h \text{ is carrier density of the holes)}$$

$$R_H = \frac{3\Omega}{8} \times \frac{1}{en_h}$$

$$\left(A = \text{constant} = \frac{3\Omega}{8} \text{ for simple semiconductor model}\right)$$

$$n_h = \frac{3\Omega}{8} \times \frac{1}{R_H \times e}$$

$$= \frac{3}{8} \times \frac{1}{7.2 \times 10^{-4} \times 1.6 \times 10^{-19}}$$

$$= 1.022 \times 10^{22}\ m^{-3}$$

and mobility of holes, $\mu_h = \dfrac{1}{\rho_i n_h e}$

$$= \frac{1}{9.00 \times 10^{-3} \times 1.02 \times 10^{22} \times 1.6 \times 10^{-19}}$$

$$= 0.06808\ m^3\ volt^{-1}\ s^{-1}$$

Q.6 (b) (ii) Solution:

Superconductors are classified into two groups: Type-I and Type-II.

Type-I:

Superconductors that show perfect diamagnetism up to the critical field H_c and go to the normal state as shown in figure (a) are called type-I superconductors.

The critical field of these superconductors are low; even tantalum, which has highest H_c, has value at 0 K or $\mu_0 H_c(0) = 83$ mT.

Type-I superconductors are not suitable for high field applications. They are also called soft superconductors (or ideal).

Soft metals such as lead or indium belong to this group.

Type-II:

Hard metals and alloys have different magnetization characteristics as shown schematically in figure (b), and are called type-II superconductors (or hard superconductors).

They are characterized by high transition temperature, high critical field, incomplete Meissner effect, breakdown of Silsbee's rule, and or broad transition region.

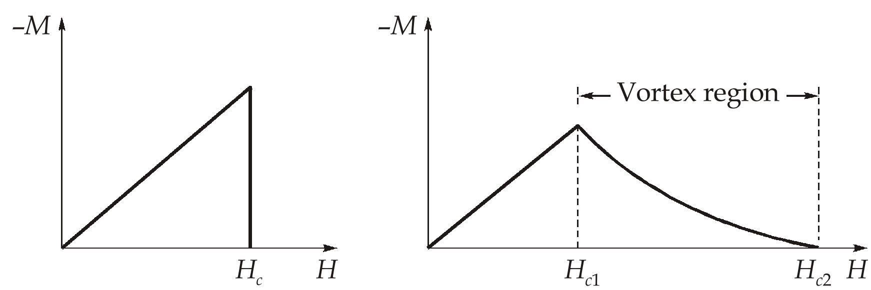


Fig. (a): Type-I Superconductor Fig. (b): Type-II Superconductor

- Superconductivity is observed for dc and upto radio frequencies. It is not observed for higher frequencies. For a superconductor the resistance is zero only when the current is steady or varies slowly. When the current fluctuates or alternates, small absorption of energy roughly proportional to rate of alternation rises above 10 MHz appreciable resistance arises, and at infrared frequencies (10^{13} Hz) the resistivity is the same in the normal and superconducting states, and is independent of temperature.

Q.6 (c) (i) Solution:

Soft magnetic materials features:

- These materials are easy to magnetize and demagnetize.
- These materials favour rapid switching of magnetization to the applied AC field.
- Their retentivity is low.
- Their coercivity is low.
- They have high permeability.
- They have high magnetic saturation.
- They have high Curie temperature.
- They have low hysteresis loss (because of small area of hysteresis loop).
- Nature of hysteresis loop is tall and narrow.

Examples:

- Fe-Si alloy or soft-iron or Si-steel.
- Fe-Ni alloys like permalloy, supermalloy and Mu-metal etc.

Application: These are used for construction of transformers and inductor cores.

Q.6 (c) (ii) Solution:

Initially magnetic material, $B = 4 \text{ Wb/m}^2$

Also, Magnetic field density, $B = \mu_1 H$

Magnetic field intensity, $H = 4800 \text{ A/m}$

$$4 = (\mu_1)(4800)$$

$$\mu_1 = \frac{4}{4800} = \frac{1}{1200}$$

$$\mu_0\mu_{r1} = \mu_1$$

$$\mu_{r1} = \frac{1}{1200 \times 4\pi \times 10^{-7}} = 663.145$$

After reducing $\vec{H}$

$$B = \mu_2 H$$

$$1.8 = \mu_2 640$$

$$\mu_2 = \frac{1.8}{640}$$

Also,

$$\mu_0\mu_{r2} = \mu_2$$

$$\mu_{r2} = \frac{1.8}{640 \times 4\pi \times 10^{-7}} = 2238.116$$

$$\chi_{m1} = \mu_{r1} - 1 = 663.145 - 1 = 662.145$$

$$M_1 = \chi_{m1} H_1 = 662.145 \times 4800$$

$$M_1 = 3178296$$

Similarly,

$$\chi_{m2} = \mu_{r2} - 1 = 2238.116 - 1 = 2237.116$$

$$M_2 = \chi_{m2} H_2 = (2237.116) \times 640 = 1431754.24$$

$$\text{Percentage change} = \frac{\Delta M}{M_1} \times 100 = \frac{1746541.76}{3178296} \times 100$$

$$= 0.54952 \times 100 = 54.95\%$$

Q.7 (a) Solution:

Superconductivity :

- A state of material in which it has zero resistivity is called superconductivity. Superconductivity appears at low temperatures and in magnetic fields lower than a particular level. Superconductors are also perfect diamagnet. This is the Meissner effect. Perfect diamagnetism is an independent property of superconductors and shows that superconductivity involves a change of thermodynamic state, not just a spectacular change in electrical resistance.

  In a superconductor, magnetic flux density B is zero. i.e. $B = 0$

  or $\mu_0 (H + M) = 0$

  or $H = -M$

  ⇒ Since χ_m = M/H, it can be stated that the magnetic susceptibility in a superconductor is negative. This is referred to as perfect diamagnetism.

  ⇒ Thus, a perfect diamagnetism and zero resistivity are two independent, essential properties of the superconducting state.

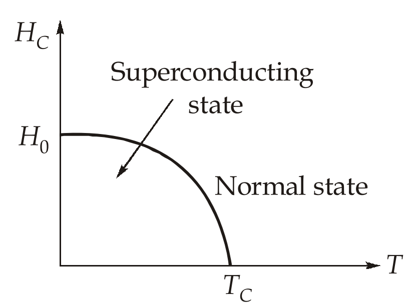
  ⇒ The critical value of magnetic field for the destruction of superconductivity, H_C is a function of temperature.

  Mathematically,

$$H_C = H_0\left[1-\left(\frac{T}{T_C}\right)^2\right]$$

  where H_0 is the critical field at absolute zero and T_C is the transition temperature.

  ⇒ For any particular super conductor the shape of variation of 'H_C' with temperature (T) is shown as:



  ⇒ Some other features of superconductivity are following :

  - Superconductivity is observed for d.c. and upto radio frequencies. It is not observed for higher frequencies.
  - Entropy increases on going from superconducting state to normal state.

- In an ideal superconductor, there is a marked drop in the thermal conductivity when superconductivity sets in.
- The critical temperature of superconductors varies with isotopic mass. The relation is

$$M^{1/2}T_C = \text{Constant}$$

where M is the mass of the isotope.

⇒ Superconducting materials are used as electronic switching devices called cryotrons (based on the destruction of superconductive state in a strong magnetic field).

⇒ Superconducting magnets find applications in the following areas :

- Magnets for nuclear fusion
- Magnetically Levitated Transportation
- Magnetic Resonance Imaging (MRI)
- Generators and motors
- Super conducting magnets for energy storage device
- It is also used in the field of electronics.

Radius of copper disk $r = 50 \text{ cm} = 50 \times 10^{-2} \text{ m}$

Thickness of the disk $t = 10^{-3} \text{ mm} = 10^{-6} \text{ m}$

Voltage maintained at disk

$$V_1 = 50 \text{ V}$$

Resistivity of the disk $\rho = 1.7 \times 10^{-8}\ \Omega\text{m}$

Now cross-sectional area of disk $A = 2\pi rt$

$$A = 2\pi \times 50 \times 10^{-2} \times 10^{-6} = 100\pi \times 10^{-8} = 10^{-6}\ \pi \text{ m}^2$$

Length through which current flow

$$l = r = 50 \times 10^{-2} \text{ m}$$

∴ resistance of the disk

$$R = \rho \cdot \frac{l}{A} = \frac{1.7 \times 10^{-8} \times 50 \times 10^{-2}}{10^{-6} \times \pi}$$

$$= 27.06 \times 10^{-4}\ \Omega$$

Now voltage of thin rod $V_2 = 49$ V

∴ current flow through disk

$$I = \frac{V_1 - V_2}{R} = \frac{50 - 49}{27.06 \times 10^{-4}}$$

$$= 3.7 \times 10^2 \text{ A}$$

Q.7 (b) (i) Solution:

When an external magnetic field is applied to a material, the value of electric resistance changes. This property of material is called magnetoresistance.

Given, plate area $= 1\ cm^2 = 10^{-4}\ m^2$

Thickness $= 0.3\ mm = 3 \times 10^{-4}\ m$

Concentration of free electrons in germanium

$$n = 2 \times 10^{19}/m^3$$

Mobility of electrons, $\mu_e = 0.40\ m^2/V\text{-sec}$

Mobility of holes, $\mu_h = 0.20\ m^2/V/sec$

$$\text{Resistivity of germanium, } \rho = \frac{1}{ne(\mu_e + \mu_h)}$$

$$\rho = \frac{1}{2\times10^{19}\times1.6\times10^{-19}\times(0.4+0.20)} = 0.67\ \Omega\text{-m}$$

$$\text{Resistance of germanium, } R = \rho\frac{l}{A}$$

$$= 0.67\times\frac{3\times10^{-4}}{1\times10^{-4}} = 2\ \Omega$$

$$\text{Current produced, } I = \frac{V}{R} = \frac{2}{2} = 1\ A$$

Q.7 (b) (ii) Solution:

In a tetragonal crystal system, the unit cell is defined by three lattice parameters: a, b, and c, where $a = b \neq c$. An end-centered unit cell contains atoms at the centre of any two opposite faces along with eight atoms at its corners. Since, $a = b \neq c$ in tetragonal system, the end-centered tetragonal unit cell disrupts the symmetry of the crystal.

The only possible tetragonal unit cell arrangements are:

1. Simple tetragonal, with atoms only at the corner positions.
2. Body-centered tetragonal, with atoms at the corner positions and at the body centre.

In order to have end centered closed packing structure, unit cell must possess lattice parameters with $a \neq b \neq c$. Thus, the end centered lattices exist only in orthorhombic and monoclinic bravais lattices because the end centered lattices are not having all the symmetrical elements like body centered, face centered and simple cubic unit cell.

Q.7 (c) Solution:

In dielectric materials, all electrons are bound: the only motion possible in the presence of an electric field is a minute displacement of positive and negative charges in opposite directions. The displacement is usually small compared to atomic dimensions. A dielectric in which this charge displacement takes place is said to be polarized, and its molecules are said to possess induced dipole moment. These dipoles produce their own field, which adds to that of external fields. In addition to displacing the positive and negative charges, an applied electric field can also polarize a dielectric by orienting molecules that possess a permanent dipole moment.

The four basic *polarization mechanism:*

(a) Electronic or induced polarization
(b) Ionic Polarization
(c) Orientational polarization
(d) Interfacial or space charge polarization.

For the given material,

Polarization is given by, $\vec{P} = \in_0 (\in_r - 1)\vec{E}$

Given, $\in_r = 2.4$

and $\vec{E} = 10^4 \vec{a}_x \text{ V/m}$

$$\vec{P} = 8.85 \times 10^{-12} \times (2.4 - 1)10^4 \vec{a}_x$$
$$= 8.85 \times 10^{-12} \times 1.4 \times 10^4$$
$$= 12.39 \times 10^{-8} \hat{a}_x \text{C/m}^2$$

Now for individual dipole moment,

$$\vec{P} = N\vec{p}$$
$$12.39 \times 10^{-8} \vec{a}_x = 3.2 \times 10^{19} \vec{p}$$

Dipole moment, $\vec{p} = \dfrac{12.39 \times 10^{-8} \vec{a}_x}{3.2 \times 10^{19}} = 3.872 \times 10^{-27} \vec{a}_x \text{C/m}$

Q.8 (a) (i) Solution:

Given, Polarizability $= \alpha$

Local field or internal field, *Ei*

Assuming *N* is concentration of atoms per unit volume

Electric polarization of dielectric containing *N*, molecules per unit volume,

$$P = Np = N \alpha E_i$$

According to Lorentz equation,

$$E_i = E + \frac{P}{3\epsilon_0}$$

$$\therefore \quad P = N\alpha\left[E + \frac{P}{3\epsilon_0}\right] \quad ...(i)$$

Also $$P = \epsilon_0 E(\epsilon_r - 1) \quad ...(ii)$$

Equating equation (i) and (ii),

$$(\epsilon_r - 1)\epsilon_0 E = N\alpha\left[E + \frac{\epsilon_0 E(\epsilon_r - 1)}{3\epsilon_0}\right]$$

$$(\epsilon_r - 1)\epsilon_0 E = N\alpha E\left[1 + \frac{\epsilon_r - 1}{3}\right]$$

$$(\epsilon_r - 1)\epsilon_0 = \frac{N\alpha[\epsilon_r + 2]}{3}$$

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

Q.8 (a) (ii) Solution:

1. Given : $R_H = -8.25 \times 10^{-5}\ \text{m}^3/\text{C}$

$\sigma = 2.50\ \Omega^{-1}\ \text{cm}^{-1}$

Here, R_H is negative. So, the type of semiconductor is n-type.

2. Density of charge carrier,

$$n = \left|\frac{-1}{R_H e}\right| = \left|\frac{-1}{8.25 \times 10^{-5} \times 1.6 \times 10^{-19}}\text{m}^{-3}\right|$$

$$n = 7.575 \times 10^{22}\ \text{m}^{-3}$$

3. We know,

$$\sigma = ne\mu_n$$

Mobility, $$\mu_n = \frac{\sigma}{ne}$$

$$\mu_n = \frac{2.5 \times 100\ ℧/\text{m}}{7.575 \times 10^{22} \times 1.6 \times 10^{-19}}$$

$$\mu_n = 0.020625\ \text{m}^2/\text{V-s}$$

$$\mu_n = 206.25\ \text{cm}^2/\text{V-s}$$

Q.8 (b) (i) Solution:

Type of Magnetic Materials	Characteristics of Magnetic Dipoles	Characteristics of Hysteresis Loop
Diamagnetic Materials	When an external magnetic field is applied, dipoles are induced in the diamagnetic materials in such a way that induced dipoles oppose the external magnetic field. They do not have permanent magnetic dipole moment.	There is no hysteresis loop. Diamagnetic materials have a small negative susceptibility. Their B-H curve lies slightly below the origin (H=0) and increases linearly with the applied magnetic field in the opposite direction to it.
Paramagnetic Materials	The paramagnetic materials have permanent magnetic dipoles, even in the absence of an applied field. They are randomly oriented in the absence of an external field, resulting in zero net magnetic moment. When a magnetic field is applied, the dipoles will align weakly with the applied field, resulting in a net magnetic moment in the direction of the applied field.	There is no hysteresis loop. Paramagnetic materials have a small positive susceptibility. Their B-H curve lies slightly above the origin (H=0) and increases linearly with the applied magnetic field.
Ferromagnetic Materials	Ferromagnetic materials have permanent magnetic dipoles. These dipoles strongly align in the direction of the applied field.	It exhibits a large and wide hysteresis loop with high retentivity.
AntiFerromagnetic Materials	Anti-ferromagnetic materials have permanent dipoles, but they align in anti-parallel directions having equal magnitude resulting in net magnetization equal to zero.	It exhibits very narrow hysteresis loop.
Ferrimagnetic Materials	Ferrimagnetic materials have permanent dipoles, but they align in anti-parallel having unequal magnitude resulting in net magnetization.	Its hysteresis loop is wide but retentivity is less as compared to ferromagnetic materials.

Q.8 (b) (ii) Solution:

Given that,

$$\varepsilon_r = 4.94,\ n^2 = 2.69$$

We know from Clausius – Mosatti relation that,

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N(\alpha_e + \alpha_i)}{3\varepsilon_0} \quad \text{...(i)}$$

If the measurement are done in the optical frequency region then we have, from equation (i),

$$\varepsilon_r = n^2 \text{ and } \alpha_i = 0$$

or, $$\frac{n^2-1}{n^2+2} = \frac{N\alpha_e}{3\varepsilon_0} \quad \text{...(ii)}$$

From these above two equation (i) and (ii) we get

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

$$1+\frac{\alpha_i}{\alpha_e} = \frac{4.94-1}{4.94+2}\times\frac{2.69+2}{2.69-1} = \frac{3.94\times4.69}{6.94\times1.69}=1.576$$

or $$\frac{\alpha_i}{\alpha_e} = 0.576$$

or, $$\frac{\alpha_e}{\alpha_i} = 1.735$$

Ratio between electronic and ionic polarizability.

Q.8 (c) (i) Solution:

$$\text{Volume of 1 kg iron} = \frac{1}{\text{Density}} = \frac{1}{7200}\text{m}^3/\text{kg}$$

$$\text{Energy density} = \text{B.H.} = 0.004 \times 10 = 0.04$$

Hysteresis energy loss per cycle

$$= \text{Area of loop} \times \text{Energy density}$$

$$= 0.04 \times 180$$

$$= 7.2 \text{ J/m}^3\text{-cycle}$$

Hysteresis energy loss in 20 kg iron per cycle

$$= 7.2\times\frac{1}{7200}\times 20 = 0.02 \text{ J/cycle}$$

$$\text{Energy loss per hour} = 0.02 \times 60 \times 60 \times 60$$

$$= 4320 \text{ J/hr}$$

Q.8 (c) (ii) Solution:

Soft magnetic materials: The soft magnetic materials are characterized by low hysteresis and eddy current losses. These materials are easy to magnetize and demagnetize. This enables them to reverse magnetization rapidly in response to alternating electric fields where they are required to concentrate magnetic flux in transformers and inductances.

The soft magnetic materials forms the magnetic circuit in an electric machine like transformers, motors, power transformers, electromagnets etc.

Properties:
- Low Retentivity
- Low Coercivity
- High permeability
- High saturation magnetization
- Tall and narrow hysteresis loop
- Used upto power frequency (100 Hz)

Example: Fe-Si alloy, Si steel, fe-Ni alloys.

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